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PROXIMITY SENSOR

Abstract

Provided is a proximity sensor capable of sufficiently extending a detection distance by suppressing an influence of embedded metal. The proximity sensor includes a first coil, a second coil, a transmission circuit, a ferrite core, a reception circuit, a control circuit, and an electric shield. The second coil disposed radially outside the first coil. The transmission circuit periodically applies a pulsed excitation current to at least one of the coils. The control circuit detects the detection object D based on the change in the detected voltage or current generated in at least one of the coils by the magnetic field. The electric shield is a press-molded product having a bottomed tubular shape disposed outside the second coil in the radial direction and having a peripheral portion and a detection surface portion in which a cut crossing a direction around an axis is formed.

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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] The present application claims foreign priority based on Japanese Patent Application No. 2024-022090, 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 transmission circuit, and a ferrite core. The coil generates a magnetic field by an excitation current. The transmission circuit periodically applies a pulsed excitation current to the coil. The ferrite core guides a magnetic field generated from the coil. 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 reception circuit, a control circuit, and an electric shield. The reception circuit detects a voltage or a current generated in at least any 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 D on the basis of the change in the voltage or the current detected by the reception circuit. The electric shield has a bottomed cylindrical shape disposed outside the second coil in the radial direction. The electric shield includes a peripheral portion and a detection surface portion. The peripheral portion covers the second coil from the outside in the radial direction. The detection surface portion is located on the side where the detection object is detected. In the electric shield, a cut crossing the direction around the axis is formed in the detection surface portion and the peripheral portion. The electric shield is a press-molded product of a punched thin metal plate in a sheet metal configuration.

[0009] According to the proximity sensor of the invention, the detection distance can be sufficiently extended by suppressing the influence of the embedded metal.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] FIG. **1** is an external view of a proximity sensor;

[0011] FIG. **2** is an external view of the proximity sensor in a used state;

[0012] FIG. **3** is an exploded perspective view from a coil constituting the proximity sensor to a substrate;

[0013] FIG. **4** is an exploded perspective view of components housed in a casing of the proximity sensor;

[0014] FIG. **5** is a central longitudinal sectional view of the proximity sensor;

[0015] FIG. **6** is a block diagram for explaining a main circuit configuration of the proximity sensor;

[0016] FIG. **7** is a block diagram for explaining a main circuit configuration of the proximity sensor in detail;

[0017] FIG. **8**A is a graph illustrating an image of a reception waveform in a case where there is no embedded metal and a detection object is not within a detection range;

[0018] FIG. **8**B is a graph illustrating an image of a reception waveform in a case where there is no embedded metal and a detection object is within a detection range;

[0019] FIG. **9**A is a graph illustrating an image of a reception waveform in a case where there is embedded metal and a detection object is not within a detection range;

[0020] FIG. **9**B is a graph illustrating an image of a reception waveform in a case where there is an embedded metal and a detection object is within a detection range;

[0021] FIG. **10**A is a graph illustrating an image of a reception waveform adjusted to 0 in a case where there is no embedded metal and a detection object is not within a detection range;

[0022] FIG. **10**B is a graph illustrating an image of a reception waveform adjusted to 0 in a case where there is no embedded metal and a detection object is within a detection range;

[0023] FIG. **11**A is a graph illustrating an image of a reception waveform adjusted to 0 in a case where there is an embedded metal and a detection object is not within a detection range;

[0024] FIG. **11**B is a graph illustrating an image of a reception waveform adjusted to 0 in a case where there is an embedded metal and a detection object is within a detection range;

[0025] FIG. **12** is a view for explaining sizes and arrangements of the first coil and the second coil;

[0026] FIG. **13**A is a central longitudinal sectional view in a state in which the influence of an embedded metal is slightly suppressed;

[0027] FIG. **13**B is a central longitudinal sectional view in a state in which the influence of an embedded metal is further suppressed;

[0028] FIG. **14** is an exploded perspective view for explaining in detail a magnetic shield illustrated in FIG. **4**;

[0029] FIG. **15** is a developed view of an electric shield;

[0030] FIG. **16** is a developed view of the electric shield in which the shape of a detection surface cut is different from that in FIG. **15**;

[0031] FIG. **17** is a central longitudinal sectional view of the first coil and the ferrite core;

[0032] FIG. **18** is a graph illustrating a result of electromagnetic field simulation;

[0033] FIG. **19** is a magnetic flux diagram in a case where the shaft body of the ferrite core is thin; and

[0034] FIG. **20** is a magnetic flux diagram in a case where the shaft body of the ferrite core is not thin.

DETAILED DESCRIPTION

[0035] 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.

[0036] Hereinafter, a proximity sensor according to an embodiment of the invention will be described with reference to the drawings.

[0037] 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.

[0038] 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. As illustrated in FIG. **2**, the proximity sensor **100** in a used state 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.

[0039] Hereinafter, a main component configuration of the proximity sensor **100** will be described with reference to FIGS. **3** to **5**. FIG. **3** is an exploded perspective view from a coil **20** to a substrate **50** constituting the proximity sensor **100**. FIG. **4** is an exploded perspective view of components housed in a casing **10** of the proximity sensor **100**. FIG. **5** is a central longitudinal sectional view of the proximity sensor **100**.

[0040] As illustrated in FIG. **3**, the proximity sensor **100** includes a coil **20**, a ferrite core **30**, a core holder **40**, and a substrate **50**. Hereinafter, the coil **20**, the ferrite core **30**, the core holder **40**, and the substrate **50** may be collectively referred to as a sensor unit **25**.

[0041] 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 core holder **40** holds the ferrite core **30**. The substrate **50** is electrically connected to the coil **20** via a lead wire **23**.

[0042] As illustrated in FIGS. **3** and **4**, a plurality of (four in the illustrated example) lead wires **23** are provided from the coil **20**. All of the plurality of lead wires **23** are disposed at positions that are not point-symmetric with respect to the axis of the coil **20**. That is, all of the plurality of lead wires **23** are disposed at positions not facing the axis of the coil **20** at 180°.

[0043] With this arrangement, as illustrated in FIG. **4**, the plurality of lead wires **23** can be collectively soldered to one surface of the substrate **50**. Therefore, the proximity sensor **100** can be easily manufactured by collectively soldering the plurality of lead wires **23** on one surface of the substrate **50**. The plurality of lead wires **23** reach the substrate **50** from the coil **20** through the gap between the ferrite core **30** and the core holder **40**.

[0044] In addition to the sensor unit **25**, the proximity sensor **100** further includes an electric shield **80**, a magnetic shield **90**, and a casing **10**.

[0045] 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 substrate **50**.

[0046] 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 substrate **50**.

[0047] The casing **10** has a casing body **11** in which the outer screw **12** is formed. As illustrated in FIGS. **4** and **5**, the casing body **11** completely covers the magnetic shield **90**, the electric shield **80**, and the sensor unit **25**. As illustrated in FIG. **5**, the casing **10** further includes a casing base end **13** in which a cable attachment port **14** is formed. The casing base end **13** is inserted into the casing body **11** from the substrate **50** side.

[0048] The proximity sensor **100** further includes a cable **19**. The cable **19** is electrically connected to the substrate **50**. The cable **19** extends from the inside to the outside of the casing **10** through the cable attachment port **14** of the casing base end **13**.

[0049] Hereinafter, a main circuit configuration of the proximity sensor **100** will be described with reference to FIG. **6**. FIG. **6** is a block diagram for explaining a main circuit configuration of the proximity sensor **100**.

[0050] As illustrated in FIG. **6**, the proximity sensor **100** further includes a transmission circuit **70**, a reception circuit **60**, and a control circuit **76** as main circuit configurations.

[0051] 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 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**.

[0052] 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**.

[0053] 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. 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**.

[0054] 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.

[0055] In the example illustrated in FIG. **6**, 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.
[0056] In the example illustrated in FIG. **6**, the transmission circuit **70**, the reception circuit **60**, and the control circuit **76** are provided on the substrate **50**. By providing the transmission circuit **70**, the reception circuit **60**, and the control circuit **76** on the 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 substrate **50**. For example, the transmission circuit **70**, the reception circuit **60**, and the control circuit **76** may be provided in different members. Furthermore, any one or two of the transmission circuit **70**, the reception circuit **60**, and the control circuit **76** may be provided on the substrate **50**, and the other circuits may be provided on another substrate or member (a substrate or member disposed inside or outside the casing **10**).
[0057] 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.
[0058] 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.
[0059] Hereinafter, details of the transmission circuit **70**, the reception circuit **60**, and the control circuit **76** will be described with reference to FIG. **7**. FIG. **7** is a block diagram for explaining a main circuit configuration of the proximity sensor **100** in detail.
[0060] The transmission circuit **70** includes an excitation circuit **71**. The excitation circuit **71** 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**.
[0061] The control circuit **76** includes an arithmetic circuit **77** and an output circuit **78**. The arithmetic circuit **77** 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. The arithmetic circuit **77** performs an arithmetic operation on the basis of both the first reception waveform and the second reception waveform. The output circuit **78** outputs the result of the arithmetic operation by the arithmetic circuit **77** to the outside via the cable **19**. The arithmetic circuit **77** may be configured to perform 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 the response speed increases in a case where the arithmetic operation is performed on the basis of only one of the first reception waveform and the second reception waveform.
[0062] Hereinafter, images of the first reception waveform and the second reception waveform will be described with reference to FIGS. **8**A, **8**B, **9**A, and **9**B. In FIGS. **8**A to **9**B, the first reception

waveform is indicated by symbol R**1**, and the second reception waveform is indicated by symbol R**2**.

[0063] FIG. **8**A is a graph illustrating an image of a reception waveform in a case where there is no embedded metal E and the detection object D is not within the detection range. FIG. **8**B is a graph illustrating an image of a reception waveform in a case where there is no embedded metal E and the detection object D is within the detection range. FIG. **9**A is a graph illustrating an image of a reception waveform in a case where the embedded metal E is present and the detection object D is not within the detection range. FIG. **9**B is a graph illustrating an image of the reception waveform in a case where the embedded metal E is present and the detection object D is within the detection range. In the graphs of FIGS. **8**A to **9**B, the horizontal axis represents time, and the vertical axis represents the signal intensity of the reception waveform.

[0064] FIGS. **8**A and **8**B are graphs when there is no embedded metal E. As illustrated in FIG. **8**A, in a case where the detection object D is not within the detection range, the proximity sensor **100** itself is slightly detected, so that the first reception waveform and the second reception waveform reflecting the detection appear. As illustrated in FIG. **8**B, in a case where the detection object D is within the detection range, the detection object D is detected, and thus, both the change amount of the first reception waveform and the change amount of the second reception waveform are larger than those in a case where the detection object D is not within the detection range. In particular, the first reception waveform that is more susceptible to the detection object D than the second reception waveform has a larger change amount than the second reception waveform.

[0065] FIGS. **9**A and **9**B are graphs in a case where the embedded metal E is present. As illustrated in FIG. **9**A, in a case where the detection object D is not within the detection range, the embedded metal E is detected, so that both the change amount of the first reception waveform and the change amount of the second reception waveform are larger than those in a case where the embedded metal E in FIG. **8**A is not present and the detection object D is not within the detection range. In particular, the second reception waveform that is more susceptible to the embedded metal E than the first reception waveform has a larger change amount than the first reception waveform. As illustrated in FIG. **9**B, in a case where the detection object D is within the detection range, the detection object D is also detected, so that both the change amount of the first reception waveform and the change amount of the second reception waveform are larger than those in the case where the detection object D is not within the detection range. In particular, the first reception waveform that is more susceptible to the detection object D than the second reception waveform has a larger difference in the change amount with respect to the change amount in a case where the detection object D is not within the detection range than the second reception waveform.

[0066] Although the first reception waveform is more susceptible to the detection object D than the second reception waveform, the difference in the change amount of the waveform depending on whether or not the detection object D is within the detection range is small in a case where the embedded metal E is present as illustrated in FIGS. **9**A and **9**B as compared with the case where the embedded metal E is not present as illustrated in FIGS. **8**A and **8**B. In particular, the longer the distance between the detection object D and the coil **20**, the smaller the difference in the change amount of the waveform caused by whether or not the detection object D is within the detection range. However, as illustrated in FIGS. **8**A to **9**B, the first reception waveform is more susceptible to the detection object D than the second reception waveform, the second reception waveform is more susceptible to the embedded metal E than the first reception waveform, and the second reception waveform has a difference in change amount with a tendency different from the first reception waveform. More specifically, in the second reception waveform, the difference in the change amount of the waveform due to the presence or absence of the detection object D within the detection range is smaller than the first reception waveform, and the difference in the change amount of the waveform due to the presence or absence of the embedded metal E is larger than the first reception waveform. Therefore, the detection object D is efficiently detected while the influence of the embedded metal E is suppressed by the arithmetic operation based on both the first reception waveform and the second reception waveform.

[0067] Hereinafter, images of the first reception waveform and the second reception waveform subjected to the zero adjustment will be described with reference to FIGS. **10**A, **10**B, **11**A, and **11**B. In FIGS. **10**A to **11**B, the first reception waveform subjected to the zero adjustment is indicated by a symbol AR**1**, and the second reception waveform subjected to the zero adjustment is indicated by a symbol AR**2**.

[0068] FIG. **10**A is a graph illustrating an image of a reception waveform adjusted to 0 in a case where there is no embedded metal E and the detection object D is not within the detection range. FIG. **10**B is a graph illustrating an image of the reception waveform adjusted to 0 in a case where there is no embedded metal E and the detection object D is within the detection range. FIG. **11**A is a graph illustrating an image of a reception waveform adjusted to 0 in a case where the embedded metal E is present and the detection object D is not within the detection range. FIG. **11**B is a graph illustrating an image of the reception waveform subjected to the zero adjustment when the embedded metal E is present and the detection object D is within the detection range. In the graphs of FIGS. **10**A to **11**B, the horizontal axis represents time, and the vertical axis represents the signal intensity of the reception waveform.

[0069] FIGS. **10**A and **10**B are graphs when there is no embedded metal E. As illustrated in FIG. **10**A, in a case where the detection object D is not within the detection range, the measurement value is calibrated to be 0 (zero adjustment), so that the zero-adjusted first reception waveform and second reception waveform do not appear. As illustrated in FIG. **10**B, in a case where the detection object D is within the detection range, the detection object D is detected, so that both the change amount of the first reception waveform subjected to the zero adjustment and the change amount of the second reception waveform subjected to the zero adjustment increase. In particular, the first reception waveform subjected to the zero adjustment, which is more susceptible to the influence of the detection object D than the second reception waveform subjected to the zero adjustment, has a larger change amount than the second reception waveform subjected to the zero adjustment.

[0070] FIGS. **11**A and **11**B are graphs in a case where embedded metal E is present. As illustrated in FIG. **11**A, in a case where the detection object D is not within the detection range, the embedded metal E is detected, so that both the change amount of the first reception waveform subjected to the zero adjustment and the change amount of the second reception waveform subjected to the zero adjustment increase. In particular, the second reception waveform subjected to the zero adjustment, which is more susceptible to the influence of the embedded metal E than the first reception waveform subjected to the zero adjustment, has a larger change amount than the first reception waveform subjected to the zero adjustment. As illustrated in FIG. **11**B, in a case where the detection object D is within the detection range, the detection object D is also detected, so that both the change amount of the first reception waveform subjected to the zero adjustment and the change amount of the second reception waveform subjected to the zero adjustment are larger than those in a case where the detection object D is not within the detection range. In particular, in the first reception waveform subjected to the zero adjustment, which is more susceptible to the influence of the detection object D than the second reception waveform subjected to the zero adjustment, the difference in the change amount with respect to the change amount in a case where the detection object D is not within the detection range is larger than the second reception waveform subjected to the zero adjustment.

[0071] As illustrated in FIGS. **10**A to **11**B, the first reception waveform subjected to the zero adjustment is susceptible to the detection object D, and the second reception waveform subjected to the zero adjustment is susceptible to the embedded metal E. Therefore, the detection object D is efficiently detected while the influence of the embedded metal E is suppressed by the arithmetic operation based on both the first reception waveform and the second reception waveform which are subjected to the zero adjustment.

[0072] This arithmetic operation is, for example, a difference between the first reception waveform and the second reception waveform subjected to the zero adjustment. The difference is subtraction ($\Delta R\mathbf{1}-\Delta R\mathbf{2}$) of the second reception waveform subjected to the zero adjustment from the first reception waveform subjected to the zero adjustment.
[0073] Hereinafter, the size and arrangement of the first coil **21** and the second coil **22** will be described in detail with reference to FIG. **12**. FIG. **12** is a view illustrating sizes and arrangements of the first coil **21** and the second coil **22**.
[0074] As illustrated in FIG. **12**, the radial direction of the first coil **21** and the radial direction of the second coil **22** are the same direction (left-right direction in FIG. **12**). Therefore, hereinafter, the radial direction of the first coil **21** or the second coil **22** may be simply referred to as a radial direction.
[0075] The axial direction of the first coil **21** and the axial direction of the second coil **22** are the same direction (up-down direction in FIG. **12**). Therefore, hereinafter, the axial direction of the first coil **21** or the second coil **22** may be simply referred to as an axial direction. The radial direction (left-right direction in FIG. **12**) and the axial direction (up-down direction in FIG. **12**) are orthogonal to each other.
[0076] Hereinafter, in the axial direction, the side on which the detection object D is detected (the upper side in FIG. **12**) may be referred to as a distal end side, and the side opposite to the distal end side (the lower side in FIG. **12**) may be referred to as a proximal end side.
[0077] The second coil **22** is shorter than the first coil **21** in a direction (axial direction) orthogonal to the radial direction thereof. That is, an axial length L**2** of the second coil **22** is shorter than an axial length L**1** of the first coil **21** (L**2**<L**1**). Since the axial length L**2** of the second coil **22** is shorter than the axial length L**1** 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. In addition, with such a configuration, the second coil **22** has a lower sensitivity to the magnetic flux with respect to the first coil **21**. From the detection result of the second coil **22**, it is preferable to reduce the influence of the magnetic flux passing through both the detection object D and the embedded metal E. 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 D and the embedded metal E is reduced.
[0078] 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**. Specifically, the second coil **22** is located on the distal end side of the first coil **21** by a predetermined distance ΔL. 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.
[0079] 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**.
[0080] Hereinafter, a magnetic field and magnetic flux lines thereof will be described with reference to FIGS. **13**A and **13**B. FIG. **13**A is a central longitudinal sectional view in a state in which the influence of the embedded metal E is slightly suppressed. FIG. **13**B is a central longitudinal sectional view in a state where the influence of the embedded metal E is further suppressed.
[0081] As illustrated in FIGS. **13**A and **13**B, 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.

[0082] The core holder **40** preferably has a structure for fixing the substrate **50**. With the structure in which the core holder **40** fixes the substrate **50**, the positioning accuracy between the substrate **50** and the coil **20** is enhanced, and the proximity sensor **100** can be easily manufactured in a space-saving manner. The core holder **40** is made of resin, for example.

[0083] Next, the magnetic flux lines of the magnetic field received by the coil **20** will be described while comparing FIGS. **13**A and **13**B.

[0084] In FIGS. **13**A and **13**B, 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.

[0085] 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.

[0086] 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.

[0087] As compared with FIG. **13**A, in FIG. **13**B, 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. Therefore, in FIG. **13**B, the magnetic flux lines (dotted line: symbol C) received by both the first coil **21** and the second coil **22** decrease more than that in FIG. **13**A. In order to achieve the state illustrated in FIG. **13**B, the magnetic shield **90** and the ferrite core **30** are appropriately provided.

[0088] As illustrated in FIG. **13**B, 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.

[0089] 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.

[0090] Hereinafter, the magnetic shield **90** will be described in detail with reference to FIGS. **13**B and **14**. FIG. **14** is an exploded perspective view for explaining the magnetic shield **90** illustrated in FIG. **4** in detail.

[0091] As illustrated in FIG. **13**B, 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.

[0092] 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 casing **10**) in the radial direction. The magnetic shield **90** may constitute the casing **10**.
[0093] As illustrated in FIG. **14**, the magnetic shield **90** includes a sheet member kneaded with ferromagnetic powder **91**. 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 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.
[0094] 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.
[0095] 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.
[0096] 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.
[0097] Hereinafter, details of the electric shield **80** will be described with reference to FIGS. **14** to **16**. The electric shield **80** is a bottomed cylindrical metal body that protects the coil **20** and the ferrite core **30** from external noise.
[0098] As illustrated in FIG. **14**, the electric shield **80** is disposed outside the second coil **22** in the radial direction. A cut **81** (slit) 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.
[0099] 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.
[0100] 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** is located on the side where the detection object D is detected. The detection surface portion **87** closes the distal end side which is one end of the peripheral portion **84**.
[0101] 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**.
[0102] 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**.

[0103] 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**.
[0104] The thin metal plate before being bent as the electric shield **80** is illustrated in FIGS. **15** and **16**. FIG. **15** is a developed view of the electric shield **80**. FIG. **16** is a developed view of the electric shield **80** in which the shape of the detection surface cut **83** is different from that in FIG. **15**.
[0105] As illustrated in FIGS. **15** and **16**, the thin metal plate before being bent as the electric shield **80** is punched out. The thin metal plate is stamped such that the cuts **81** are also formed simultaneously. The electric shield **80** has a bottomed cylindrical three-dimensional shape illustrated in FIG. **14** by pressing the punched thin metal plate. That is, the electric shield **80** is 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** is, for example, copper foil or brass foil.
[0106] The peripheral portion **84** has a left half peripheral portion **85** and a right half peripheral portion **86**. The left half peripheral portion **85** and the right half peripheral portion **86** are connected to the detection surface portion **87** from the left side and the right side, respectively. The left half peripheral portion **85** and the right half peripheral portion **86** are bent so as to be perpendicular to the detection surface portion **87**. Further, the left half peripheral portion **85** and the right half peripheral portion **86** are subjected to roll bending and pressing such that the edge on the side close to the detection surface portion **87** is along the edge of the detection surface portion **87**.
[0107] The peripheral cut **82** is a gap between the left half peripheral portion **85** and the right half peripheral portion **86**. The detection surface cut **83** is a radial gap from the center of the detection surface portion **87**.
[0108] In the example illustrated in FIG. **15**, in the clock position in which the upward direction in FIG. **15** is 0:00, the radial gaps extending in the directions of 0:00, 3:00, 6:00, and 9:00 do not reach the edge of the detection surface portion **87** while passing through the center of the detection surface portion **87**. The radial gaps extending in the directions between 1:00 and 2:00, between 4:00 and 5:00, between 7:00 and 8:00, and between 10:00 and 11:00 do not pass through the center of the detection surface portion 87 but reach the edge of the detection surface portion **87**.
[0109] In the example illustrated in FIG. **16**, the radial gaps extending in the directions of 0:00 and 6:00 do not pass through the center of the detection surface portion **87** but reach the edge of the detection surface portion **87**. The linear gaps extending in the directions of 3:00 and 9:00 pass through the center of the detection surface portion **87** and do not reach the edge of the detection surface portion **87**. The radial gaps extending between 1:00 and 2:00, between 4:00 and 5:00, between 7:00 and 8:00, and between 10:00 and 11:00 do not pass through the center of the detection surface portion **87** and do not reach the edge of the detection surface portion **87**.
[0110] The electric shields **80** shown in FIGS. **15** and **16** both equally suppress eddy current loops. Since the path of the current is shorter in the electric shield **80** illustrated in FIG. **16** than in FIG. **15**, the electric resistance is lowered, thereby improving the resistance to external noise.
[0111] 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.
[0112] Hereinafter, the ferrite core **30** will be described in detail with reference to FIGS. **17** to **20**. FIG. **17** is a central longitudinal sectional view of the first coil **21** and the ferrite core **30**. FIG. **18** is a graph illustrating a result of electromagnetic field simulation. FIG. **19** is a magnetic flux diagram in a case where the shaft body **31** of the ferrite core **30** is thin. FIG. **20** is a magnetic flux diagram in a case where the shaft body **31** of the ferrite core **30** is not thin.
[0113] As illustrated in FIG. **17**, 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.

[0114] In order to know the relationship between the relative shaft width w/W and the influence of the embedded metal E, electromagnetic field simulation has been performed under the following conditions.

[0115] As a condition of the electromagnetic field simulation, the entire width W (outer diameter) of the ferrite core **30** in the radial direction has been set to 7 mm. The width w of the shaft body **31** in the radial direction has been set to the following seven ways. Specifically, the width w of the shaft body **31** in the radial direction has been set to 3.5 mm, 3 mm, 2.5 mm, 2 mm, 1.5 mm, 1 mm, and 0.5 mm. In each of these seven ways, an intensity ratio Vd/Ve has been calculated by dividing a signal intensity Ve of the reception waveform based on the embedded metal E from a signal intensity Vd of the reception waveform based on the detection object D. Note that the signal intensities Vd and Ve of the respective reception waveforms are voltages at both ends of the coil **20**.

[0116] The results of the electromagnetic field simulation are illustrated in FIG. **18**. In the graph illustrated in FIG. **18**, the horizontal axis represents the relative shaft width w/W, and the vertical axis represents the intensity ratio Vd/Ve. As is clear from the graph illustrated in FIG. **18**, the intensity ratio Vd/Ve has increased as the relative shaft width w/W has decreased. However, when the relative shaft width w/W has decreased to some extent, the intensity ratio Vd/Ve has leveled off.

[0117] In particular, when the relative shaft width w/W has been 30% or less, the intensity ratio Vd/Ve has been 1 or more. That is, when the relative shaft width w/W has been 30% or less, the signal intensity Vd of the reception waveform based on the detection object D has been equal to or higher than the signal intensity Ve of the reception waveform based on the embedded metal E. When the relative shaft width w/W has been less than 15%, the intensity ratio Vd/Ve has been flat. Furthermore, when the relative shaft width w/W is less than 15%, it is difficult to manufacture the ferrite core **30**. In other words, when the relative shaft width w/W is 15% or more, the intensity ratio Vd/Ve is high, and manufacturing becomes easy.

[0118] When the intensity ratio Vd/Ve is high, the signal intensity Vd of the reception waveform based on the detection object D becomes relatively high. In other words, when the intensity ratio Vd/Ve is high, the signal intensity Ve of the reception waveform based on the embedded metal E becomes relatively low. Therefore, since the relative shaft width w/W is 30% or less, the proximity sensor **100** can sufficiently extend the detection distance by suppressing the influence of the embedded metal E. Further, since the relative shaft width w/W is 15% or more, the proximity sensor **100** can sufficiently extend the detection distance and can be easily manufactured.

[0119] From the results of the electromagnetic field simulation, 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.

[0120] Next, the magnetic flux lines in the electromagnetic field simulation are illustrated in FIGS. **19** and **20**. FIG. **19** illustrates a case where the width w of the shaft body **31** in the radial direction is 1.5 mm, and FIG. **20** illustrates a case where the width w of the shaft body **31** in the radial direction is 3 mm.

[0121] In the example illustrated in FIG. **19**, since 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, 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. **19**, three magnetic flux lines m**1** to m**3** pass through the embedded metal E.

[0122] On the other hand, in the example shown in FIG. **20**, since 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, 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. **20**, four magnetic flux lines M**1** to M**4** pass through the embedded metal E.

[0123] As is clear from the comparison between FIGS. **19** and **20**, in FIG. **19** 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. **20** 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, also from FIGS. **19** and **20**, it can be said that the influence of the embedded metal E is suppressed when the relative shaft width w/W is 30% or less.
[0124] 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. [0125] (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. [0126] (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. [0127] (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**.
[0128] The invention provides a proximity sensor, and has industrial applicability.

Claims

1. A proximity sensor comprising: a coil that generates a magnetic field by an excitation current; a transmission circuit that periodically applies a pulsed excitation current to the coil; and a ferrite core that guides the magnetic field generated from the coil, wherein the coil includes: a first coil; and a second coil disposed concentrically with the first coil, the proximity sensor further comprises: 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; 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 an electric shield having a bottomed cylindrical shape which is disposed outside the second coil in a radial direction, 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, a cut crossing a direction around an axis of the electric shield is formed in the detection surface portion and the peripheral portion, and the electric shield is a press-molded product of a punched thin metal plate in a sheet metal configuration.
2. The proximity sensor according to claim 1, wherein 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, and the control circuit detects the detection object on a basis of a change in the voltage or the current generated in each of the first coil and the second coil detected by the reception circuit.
3. The proximity sensor according to claim 1, wherein the second coil is disposed outside the first coil in a radial direction, and the first coil generates the magnetic field by causing the pulsed excitation current to periodically flow from the transmission circuit.
4. The proximity sensor according to claim 1, further comprising a substrate on which the transmission circuit, the reception circuit, and the control circuit are provided.
5. The proximity sensor according to claim 2, 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.
6. The proximity sensor according to claim 5, 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 detected by the second reception circuit.
7. 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.
8. 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.
9. 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.
10. The proximity sensor according to claim 1, further comprising a magnetic shield that is disposed outside the second coil in a radial direction.
11. The proximity sensor according to claim 10, wherein the magnetic shield includes a sheet member kneaded with ferromagnetic powder.
12. 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.
13. The proximity sensor according to claim 12, 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.