

# US Patent & Trademark Office

## Patent Public Search | Text View

---

United States Patent	12392804
Kind Code	B2
Date of Patent	August 19, 2025
Inventor(s)	Minami; Hiroki et al.

---

### Current detection apparatus

---

#### Abstract

A current detection apparatus (**10**) according to the present disclosure includes an annular magnetic core (**13**), a first coil group (**14**) including a plurality of first coils (La) connected in series, a second coil group (**15**) including a plurality of second coils (Lb) connected in series, and a detector (**12**). The first coil group (**14**) and the second coil group (**15**) are connected in parallel between a first node (**21**) and a second node (**22**), a count of the plurality of first coils (La) and a count of the plurality of second coils (Lb) are identical, and a first coil (La), among the plurality of first coils (La), in i.sup.th place from the first node (**21**) and a second coil (Lb), among the plurality of second coils (Lb), in i.sup.th place from the first node (**21**) are arranged at opposing positions, where i is an integer.

---

**Inventors:** Minami; Hiroki (Hachioji, JP), Ishida; Hiroyuki (Hachioji, JP), Sakamoto; Kazuki (Hachioji, JP), Yoshihara; Tomoaki (Hachioji, JP)

**Applicant:** Yokogawa Electric Corporation (Musashino, JP); Yokogawa Test & Measurement Corporation (Hachioji, JP)

**Family ID:** 1000008763266

**Assignee:** YOKOGAWA ELECTRIC CORPORATION (Tokyo, JP); YOKOGAWA TEST & MEASUREMENT CORPORATION (Tokyo, JP)

**Appl. No.:** 18/219343

**Filed:** July 07, 2023

#### Prior Publication Data

<b>Document Identifier</b>	<b>Publication Date</b>
US 20240012031 A1	Jan. 11, 2024

#### Foreign Application Priority Data

JP	2022-111445	Jul. 11, 2022
----	-------------	---------------

## Publication Classification

**Int. Cl.:** G01R15/18 (20060101)

**U.S. Cl.:**

**CPC** G01R15/185 (20130101);

## Field of Classification Search

**CPC:** G01R (15/185); G01R (15/14); G01R (19/0092)

---

## References Cited

### U.S. PATENT DOCUMENTS

Patent No.	Issued Date	Patentee Name	U.S. Cl.	CPC
7253634	12/2006	Kasztenny	324/509	H02H 7/06
9634605	12/2016	Masuda	N/A	H02P 6/28
2017/0336443	12/2016	Yokota et al.	N/A	N/A
2018/0164362	12/2017	Premarlani	N/A	G01R 31/007
2018/0328974	12/2017	Nikolic	N/A	N/A
2019/0004095	12/2018	Hayashi	N/A	G01R 15/185
2021/0130948	12/2020	Lam	N/A	B01L 1/025
2022/0084737	12/2021	Lai	N/A	H02M 1/0064
2023/0136151	12/2022	Cima	N/A	N/A
2024/0353492	12/2023	Kondo	N/A	G01R 31/34

### FOREIGN PATENT DOCUMENTS

Patent No.	Application Date	Country	CPC
499239	12/1938	GB	N/A
522276	12/1939	GB	N/A
2000-131343	12/1999	JP	N/A
2016-114558	12/2015	JP	N/A
2019-12028	12/2018	JP	N/A
2021/198590	12/2020	WO	N/A

### OTHER PUBLICATIONS

Office Action dated Feb. 12, 2024, issued in counterpart JP application No. 2022-111445, with English translation. (8 pages). cited by applicant

Office Action dated Mar. 4, 2025, issued in counterpart EP Application No. 23184630.4. (5 pages). cited by applicant

---

*Primary Examiner:* Rodak; Lee E

*Assistant Examiner:* Ferdous; Zannatul

*Attorney, Agent or Firm:* WHDA, LLP

---

## Background/Summary

### CROSS-REFERENCE TO RELATED APPLICATION

(1) The present application claims priority to Japanese Patent Application No. 2022-111445 filed on Jul. 11, 2022, the entire contents of which are incorporated herein by reference.

### TECHNICAL FIELD

(2) The present disclosure relates to a current detection apparatus.

### BACKGROUND

(3) A current detection apparatus that includes an annular magnetic core, surrounding a conductor to be measured through which a current to be measured flows, and a feedback coil arranged to wind around the magnetic core is known.

(4) In such a current detection apparatus, when a current flows in the conductor to be measured, a magnetic flux is generated in the magnetic core, and a current flows in the feedback coil to cancel this magnetic flux. The current detection apparatus can detect the current flowing in the conductor to be measured by detecting the current flowing in this feedback coil.

(5) In the above-described current detection apparatus, it is usually assumed that the conductor to be measured passes through the center of the magnetic core, but the position of the conductor to be measured may shift from the center of the magnetic core. If the position of the conductor to be measured is shifted from the center of the magnetic core, varying current values may be detected even if the current flowing through the conductor to be measured is the same.

(6) For example, if the feedback coil is located only in a portion of the magnetic core, a large current value is detected when the position of the conductor to be measured is close to the feedback coil, whereas a small current value is detected when the position of the conductor to be measured is far from the feedback coil.

(7) In order to reduce such variation in the measured current value, a configuration in which the feedback coils are evenly arranged over the entire circumferential direction of the magnetic core is known. In this way, in a case in which the conductor to be measured is shifted from the center, the magnetic flux generated in the feedback coil that is closer to the conductor to be measured becomes larger, whereas the magnetic flux generated in the feedback coil located opposite to this feedback coil becomes smaller. The magnetic flux is thus averaged out overall, reducing the variation in the measured current value.

(8) Even with the feedback coils evenly arranged over the entire circumferential direction of the magnetic core, however, if the loads on the feedback coils arranged at opposing positions differ in magnitude, the measured current value will end up varying when the current flowing in the conductor to be measured is a high frequency current, because the effect of the load cannot be ignored. The load on the feedback coil includes stray capacitance, DC resistance, inductance, and the like.

(9) To address this issue, a known current detection apparatus includes feedback coils that are evenly arranged over the entire circumferential direction of the magnetic core, and the magnitudes of the loads on the feedback coils arranged at opposing positions are aligned insofar as possible.

For example, see Patent Literature (PTL) 1.

### CITATION LIST

Patent Literature

(10) PTL 1: JP 2019-12028 A

### SUMMARY

(11) A current detection apparatus according to an embodiment includes an annular magnetic core that can be arranged to surround a conductor to be measured through which a current to be measured flows; a first coil group including a plurality of first coils arranged to wind around the

magnetic core and connected in series; a second coil group including a plurality of second coils arranged to wind around the magnetic core and connected in series; and a detector configured to detect both a current flowing in the first coil group and a current flowing in the second coil group, wherein the first coil group and the second coil group are connected in parallel between a first node and a second node, a count of the plurality of first coils and a count of the plurality of second coils are identical, and a first coil, among the plurality of first coils, in  $i^{\text{sup.th}}$  place from the first node and a second coil, among the plurality of second coils, in  $i^{\text{sup.th}}$  place from the first node are arranged at opposing positions, where  $i$  is an integer.

(12) A current detection apparatus according to an embodiment includes an annular magnetic core that can be arranged to surround a conductor to be measured through which a current to be measured flows, a first coil group including a plurality of first coils arranged to wind around the magnetic core and connected in series, a second coil group including a plurality of second coils arranged to wind around the magnetic core and connected in series, a first resistor through which flows a current flowing in the first coil group, a second resistor through which flows a current flowing in the second coil group, and a detector configured to detect a voltage at both ends of the first resistor and a voltage at both ends of the second resistor, wherein the first coil group and the second coil group are connected in parallel between a first node and a second node, a count of the plurality of first coils and a count of the plurality of second coils are identical, and a first coil, among the plurality of first coils, in  $i^{\text{sup.th}}$  place from the first node and a second coil, among the plurality of second coils, in  $i^{\text{sup.th}}$  place from the first node are arranged at opposing positions, where  $i$  is an integer.

---

## Description

### BRIEF DESCRIPTION OF THE DRAWINGS

- (1) In the accompanying drawings:
- (2) FIG. 1 is a diagram illustrating a schematic configuration of a current detection apparatus according to an embodiment;
- (3) FIG. 2 is a diagram illustrating a circuit configuration of the current detection apparatus according to an embodiment;
- (4) FIG. 3 is a diagram illustrating how stray capacitance is generated in the circuit configuration illustrated in FIG. 2;
- (5) FIG. 4 is a diagram illustrating a circuit configuration of a current detection apparatus according to a first variation; and
- (6) FIG. 5 is a diagram illustrating a circuit configuration of a current detection apparatus according to a second variation.

### DETAILED DESCRIPTION

(7) In the current detection apparatus disclosed in PTL 1, unit windings (feedback coils) connected in series are evenly arranged over the entire circumferential direction of the magnetic core. Also, feedback coils at equivalent positions in terms of the electrical circuit are arranged at opposing positions and connected so that the loads of the feedback coils arranged at opposing positions are equivalent.

(8) Since all of the feedback coils are connected in series in the current detection apparatus disclosed in PTL 1, the wiring to connect the feedback coils becomes complicated when implementing the equalization of the loads on the feedback coils arranged at opposing positions.

(9) It would be helpful to provide a current detection apparatus that can reduce the variation in the measured current value according to the position of the conductor to be measured and that enables connection of the feedback coils with simple wiring.

(10) A current detection apparatus according to an embodiment includes an annular magnetic core

that can be arranged to surround a conductor to be measured through which a current to be measured flows; a first coil group including a plurality of first coils arranged to wind around the magnetic core and connected in series; a second coil group including a plurality of second coils arranged to wind around the magnetic core and connected in series; and a detector configured to detect both a current flowing in the first coil group and a current flowing in the second coil group, wherein the first coil group and the second coil group are connected in parallel between a first node and a second node, a count of the plurality of first coils and a count of the plurality of second coils are identical, and a first coil, among the plurality of first coils, in  $i$ th place from the first node and a second coil, among the plurality of second coils, in  $i$ th place from the first node are arranged at opposing positions, where  $i$  is an integer. According to this current detection apparatus, the variation in the measured current value according to the position of the conductor to be measured can be reduced, and the feedback coils can be connected with simple wiring.

(11) The current detection apparatus according to an embodiment may further include a resistor through which flow both the current flowing in the first coil group and the current flowing in the second coil group, and the detector may be configured to detect a voltage at both ends of the resistor. Both the current flowing in the first coil group and the current flowing in the second coil group can thereby be detected with a simple configuration.

(12) In the current detection apparatus according to an embodiment, the magnetic core may have a shape that is one of a circular ring shape, a ring shape with an elliptical cross-section, and a ring shape with a polygonal cross-section. The magnetic core can thus have various shapes.

(13) The current detection apparatus according to an embodiment may further include a shield configured to house the first coil group and the second coil group. This can stabilize the value of stray capacitance.

(14) The current detection apparatus according to an embodiment may further include a plurality of spacers installed between adjacent first coils and between adjacent second coils. This enables the spacing between adjacent first coils and adjacent second coils to be maintained at a fixed distance.

(15) A current detection apparatus according to an embodiment includes an annular magnetic core that can be arranged to surround a conductor to be measured through which a current to be measured flows, a first coil group including a plurality of first coils arranged to wind around the magnetic core and connected in series, a second coil group including a plurality of second coils arranged to wind around the magnetic core and connected in series, a first resistor through which flows a current flowing in the first coil group, a second resistor through which flows a current flowing in the second coil group, and a detector configured to detect a voltage at both ends of the first resistor and a voltage at both ends of the second resistor, wherein the first coil group and the second coil group are connected in parallel between a first node and a second node, a count of the plurality of first coils and a count of the plurality of second coils are identical, and a first coil, among the plurality of first coils, in  $i$ th place from the first node and a second coil, among the plurality of second coils, in  $i$ th place from the first node are arranged at opposing positions, where  $i$  is an integer. According to this current detection apparatus, the variation in the measured current value according to the position of the conductor to be measured can be reduced, and the feedback coils can be connected with simple wiring.

(16) According to the present disclosure, a current detection apparatus that can reduce the variation in the measured current value according to the position of the conductor to be measured and that enables connection of the feedback coils with simple wiring can be provided.

(17) Embodiments of the present disclosure are now described with reference to the drawings.

(18) FIG. 1 is a diagram illustrating a schematic configuration of a current detection apparatus **10** according to an embodiment. The current detection apparatus **10** includes a resistor **11**, a detector **12**, a magnetic core **13**, a plurality of first coils La1 to La4, and a plurality of second coils Lb1 to Lb4.

(19) The first coils La1 to La4 may be referred to simply as the “first coil La” when no distinction

therebetween need be made. The second coils Lb1 to Lb4 may be referred to simply as the “second coil Lb” when no distinction therebetween need be made.

(20) The current detection apparatus **10** detects the current flowing in the conductor to be measured **30**. The conductor to be measured **30** is a linear conductor through which a current to be measured flows. In the example illustrated in FIG. **1**, the current to be measured flows in the conductor to be measured **30** from the positive direction towards the negative direction of the Z-axis.

(21) FIG. **2** is a diagram illustrating a circuit configuration of the current detection apparatus **10** illustrated in FIG. **1**. In FIG. **2**, a depiction of the magnetic core **13** is omitted. FIG. **3** illustrates the stray capacitance generated in the first coils La1 to La4 and the stray capacitance generated in the second coils Lb1 to Lb4 in the circuit configuration of the current detection apparatus **10** illustrated in FIG. **2**.

(22) The configuration and functions of the current detection apparatus **10** are described with reference to FIGS. **1** to **3**.

(23) The magnetic core **13** can be arranged to surround the conductor to be measured **30**. For example, if the conductor to be measured **30** passes near the center of the magnetic core **13**, the magnetic core **13** can surround the conductor to be measured **30**.

(24) In the example illustrated in FIG. **1**, the magnetic core **13** has a circular ring shape. The shape of the magnetic core **13** is not limited to a circular ring shape, however, and may be any other ring shape. For example, the magnetic core **13** may have a ring shape with an elliptical cross-section, a ring shape with a polygonal cross-section, or the like.

(25) As illustrated in FIG. **1**, the first coils La1 to La4 are each arranged to wind around the magnetic core **13**. The first coils La1 to La4 are connected in series. The configuration of the first coils La1 to La4 connected in series as illustrated in FIG. **2** may be referred to hereinafter as the “first coil group **14**”. The first coils La1 to La4 function as feedback coils.

(26) Although a configuration in which the first coil group **14** includes four first coils La1 to La4 is illustrated, the number of first coils La included in the first coil group **14** is not limited to four. The first coil group **14** may include two, three, or five or more first coils La. In the present embodiment, the case in which the first coil group **14** is configured to include the four first coils La1 to La4 is described as an example.

(27) As illustrated in FIG. **1**, the second coils Lb1 to Lb4 are each arranged to wind around the magnetic core **13**. The second coils Lb1 to Lb4 are connected in series. The configuration of the second coils Lb1 to Lb4 connected in series as illustrated in FIG. **2** may be referred to hereinafter as the “second coil group **15**”. The second coils Lb1 to Lb4 function as feedback coils.

(28) Although a configuration in which the second coil group **15** includes four second coils Lb1 to Lb4 is illustrated, the number of second coils Lb included in the second coil group **15** is not limited to four. The second coil group **15** may include two, three, or five or more first coils Lb. In the present embodiment, the case in which the second coil group **15** is configured to include the four second coils Lb1 to Lb4 is described as an example.

(29) As illustrated in FIGS. **1** and **2**, the first coil group **14** and the second coil group **15** are connected in parallel between the first node **21** and the second node **22**. The count of the first coils La included in the first coil group **14** and the count of the second coils Lb included in the second coil group **15** are identical. In the present embodiment, the first coil group **14** includes four first coils La1 to La4, and the second coil group **15** includes four second coils Lb1 to Lb4.

(30) As illustrated in FIG. **1**, the first coils La1 to La4 and the second coils Lb1 to Lb4 are arranged at equal intervals along the magnetic core **13**. In the present embodiment, the first coils La1 to La4 and the second coils Lb1 to Lb4 are arranged every 45 degrees along the magnetic core **13**, since the total number of first coils La1 to La4 and second coils Lb1 to Lb4 is eight.

(31) As illustrated in FIG. **1**, the first coil La, among the first coils La1 to La4 of the first coil group **14**, in i.sup.th place from the first node **21** and the second coil Lb, among the second coils Lb1 to Lb4 of the second coil group **15**, in i.sup.th place from the first node **21** are arranged at opposing

positions, where  $i$  is an integer.

(32) For example, the first coil La1 is in first place from the first node 21. The second coil Lb1 is in first place from the first node 21. Referring to FIG. 1, the first coil La1 and the second coil Lb1 are arranged at opposing positions. Arranged at opposing positions refers to how the coils are arranged at 180 degree positions along the magnetic core 13.

(33) The first coil La2 is in second place from the first node 21. The second coil Lb2 is in second place from the first node 21. Referring to FIG. 1, the first coil La2 and the second coil Lb2 are arranged at opposing positions. The first coil La3 and the second coil Lb3 are similarly arranged at opposing positions. The first coil La4 and the second coil Lb4 are similarly arranged at opposing positions.

(34) The first coil La, among the first coils La1 to La4 of the first coil group 14, in  $i$ .sup.th place from the first node 21 and the second coil Lb, among the second coils Lb1 to Lb4 of the second coil group 15, in  $i$ .sup.th place from the first node 21 have equal inductor characteristics.

(35) For example, the first coil La1 is in first place from the first node 21. The second coil Lb2 is in first place from the first node 21. Therefore, the first coil La1 and the second coil Lb1 have equal inductor characteristics. Similarly, the first coil La2 and the second coil Lb2 have equal inductor characteristics. The first coil La3 and the second coil Lb3 also have equal inductor characteristics. The first coil La4 and the second coil Lb4 also have equal inductor characteristics.

(36) The first coils La1 to La4 and the second coils Lb1 to Lb4 may suitably all have equal inductor characteristics.

(37) This arrangement enables the first coils La and the second coils Lb, which have equal appearance in terms of electrical load, to be arranged at opposing positions. The equal appearance in terms of electrical load is explained with reference to FIG. 3.

(38) FIG. 3 is a diagram also illustrating the stray capacitance generated in the first coils La1 to La4 and the stray capacitance generated in the second coils Lb1 to Lb4. In FIG. 3, the stray capacitance Cp1 is the stray capacitance generated between the first coils La1 to La4 or the second coils Lb1 to Lb4 and ground. The stray capacitance Cp2 is the stray capacitance generated between the terminals in each of the first coils La1 to La4 and the second coils Lb1 to Lb4.

(39) Referring to FIG. 3, the first coil La, among the first coils La1 to La4 of the first coil group 14, in  $i$ .sup.th place from the first node 21 and the second coil Lb, among the second coils Lb1 to Lb4 of the second coil group 15, in  $i$ .sup.th place from the first node 21 have equal appearance in terms of electrical load, even if the stray capacitance Cp1 and stray capacitance Cp2 are taken into account.

(40) For example, the first coil La1 is in first place from the first node 21. The second coil Lb2 is in first place from the first node 21. Referring to FIG. 3, the appearance in terms of electrical load as seen from the first coil La1 and the appearance in terms of electrical load as seen from the second coil Lb1 are equal.

(41) Similarly, the appearance in terms of electrical load as seen from the first coil La2 and the appearance in terms of electrical load as seen from the second coil Lb2 are equal. The appearance in terms of electrical load as seen from the first coil La3 and the appearance in terms of electrical load as seen from the second coil Lb3 are also equal. The appearance in terms of electrical load as seen from the first coil La4 and the appearance in terms of electrical load as seen from the second coil Lb4 are also equal.

(42) In this way, the first coils La and the second coils Lb, which have equal appearance in terms of electrical load even when stray capacitance is taken into account, are arranged at opposing positions in the current detection apparatus 10. This enables the current detection apparatus 10 to detect, with small variation, the current flowing in the conductor to be measured 30 even when the current flowing in the conductor to be measured 30 is a high frequency current, and the position of the conductor to be measured 30 is shifted from the center of the magnetic core 13.

(43) The resistor 11 is connected between the first node 21 and the second node 22. Both the

current flowing in the first coil group **14** and the current flowing in the second coil group **15** flow in the resistor **11**.

(44) When a current flows in the conductor to be measured **30**, a magnetic field is generated around the conductor to be measured **30**. When the magnetic field is generated around the conductor to be measured **30**, magnetic flux is generated inside the magnetic core **13**.

(45) When the magnetic flux is generated inside the magnetic core **13**, a current flows in the first coil group **14** and the second coil group **15** to cancel this magnetic flux. The current flowing in the first coil group **14** and the second coil group **15** flows through the resistor **11**.

(46) The current flowing in the first coil group **14** and the second coil group **15** is proportional to the magnetic flux generated inside the magnetic core **13**. The magnetic flux generated inside the magnetic core **13** is also proportional to the current flowing in the conductor to be measured **30**. Therefore, the current flowing through the resistor **11** is proportional to the current flowing in the conductor to be measured **30**.

(47) In a case in which the conductor to be measured **30** is at the center of the magnetic core **13**, the current flowing in the first coil group **14** and the current flowing in the second coil group **15** are equal.

(48) Consider the case in which the position of the conductor to be measured **30** is shifted from the center of the magnetic core **13**. For example, suppose that the conductor to be measured **30** is closer to the first coil **La2**. In this case, the current flowing in the first coil group **14** increases, and the current flowing in the second coil group **15** decreases. Since both the current flowing in the first coil group **14** and the current flowing in the second coil group **15** flow through the resistor **11**, the larger current and the smaller current offset each other, and the current flowing through the resistor **11** is nearly the same as when the conductor to be measured **30** is at the center of the magnetic core **13**.

(49) The detector **12** detects the voltage at both ends of the resistor **11**. Since the voltage at both ends of the resistor **11** is proportional to the current flowing through the resistor **11**, the detector **12** can detect the current flowing through the conductor to be measured **30** by detecting the voltage at both ends of the resistor **11**.

(50) The detector **12** includes at least a voltage sensor. The detector **12** may further include an amplifier that amplifies the voltage. The detector **12** may further include an AD converter that converts the voltage detected as an analog signal to a digital signal. In this case, the detector **12** detects the voltage at both ends of the resistor **11** as a digital signal.

(51) The current detection apparatus **10** may further include a shield that houses the first coil group **14** and the second coil group **15**. The shield may, for example, be in the shape of a conductive box. By connecting the shield to ground, the value of the stray capacitance  $C_{p1}$  illustrated in FIG. 3 can be stabilized.

(52) The current detection apparatus **10** may further include a plurality of spacers installed between adjacent first coils **La** and between adjacent second coils **Lb**. By installation of the spacers, the spacing between adjacent first coils **La** and adjacent second coils **Lb** can be maintained at a fixed distance.

(53) In this way, the current detection apparatus **10** can reduce the variation in the measured current value even when the position of the conductor to be measured **30** is shifted from the center, since the first coils **La1** to **La4** and the second coils **Lb1** to **Lb4** are evenly arranged along the magnetic core **13**. Furthermore, because the first coils **La** and the second coils **Lb**, which have equal appearance in terms of electrical load, are arranged at opposing positions in the current detection apparatus **10**, the variation in the measured current value can be reduced even when a high frequency current is flowing in the conductor to be measured **30**.

(54) The current detection apparatus **10** is configured so that the first coil group **14** and the second coil group **15** are connected in parallel, so that even if the first coils **La** and the second coils **Lb**, which have equal appearance in terms of electrical load, are arranged at opposing positions, the



first coils La1 to La4 and the second coils Lb1 to Lb4 can be connected with simple wiring.

(55) (Effect of Residual Magnetic Flux Reduction)

(56) The current detection apparatus **10** according to the present embodiment also has the effect of being able to reduce the residual magnetic flux generated in the magnetic core **13**. The effect of being able to reduce the residual magnetic flux is explained below.

(57) First, as a configuration that generates a residual magnetic flux, consider the case of a configuration in which the coils are evenly arranged along the magnetic core **13**, and the evenly arranged coils are all connected in series.

(58) Even with this configuration, if the conductor to be measured **30** is located at the center of the magnetic core **13**, the magnetic flux generated in the magnetic core **13** by the current flowing in the conductor to be measured **30** can be canceled by the current flowing in the evenly arranged coils.

(59) In a case in which the conductor to be measured **30** is shifted from the center of the magnetic core **13**, a strong magnetic flux is generated at the position of the magnetic core **13** to which the conductor to be measured **30** approaches, and a weak magnetic flux is generated at the position of the magnetic core **13** from which the conductor to be measured **30** moves away.

(60) At this time, a current that acts to cancel the magnetic flux generated in the magnetic core **13** flows through the coils evenly arranged along the magnetic core **13**, but because all the coils are connected in series, these coils generate an average magnetic field. In other words, the magnetic field generated by the coils evenly arranged along the magnetic core **13** is too weak to cancel the magnetic flux at the position of the magnetic core **13** to which the conductor to be measured **30** approaches, and is too strong to cancel the magnetic flux at the position of the magnetic core **13** from which the conductor to be measured **30** moves away.

(61) As a result, residual magnetic flux is generated both at the position of the magnetic core **13** to which the conductor to be measured **30** approaches and at the position of the magnetic core **13** from which the conductor to be measured **30** moves away.

(62) If the residual magnetic flux is large, the magnetic core **13** may reach magnetic saturation, and the sensitivity for detecting the current flowing in the conductor to be measured **30** may decrease. To prevent magnetic saturation from being reached, the magnetic core **13** could be increased in size, but this would increase the cost of the magnetic core **13**.

(63) By contrast, the current detection apparatus **10** according to the present embodiment has a configuration in which the first coil group **14** and the second coil group **15** are connected in parallel. In this case, if the conductor to be measured **30** approaches the first coil group **14**, for example, the magnetic flux generated in the magnetic core **13** at the position where the first coil group **14** is located becomes stronger, but a larger current flows in the first coil group **14** to cancel this strong magnetic flux. Furthermore, the magnetic flux generated in the magnetic core **13** at the position where the second coil group **15** is located becomes weaker, but a smaller current flows in the second coil group **15** to cancel this weak magnetic flux.

(64) The current detection apparatus **10** can thus reduce the residual magnetic flux, since currents of different magnitudes can flow independently in the first coil group **14** and the second coil group **15**.

(65) Also, because the residual magnetic flux can be reduced, the current detection apparatus **10** does not require a larger magnetic core **13** to prevent magnetic saturation. The current detection apparatus **10** can therefore reduce the cost of the magnetic core **13**.

(66) According to the current detection apparatus **10** of an embodiment as described above, the variation in the measured current value according to the position of the conductor to be measured **30** can be reduced, and the first coils La and the second coils Lb can be connected with simple wiring. In greater detail, the current detection apparatus **10** includes the first coil group **14** and the second coil group **15**, and the first coil La, among the first coils La1 to La4 of the first coil group **14**, in i.sup.th place from the first node **21** and the second coil Lb, among the second coils Lb1 to Lb4 of the second coil group **15**, in i.sup.th place from the first node **21** are arranged at opposing

positions. The variation in the measured current value according to the position of the conductor to be measured **30** can therefore be reduced. Furthermore, since the first coil group **14** and the second coil group **15** are connected in parallel between the first node **21** and the second node **22**, the first coils La and the second coils Lb can be connected with simple wiring.

(67) (First Variation)

(68) The current detection apparatus **10** illustrated in FIG. **1** includes the resistor **11** between the first node **21** and the second node **22**, but the position and number of resistors **11** are not limited to this configuration. FIG. **4** illustrates a current detection apparatus **10a**, according to a first variation, in which the position and number of resistors **11** differ.

(69) The differences between the current detection apparatus **10a** according to the first variation and the current detection apparatus **10** illustrated in FIG. **1** will mainly be explained, whereas an explanation of the common and similar points to the current detection apparatus **10** illustrated in FIG. **1** will be omitted.

(70) The current detection apparatus **10a** according to the first variation includes a first resistor **16a** between the first coil La2 and the first coil La3 in the first coil group **14**. The current detection apparatus **10a** according to the first variation also includes a second resistor **16b** between the second coil Lb2 and the second coil Lb3 in the second coil group **15**.

(71) Connection of the first resistor **16a** between the first coil La2 and the first coil La3 is only one example, and the first resistor **16a** may be connected between other adjacent first coils La. Connection of the second resistor **16b** between the second coil Lb2 and the second coil Lb3 is also only one example, and the second resistor **16b** may be connected between other adjacent second coils Lb.

(72) The first resistor **16a** and the second resistor **16b** may have the same resistance or different resistances. Since the first resistor **16a** and the second resistor **16b** may have different resistances, each can be adjusted to the optimum resistance.

(73) The current flowing in the first coil group **14** flows through the first resistor **16a**. The current flowing in the second coil group **15** flows through the second resistor **16b**.

(74) The detector **12** detects the voltage at both ends of the first resistor **16a** and the voltage at both ends of the second resistor **16b**. The detector **12** can detect the current flowing in the conductor to be measured **30** based on the value yielded by adding the voltage at both ends of the first resistor **16a** and the voltage at both ends of the second resistor **16b**.

(75) The detector **12** can also detect the current flowing in the first coil group **14** based on the voltage at both ends of the first resistor **16a**. The detector **12** can detect the current flowing in the second coil group **15** based on the voltage at both ends of the second resistor **16b**. The detector **12** can estimate the position of the conductor to be measured **30** by comparing the current flowing in the first coil group **14** and the current flowing in the second coil group **15**. For example, when the conductor to be measured **30** is centered, the current flows equally in the first coil group **14** and the second coil group **15**. When the conductor to be measured **30** is close to the first coil group **14**, for example, a larger current flows in the first coil group **14** and a smaller current flows in the second coil group **15**. When the conductor to be measured **30** is close to the second coil group **15**, for example, a larger current flows in the second coil group **15** and a smaller current flows in the first coil group **14**. In this way, the detector **12** can estimate the position of the conductor to be measured **30** by comparing the current flowing in the first coil group **14** and the current flowing in the second coil group **15**.

(76) For example, in a case in which the current flowing in the first coil group **14** and the current flowing in the second coil group **15** are equal, the detector **12** estimates that the conductor to be measured **30** is located near the center of the magnetic core **13**. In a case in which the current flowing in the first coil group **14** is greater than the current flowing in the second coil group **15**, the detector **12** estimates that the conductor to be measured **30** is closer to the first coil group **14**. In a case in which the current flowing in the second coil group **15** is greater than the current flowing in

the first coil group **14**, the detector **12** estimates that the conductor to be measured **30** is closer to the second coil group **15**.

(77) (Second Variation)

(78) FIG. 5 illustrates a current detection apparatus **10b**, according to a second variation, in which the position of the resistor **11** differs. The differences between the current detection apparatus **10b** according to the second variation and the current detection apparatus **10** illustrated in FIG. 1 will mainly be explained, whereas an explanation of the common and similar points to the current detection apparatus **10** illustrated in FIG. 1 will be omitted.

(79) The current detection apparatus **10b** according to the second variation includes a resistor **17** between a node connecting the first coil La2 and the second coil Lb2 and a node connecting the first coil La3 and the second coil Lb3.

(80) Note that the position of the resistor **17** illustrated in FIG. 5 is only an example. The resistor **17** may be located between a node connecting the first coil La1 and the second coil Lb1 and a node connecting the first coil La2 and the second coil Lb2, or between a node connecting the first coil La3 and the second coil Lb3 and a node connecting the first coil La4 and the second coil Lb4.

(81) The detector **12** detects the voltage at both ends of the resistor **17**. The detector **12** can detect the current flowing through the conductor to be measured **30** by detecting the voltage at both ends of the resistor **17**.

(82) In this way, the current detection apparatus **10b** according to the second variation includes the resistor **17** at a different position than the current detection apparatus **10** illustrated in FIG. 1 but can detect the current flowing in the conductor to be measured **30** in the same way as the current detection apparatus **10** illustrated in FIG. 1.

(83) It will be clear to a person of ordinary skill in the art that the present disclosure may be implemented in certain ways other than the above embodiments without departing from the spirit or essential features thereof. Accordingly, the above explanation merely provides examples that are in no way limiting. The scope of the present disclosure is to be defined by the appended claims, not by the above explanation. Among all changes, various changes that are within the range of equivalents are included therein.

(84) For example, the arrangement, number, and the like of the above-described components are not limited to the above explanation or the drawings. The arrangement, number, and the like of each component may be selected freely as long as the functions of the component can be achieved.

(85) For example, in the above embodiment, the case in which the detector **12** detects both the current flowing in the first coil group **14** and the current flowing in the second coil group **15** by detecting the voltage at both ends of the resistor **11** has been illustrated, but the means by which the detector **12** detects both the current flowing in the first coil group **14** and the current flowing in the second coil group **15** is not limited to this example. The detector **12** may use any current sensor to detect both the current flowing in the first coil group **14** and the current flowing in the second coil group **15**. For example, the detector **12** may use a non-contact current sensor to detect both the current flowing in the first coil group **14** and the current flowing in the second coil group **15**.

(86) For example, in the above embodiment, a configuration in which the first coil group **14** and the second coil group **15** are connected in parallel has been illustrated, but the number of coil groups connected in parallel is not limited to two. Three or more coil groups may be connected in parallel.

## Claims

1. A current detection apparatus comprising: an annular magnetic core that can be arranged to surround a conductor to be measured through which a current to be measured flows; a first coil group comprising a plurality of first coils different from each other, equally spaced from each other, arranged to wind around the magnetic core and connected in series; a second coil group comprising

a plurality of second coils different from each other, equally spaced from each other, arranged to wind around the magnetic core and connected in series; and a detector configured to detect both a current flowing in the first coil group and a current flowing in the second coil group, wherein the first coil group and the second coil group are connected in parallel between a first node and a second node, a count of the plurality of first coils and a count of the plurality of second coils are identical, and a first coil, among the plurality of first coils, in  $i$ .sup.th place from the first node and a second coil, among the plurality of second coils, in  $i$ .sup.th place from the first node are arranged at opposing positions, where  $i$  is an integer.

2. The current detection apparatus according to claim 1, further comprising a resistor through which flow both the current flowing in the first coil group and the current flowing in the second coil group, wherein the detector is configured to detect a voltage at both ends of the resistor.

3. The current detection apparatus according to claim 1, wherein the magnetic core has a shape that is one of a circular ring shape, a ring shape with an elliptical cross-section, and a ring shape with a polygonal cross-section.

4. The current detection apparatus according to claim 1, further comprising a shield configured to house the first coil group and the second coil group.

5. The current detection apparatus according to claim 1, further comprising a plurality of spacers installed between adjacent first coils and between adjacent second coils.

6. The current detection apparatus according to claim 1, wherein the detector is configured to compare the current flowing in the first coil group and the current flowing in the second coil group and estimate a position of the current to be measured.

7. A current detection apparatus comprising: an annular magnetic core that can be arranged to surround a conductor to be measured through which a current to be measured flows; a first coil group comprising a plurality of first coils different from each other, equally spaced from each other, arranged to wind around the magnetic core and connected in series; a second coil group comprising a plurality of second coils different from each other, equally spaced from each other, arranged to wind around the magnetic core and connected in series; a first resistor through which flows a current flowing in the first coil group; a second resistor through which flows a current flowing in the second coil group; and a detector configured to detect a voltage at both ends of the first resistor and a voltage at both ends of the second resistor, wherein the first coil group and the second coil group are connected in parallel between a first node and a second node, a count of the plurality of first coils and a count of the plurality of second coils are identical, and a first coil, among the plurality of first coils, in  $i$ .sup.th place from the first node and a second coil, among the plurality of second coils, in  $i$ .sup.th place from the first node are arranged at opposing positions, where  $i$  is an integer.

8. The current detection apparatus according to claim 7, wherein the detector is configured to compare the current flowing in the first coil group and the current flowing in the second coil group and estimate a position of the current to be measured.

---