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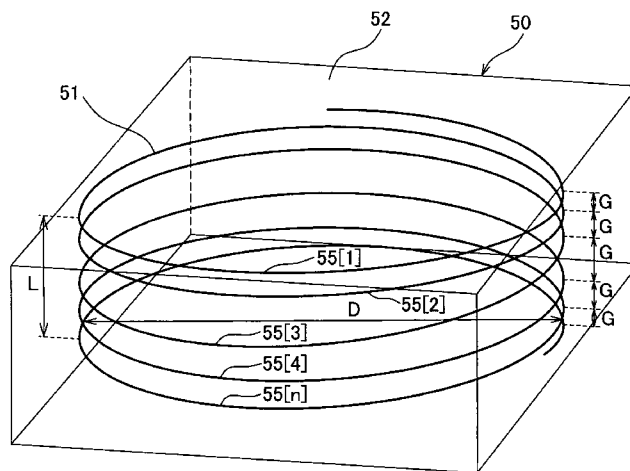
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(54) Title: RESONANCE COIL AND CONTACTLESS POWER TRANSMISSION SYSTEM INCORPORATING THE SAME
RESONANCE COIL

FIG. 1



(57) Abstract: A resonance coil is adapted to transmit via a resonance phenomenon an electric power to a counterpart coil or receive via the resonance phenomenon an electrical power transmitted from the counterpart coil. The resonance coil comprises a coil wire wound for multiple times so as to include a plurality of pairs of convolutions continuing to each other. A plurality of inter-convolutions gaps are each provided between corresponding pairs of the one convolution and the other convolution. The sizes of the inter-convolutions gaps are each defined in accordance with potential differences occurring between the corresponding pairs of the one convolution and the other convolution.

DESCRIPTION

Resonance Coil and Contactless Power Transmission System Incorporating the Same Resonance Coil

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Cross-Reference to Related Applications

This application claims priority under the Paris Convention based on Japanese Patent Applications No. 2010-283664 (filed on Dec. 20, 2010), No. 2010-283665 (filed on Dec. 20, 2010), and No. 2010-283666 (filed on
10 (Dec. 20, 2010), the entire contents of which are incorporated herein by reference.

Technical Field

The present invention generally relates to wireless power
15 transmission, also referred to as wireless energy transfer. Particularly, the present invention relates to a wireless (or contactless) power transmission system and a coil incorporated therein and adapted for wireless power transmission.

20 **Background Art**

Wireless (or contactless) power transmission techniques are used in recent years for eliminating physical connection such as plugs and thereby facilitating charging and recharging of a secondary battery (hereafter simply called “battery”) in electric vehicles.

25 By way of example, known wireless inductive power transmission systems are configured on the principles of electromagnetic induction,

electromagnetic waves, or resonance phenomena.

In the resonance-based wireless transmission scheme, an alternating current (AC) is fed to a transmitter resonance coil, and the transmitter resonance coil and a receiver resonance coil disposed opposed and in proximity to the transmitter resonance coil are placed in the resonant state by the electromagnetic field for power transmission therebetween. Such a resonance-based scheme enables transmission of large electric power in the order of several kilowatts between locations at a certain distance from each other.

A battery charging (recharging) system in an electric vehicle needs to have capability of supplying large electric power in the order of several kilowatts to several tens of kilowatts. Further, when such an in-vehicle recharging system is build on the resonance-based wireless power transmission techniques, high voltage is generated in the resonant state at or adjacent an end of a coil wire of the resonance coil, the coil wire being wound in a cylindrical or solenoidal manner to take a shape of a helix (see FIG. 12). This high voltage may cause electrical breakdown occurring between the resonance coil and a grounded case that accommodates the resonance coil. Further, the breakdown may cause spark discharge.

Japanese Patent Application Laid-Open Publication No. 2010-73885, published April 2, 2010, addresses the above technical problem.

Referring to FIG. 13, there is shown a conventional resonance coil 901 disclosed in the above-identified prior art literature. The state of the art resonance coil 901 comprises a coil wire 910 and an insulating resin 920.

The coil wire 910 is wound for several times helically to form a helix. The insulating resin 920 covers the coil wire 910, and the thickness of the

insulating resin 920 gradually increases toward an end 910a of the coil wire 910 along the length of the coil wire 910, which aims at increasing dielectric strength at the end 910a of the coil wire 910 and preventing occurrence of spark discharge.

5 The coil wire 910 of the resonance coil 901 includes gaps with a predetermined width (or height) between the convolutions (or turns) of the helically wound coil wire 910 so as to prevent spark discharge caused by breakdown between the convolutions of the coil wire 910. The term “contactless” used herein refers in general to absence of physical
10 connection such as plugs and cables.

Summary of the Invention

Technical Problem

15 In view of improved fuel efficiency, a larger interior space, and efficient use of an area dedicated to recharging functionality, it is of importance for in-vehicle battery charging/recharging systems to reduce the size of the resonance coil 901.

20 As can be appreciated from the graph of FIG. 12, the resonance coil 901 having the above-described configuration has some drawbacks. In spite of the fact that the potential differences occurring between any of the pairs of the convolutions of the coil wire 910 differ depending on the specific locations on the coil wire 910, the size (or height) of the inter-convolutions gaps is uniformly defined with reference to the largest potential difference.

25 Accordingly, the inter-convolutions gap is unnecessarily large for a location where the potential difference is small, which hinders implementation of inter-convolutions gaps with an optimal achievable

height, and accordingly reduction in size of the resonance coil 901.

Furthermore, it is appreciated that a lower-profile resonance coil 901 would have smaller inter-convolutions gaps in the coil wire 910. In order to prevent breakdown between the convolutions of the coil wire 910 in such a low-profile configuration, the insulating sheath of the coil wire has to be made of a resin material with high insulating property, or has to have a larger thickness. In either case, an insulating sheath that meets such additional insulation requirements will lead to increase in the manufacturing costs of the resonance coil.

Another approach to the above-identified drawback is to dispose the coil wire entirely in a mold, feed an insulating member made of insulating resin into the mold, and fill the spaces between the convolutions of the coil wire with the insulating member such that the entire coil wire is contained in the insulating member, thereby increase durability (dielectric strength) against breakdown between the convolutions of the coil wire, and at the same time reduce the heights of the inter-convolutions gaps of the coil wire.

Nevertheless, this alternative approach would leave the above-identified problem more or less unresolved as long as the height of the inter-convolutions gaps is uniform, i.e., the thicknesses of the insulating member filled into the spaces between the convolutions of the coil wire is uniform with reference to the largest potential difference. If the heights of the gaps are left uniform, the thickness of the insulating member is unnecessarily large, with excessive dielectric strength, at a location where the potential difference is small, which hinders optimal achievable thickness of the insulating member and reduction in the size of the

resonance coil, and leads to increase in the manufacturing costs.

Another drawback can be found. The coil wire 910 of the resonance coil 901 is covered by the insulating resin 920 such that the thickness of the insulating resin 920 gradually increases toward the end 910a in the longitudinal direction of the coil wire 910. In addition, the insulating resin 920 does not exist at the centre lengthwise thereof, or only a thin resin 920 is provided to cover the centre. Accordingly, durability against breakdown (dielectric strength) is low at the centre of the coil wire 910 along its axis, hindering reduction of the height of the inter-convolutions gaps between the convolutions and the size of the resonance coil 901 as such.

A solution to this technical aspect is to cover the entire coil wire 910 by an insulating sheath having a uniform thickness so that the dielectric strength is increased between the convolutions of the coil wire 910 and, the height (or size) of the inter-convolutions gaps of the coil wire 910 is reduced.

However, if the thickness of the insulating sheath covering the coil wire is uniform with reference to the largest potential difference, the thickness of the insulating sheath is unnecessarily large for a location where the potential difference is small, which hinders implementation of optimal achievable thickness of the insulating sheath reduction in the size of the resonance coil as such, leading to increase in the manufacturing costs.

In light of the foregoing, a need exists for a more low-profile and inexpensive resonance coil that is effectively protected against breakdown occurring between the convolutions of the coil wire and a contactless power transmission system incorporating such an improved resonance coil.

Solution to Problem

One aspect of the claimed subject provides a resonance coil transmitting via magnetic resonant coupling an electric power to a counterpart coil or receiving via the magnetic resonant coupling an electrical power transmitted from the counterpart coil, the resonance coil comprising: a coil wire wound for multiple times so as to include a plurality of pairs of convolutions continuing to each other, any of the pairs including one convolution and an other convolution adjacent the one convolution; and a plurality of inter-convolutions gaps each provided between corresponding pairs of the one convolution and the other convolution of the coil wire, sizes of the inter-convolutions gaps each being defined in accordance with potential differences occurring between the corresponding pairs of the one convolution and the other convolution.

Preferably, the coil wire is helically wound for multiple times, and the size of the inter-convolutions gap at the centre of the coil wire along an axis of the coil wire is larger than the sizes of the inter-convolutions gaps at both ends of the coil wire along the axis.

Preferably, the coil wire may include an insulating cover member covering a surface of the coil wire.

Preferably, the resonance coil may further comprise an insulating member filling the inter-convolutions gaps and containing the coil wire therein.

According to another aspect of the claimed subject, there is provided a resonance coil transmitting via magnetic resonant coupling an electric power to a counterpart coil or receiving via the magnetic resonant coupling an electrical power transmitted from the counterpart coil, the resonance coil

comprising: a coil wire wound for multiple times so as to include a plurality of pairs of convolutions continuing to each other, any of the pairs including one convolution and an other convolution adjacent the one convolution; and an insulating member provided between the pairs of the one convolution and the other convolution of the coil wire, sizes of the insulating member being defined in accordance with potential differences occurring between the corresponding pairs of the one convolution and the other convolution.

Preferably, the insulating member comprises a plurality of stacked insulating layers each having different dielectric strengths.

Preferably, the coil wire is helically wound for multiple times, the dielectric strength of the insulating layer at the centre of the coil wire along an axis of the coil wire is larger than the dielectric strengths of the insulating layers at both ends of the coil wire along the axis.

Preferably, the insulating layers comprises a pair of first insulating layers each provided at the corresponding both ends of the coil wire along its axis, and a second insulating layer provided between the pair of first insulating layers to be disposed at the centre of the coil wire along the axis, and the dielectric strength of the second insulating layer being larger than that of the pair of first insulating layers.

According to yet another aspect of the claimed subject, there is provided a resonance coil transmitting via a magnetic resonant coupling an electric power to a counterpart coil or receiving via the magnetic resonant coupling an electrical power transmitted from the counterpart coil, the resonance coil comprising: a coil wire wound for multiple times so as to include a plurality of pairs of convolutions continuing to each other, any of

the pairs including one convolution and an other convolution adjacent the one convolution; and a cover member covering the coil wire, a thickness of the cover member being defined in accordance with potential differences occurring between the corresponding pairs of the one convolution and the other convolution.

Preferably, the coil wire is helically wound for multiple times, and the thickness of the cover member at the centre of the coil wire along an axis of the coil wire is larger than the thickness of the cover member at both ends of the coil wire along the axis.

An additional illustrative embodiment provides a contactless electric power transmission system comprising: a transmitter resonance coil adapted to transmit an electric power via magnetic resonant coupling; and a receiver resonance coil adapted to receive the electric power via magnetic resonant coupling, the receiver resonance coil receiving the electric power transmitted by the transmitter resonance coil, wherein one or both of the transmitter receiving coil and the receiver resonance coil comprises the above-described resonance coil according to the aspects of the claimed subject.

The invention itself as well as a preferred mode of use, further objectives and advantages thereof, will best be understood by reference to the following detailed description of illustrative embodiments when read in conjunction with the drawings.

Brief Description of the Drawings

The accompanying drawings illustrate some exemplary embodiments of the present invention and together with the description serve to explain

the principles of the present invention, the same or like elements therein having the same or like reference signs, wherein:

FIG. 1 is a perspective view of a resonance coil according to one embodiment of the present invention;

5 FIG. 2 is a side view of a coil wire of the resonance coil of FIG. 1;

FIG. 3A is a front view of a round planar coil having a variant configuration of the resonance coil of FIG. 1;

FIG. 3B is a front view of a rectangular planar coil having another variant configuration of variant of the resonance coil of FIG. 1;

10 FIG. 4 is a perspective view of a resonance coil according to one embodiment of the present invention;

FIG. 5 is a side view of the resonance coil of FIG. 1;

FIG. 6A is a front view of a round planar coil having a variant configuration of the resonance coil of FIG. 4;

15 FIG. 6B is a front view of a rectangular planar coil having another variant configuration of the resonance coil of FIG. 4;

FIG. 7 is a perspective view of a resonance coil according to one embodiment of the present invention;

20 FIG. 8A is a cross-sectional view of a coil wire of the resonance coil of FIG. 1 taken along its length, where the coil wire is extended straight;

FIG. 8B is a cross-sectional view taken along the line X1-X1 indicated in FIG. 1;

FIG. 8C is a cross-sectional view taken along the line X2-X2 indicated in FIG. 1;

25 FIG. 9 illustrates a configuration of a wireless power transmission system in the context of the contactless power transmission system

according to one embodiment of the present invention;

FIG. 10 is a block diagram of the wireless power transmission system of FIG. 9;

FIG. 11 illustrates principles of resonance-based power transmission systems;

FIG. 12 schematically illustrates voltage distribution where the coil wire is in a resonant state; and

FIG. 13 is a partly enlarged cross-sectional view of a conventional resonance coil.

10

Description of Exemplary Embodiments

The resonance coil according to illustrative embodiments of the claimed subject matter and a wireless power transmission system incorporating the same resonance coil are described with reference to the drawings, wherein like reference numerals are used to refer to like elements throughout. Specifically, the resonance coil according to illustrative embodiments of the claimed subject matter and a wireless power transmission system incorporating the same resonance coil are described below with reference to FIGS. 1 to 11.

It should be understood that the embodiments are presented for the purpose of illustrating the general principles of the resonance coil and the wireless power transmission system of the claimed subject matter and is not meant to limit the inventive concepts claimed herein.

First Embodiment of Resonance Coil

With reference now to FIGS. 1 and 2, there is depicted a resonance

coil according to a first embodiment of the claimed subject matter.

The resonance coil 50 is adapted to transmit electric power to a counterpart coil disposed opposed to the resonance coil or receives electrical power transmitted from the counterpart coil by means of a
5 resonance phenomenon (i.e., via magnetic resonant coupling).

As shown in these figures, the resonance coil 50 comprises a coil wire 51 and a molded member 52 serving as an insulating member.

The coil wire 51 may comprise an air-cored helical coil constructed with a copper wire having a diameter of about 5 millimeters that is wound
10 in a cylindrical (solenoidal) manner for multiple times (n-turns), the helical coil having a diameter D of about 600 millimeters and a length L of about 200 millimeters.

The coil wire 51 that has been helically or solenoidally wound will comprise a plurality of circular portions (turns), which is hereafter referred
15 to as “convolutions 55[1] to 55[n]” (where n is the number of turns in the helix). Between one convolution 55[k] and another adjacent convolution 55[k+1] (where k = 1 to n-1) of the coil wire 51 (which may be hereafter simply expressed as “between convolutions 55”), there are provided minimum-sized inter-convolutions gaps G defined in accordance with a
20 potential difference between the convolutions 55. In other words, the height (or the size) of the gap G is defined such that breakdown does not occur between the convolutions 55 due to the potential difference between the convolutions 55.

It is understood by one of ordinary skills that the height of the
25 inter-convolutions gap G is defined in accordance with the voltage distribution of the coil wire 51 in resonant state. The voltage distribution of

the coil wire 51 in the resonant state is illustrated in FIG. 12.

As can be appreciated from FIG. 12, the potential difference (i.e., the slope of the graph) of the coil wire 51 by one unit distance becomes larger along the length L toward the centre of the coil wire 51 (i.e., the origin of the graph), and smaller along the length L toward both ends of the coil wire 51. In other words, the helically (solenoidally) wound coil wire 51 has varying potential differences between the convolutions 55 depending on their specific locations. Specifically, the potential difference between the convolutions 55 becomes larger along the axis (i.e., along the length L) toward the centre of the coil wire 51 and smaller along the axis toward the both ends of the coil wire 51.

This indicates that the heights of the inter-convolutions gaps G of the helically (solenoidally) wound coil wire 51 are defined such that the gaps G become gradually small from the centre of the coil wire 51 along its axis to the both ends of the coil wire 51. In other words, the height of the inter-convolutions gap G at the centre portion of the coil wire 51 is larger than the heights of the inter-convolutions gaps G at the both ends of the coil wire 51 along its axis.

A molded member 52 may be made of insulating synthetic resin with high withstand voltage such as PI (polyimide) and PFA (Tetrafluoroethylene-Perfluoro-Alkylvinylether copolymer). The insulating resin in a molten state may be filled into a cubic-frame-shaped mold in which the coil wire 51 in its entirety is accommodated, and then solidified so that the inter-convolutions gaps G are filled therewith and the entire coil wire 51 is contained therein. The AC breakdown voltage of the molded member 52 is in the order of 15 to 20 kilovolts per millimeter (kV/mm) in

the case of PI, or 150 kV/mm in the case of PFA. On the other hand, the AC breakdown voltage of air is in the order of 3 kV/mm. Accordingly, the presence of the molded member 52 allows reduction of the size of the inter-convolutions gap G.

5 In this embodiment, there are provided the inter-convolutions gaps G having the sizes in accordance with the potential differences occurring between the pairs of the convolutions of the coil wire 51. On the other hand, in the case of a conventional one, for example, the sizes of the inter-convolutions gaps G are one the same, the size will be defined
10 depending on the potential difference between the convolutions 55 at the centre portion of the coil wire 51 along its axis, i.e., depending on the largest potential difference. Accordingly, the size of the inter-convolutions gap G will be excessively large at both ends of the coil wire 51 along its axis of the coil wire 51, leaving unnecessary excess spaces.

15 Further, with regard to the inter-convolutions gap G according to this embodiment, the size of the inter-convolutions gap G is decreased at the both ends of the coil wire 51 along its axis where the potential difference between the convolutions 55 is relatively small. Also, the size of the inter-convolutions gap G is increased at the centre portion of the coil wire
20 51 along its axis where the potential difference between the convolutions 55 is relatively large. Thus, the inter-convolutions gaps G have the optimal achievable sizes depending on the specific potential differences between the convolutions 55, allowing reduction in the size of the resonance coil.

Using the coil wire 51 disclosed herein, there are provided
25 inter-convolutions gaps G between the one convolution 55[k] of the coil wire 51 and the other convolution 55[k+1] adjacent the one convolution

55[k], the gaps G having the size in accordance with the potential difference occurring between the one convolution 55[k] and the other convolution 55[k+1]. Accordingly, for example, in the case of the resonance coil described in the above-described patent literature PTL 1, where a inter-convolutions gap with a predetermined size is provided in accordance with the largest potential difference occurring between the coil wire portions, there will be excessively large inter-convolutions gap at a location where the potential difference is small, which is hindrance to reduction in the size of the resonance coil. In contrast, in the case of the claimed subject matter, by virtue of the inter-convolutions gaps G having the sizes in accordance with the potential differences between the convolutions 55 of the coil wire 51, it is made possible to eliminate the presence of the excessively large inter-convolutions gaps and thereby provide a smaller and more inexpensive resonance coil 50 free from the breakdown between the portions of the coil wire 51.

Also, the coil wire 51 is wound helically for multiple times, and the size of the inter-convolutions gap G at the centre portion of the coil wire 51 along its axis is larger than the size of the inter-convolutions gap G at the both ends of the coil wire 51 along its axis. Accordingly, it is made possible to construct a smaller and more inexpensive resonance coil free from breakdown between the portions of the coil wire 51 by virtue of the resonance coil 50 characterised by the fact that the potential differences occurring between the convolutions 55 of the coil wire 51 is the larger at the cylindrical centre portion of the coil wire 51 along its axis, and the smaller at the both ends of the coil wire 51 along its axis.

Also, there is provided the molded member 52 filling the

inter-convolutions gaps G and contains the coil wire 51 therein, the molded member 52 being made of insulating material. Accordingly, durability against breakdown between the portions of the coil wire 51 (dielectric strength) is improved, allowing reduction of the size of the inter-convolutions gap G, and the resonance coil can be made further smaller.

It is contemplated in this embodiment that the coil wire 51 only comprises a copper wire. However, the claimed subject matter is not limited to this configuration. It should be appreciated that the coil wire 51 may include an insulating cover member covering the surface of the coil wire 51, the cover member being made of, for example, PI or PFA. In this manner, the dielectric strength of the coil wire 51 is improved with reduction of the size of the inter-convolutions gap G, and the resonance coil can be made further smaller. Also, In this embodiment, there is provided the molded member 52. However, the claimed subject matter is not limited to this configuration, and the molded member 52 may be eliminated.

Also, the coil wire 51 of this embodiment is wound helically for multiple times, and the inter-convolutions gaps G gradually become smaller from the centre portion of the coil wire 51 along its axis toward the both ends of the coil wire 51 along its axis. However, the claimed subject matter is not limited to this configuration. For example, as shown in FIGS. 3A and 3B, the resonance coil may comprise a flat helical coil having the coil wire 51 wound in a plate-like manner for multiple times the inter-convolutions gaps G may gradually become smaller from the centre in the radial direction (the direction in which an object extends in a radial fashion away from the centre) toward inner peripheral portion and toward the outer

peripheral portion. As long as the spirit of the claimed subject matter is not deviated from, it suffices that there is provided the inter-convolutions gaps G whose sizes are in accordance with the potential differences occurring between the pairs of the convolutions 55 of the coil wire 51.

5

Second Embodiment of Resonance Coil

Referring now to FIGS. 4 to 6, there is depicted a resonance coil according to a second illustrative embodiment of the invention.

In the same manner as in the first illustrative embodiment, the
10 resonance coil uses resonance phenomena (magnetic resonance coupling) and is configured to transmit the electric power to the counterpart coil disposed opposed to the resonance coil or receives electrical power transmitted by the counterpart coil. Description of the basic configuration of the coil wire 51 is not repeated here.

15 The resonance coil 50 of this embodiment comprises a coil wire 51 and a molded member 52. The molded member 52 serves as an insulating member in the context of the claimed subject matter.

As shown in FIGS. 4 to 6, the coil wire 51 may comprise an air-cored helical coil having the same or similar configuration as that of the first
20 embodiment. Accordingly, the coil wire 51 comprises a plurality of circular portions (turns), i.e., convolutions 55[1] to 55[n].

As can be appreciated from FIGS. 4 to 6, there are provided predetermined inter-convolutions gaps G between the one convolution 55[k] of the coil wire and the other convolution 55[k+1] (where k = 1 to
25 n-1) adjacent the one convolution 55[k]. It should be noted here that, in contrast to the first embodiment, the “any pair of the predetermined

inter-convolutions gaps G'' have the same or substantially the same interval therebetween).

The coil wire 51 has the same or similar voltage distribution as that of the first embodiment as shown in FIG. 12. Accordingly, the potential difference between the convolutions 55 is large at the centre in the axis of the coil wire 51 (i.e., along the length L of the coil wire 51), and the potential difference between the convolutions 55 is small at the both ends of the coil wire 51 along the axis.

As shown in FIGS. 4 to 6, the molded member 52 includes a pair of first insulating layers 52a, 52b and a second insulating layer 52c stacked between the pair of first insulating layers 52a, 52b. The material for forming the pair of first insulating layer 52a, 52b and the second insulating layer 52c may be selected in view of the mechanical and electrical characteristics of the coil wire 51.

The pair of first insulating layers 52a, 52b may be made of insulating synthetic resin with intermediate withstand voltage such as PI (polyimide), and filled into the space between the convolutions 55 at the both ends in the axial direction of the coil wire 51 (i.e., the length L direction) so that the convolutions 55 are contained therein.

The second insulating layer 52 may be made of insulating synthetic resin with high withstand voltage such as PFA (Tetrafluoroethylene-Perfluoro-Alkylvinylether copolymer), and filled into the space between the convolutions 55 at the centre portion of the coil wire 51 along its axis so that the convolutions 55 are contained therein. The second insulating layer 52c is made of a material having dielectric strength larger than that of the material of the pair of first insulating layers 52a, 52b.

The AC breakdown voltage of the PI for the pair of first insulating layers 52a, 52b is in the order of 15 to 20 kilovolts per millimeter (kV/mm). The AC breakdown voltage of the PFA for the second insulating layer 52c is in the order of 150 kV/mm. On the other hand, the AC breakdown voltage of the air is in the order of 3 kV/mm. Accordingly, the presence of the molded member 52 enables reduction in the size of the inter-convolutions gaps G when compared with a coil wire 51 without a molded member.

With regard to the molded member 52, the PI in a molten state is fed into a cubic-frame-shaped mold up to a third of the mold, the mold accommodating the entire coil wire 51, and the PI is solidified, so that the first insulating layer 52b is formed. Next, the PFA in a molten state is fed into the mold up to two thirds of the mold and is solidified, so that the second insulating layer 52c is formed. Finally, The PI in a molten state is fed into the mold to fill the remaining one third of the mold and is solidified, so that the first insulating layer 52a is formed.

Thus, the synthetic resin is filled into the space between the convolutions 55 to form the insulating layer therebetween and contain the coil wire 51 therein, and thus the first insulating layer 52a, 52b and the second insulating layer 52c are provided. In other words, the molded member 52 is configured such that the dielectric strength of the centre portion of the coil wire 51 along its axis becomes larger than the dielectric strength of the both ends of the coil wire 51 along its axis in accordance with the fact that the potential difference between the convolutions 55 in the resonant state at the centre portion of the coil wire 51 along its axis is larger than the potential difference between the convolutions 55 at the both

ends of the coil wire 51 along its axis.

In the above-described embodiment, there is provided the molded member 52 comprising the first insulating layers 52a, 52b and the second insulating layer 52c. On the other hand, in the state of the art configuration
5 where a molded member 52 only comprises the PI with the relatively lower dielectric strength such that the dielectric strength becomes uniform, the inter-convolutions gap G (i.e., the thickness of the molded member 52 filling the space between the convolutions 55) is provided in accordance with the potential difference between the convolutions 55 at the centre
10 portion of the coil wire 51 along its axis, i.e., the largest potential difference.

Accordingly, in order to provide sufficient dielectric strength, the thickness of the molded member 52 filling the space between the convolutions 55 becomes large, and the external dimensions of the molded
15 member 52 (i.e., length L) also becomes large.

Also, when the molded member 52 is configured only using the PFA with the relatively large dielectric strength so that the dielectric strength is uniform, it is made possible to reduce the thickness of the molded member 52 filling the space between the convolutions 55 and thus reduce the
20 external dimensions. However, a material is expensive that has larger dielectric strength, and, the thickness of the molded member 52 filling the space between the convolutions 55 is defined depending on the potential difference between the convolutions 55 at the centre portion of the coil wire 51 along its axis, i.e., the largest potential difference.

25 Accordingly, the thickness of the molded member 52 filling the space between the convolutions 55 will be excessive large at the both ends of the

coil wire 51 along its axis, failing to provide optimized construction. Also the same problem of failure to provide optimized construction applies even when the PI is used.

Further, according to this embodiment, with regard to the molded member 52, the pair of first insulating layers 52a, 52 are provided at the both ends of the coil wire 51 along its axis where the potential difference between the convolutions 55 is relatively small, the first insulating layers 52a, 52 being made of insulating material having a relatively small dielectric strength, and the second insulating layer 52c is provided at the centre portion of the coil wire 51 along its axis where the potential difference between the convolutions 55 is relatively large, the second insulating layer 52c being made of material having a relatively large dielectric strength.

Thus, insulating member has the dielectric strength in accordance with the potential difference between the convolutions 55, eliminating presence of excessive dielectric strength and thereby reducing both the size and the costs of the resonance coil.

As has been described in the foregoing, some of the advantageous effects achieved by the resonance coil according to the second embodiment are as follows.

There is provided the molded member 52 between the space of the one convolution 55[k] and the adjacent other convolution 55[k+1] of the coil wire 51, the molded member 52 having the dielectric strength in accordance with the potential difference occurring between the one convolution 55[k] and the other convolution 55[k+1].

If the dielectric strength of the molded member 52 between the each

pair of the convolutions 55 of the coil wire 51 is uniform, excessive dielectric strength is provided between some of the convolutions 55 of the coil wire 51.

In contrast, the first insulating layers 52a, 52b and the second
5 insulating layer 52c have the dielectric strengths adjusted in accordance with the potential differences occurring between the specific pair of the convolutions 55 of the coil wire 51. Accordingly, it is made possible to eliminate excessive dielectric strength within the molded member 52, and thus provide smaller and more inexpensive resonance coils 50 free from
10 breakdown between the convolutions of the coil wire 51.

Also, the coil wire 51 is wound helically for multiple times such that the dielectric strength in the molded member 52 at the centre portion of the coil wire 51 along its axis is larger than that of the both ends of the coil wire 51 along its axis.

15 Accordingly, in the resonance coil 50 in which the potential difference occurring between the convolutions 55 of the coil wire 51 is the larger at the centre portion of the helical coil wire 51 along its axis and the smaller at the both ends thereof, it is made possible to construct a smaller and more inexpensive resonance coil 50 free from break down between the
20 convolutions of the coil wire 51.

Further, the molded member 52 comprises (a) the pair of first insulating layers 52a, 52b provided between the both ends of the coil wire 51 along its axis and (b) the second insulating layer 52c stacked between the pair of first insulating layers 52a, 52b at the centre portion of the coil
25 wire 51 along its axis, the second insulating layer 52c having the dielectric strength larger than that of the pair of first insulating layers 52a, 52b.

Accordingly, in the resonance coil in which the potential difference occurring between the convolutions 55 of the coil wire 51 is the larger at the centre of the helical coil wire in its axis direction and is the smaller at the both ends thereof, the molded member 52 has a simple three-layer structure made of insulating materials having difference dielectric strengths,
5 which enables to provide inexpensive resonance coil 50.

In this embodiment, the molded member 52 has the three-layer configuration comprising the pair of first insulating layers 52a, 52b and the second insulating layer 52c. However, the claimed subject matter is not
10 limited to this configuration. For example, the molded member 52 may include four or more insulating layers. The simple configuration of the molded member 52 with the stacked insulating layers allows realization of inexpensive resonance coils.

Also, with regard to the molded member 52, the configuration is not
15 limited to the stacked structure of the insulating layers. As long as the object of the claimed subject matter is not deviated from, there may be provided a molded member 52 between the one convolution 55[k] and the adjacent other convolution 55[k+1] of the coil wire 51, the molded member 52 having a dielectric strength in accordance with the potential difference
20 occurring between the one convolution 55[k] and the other convolution 55[k+1] and in view of the voltage distribution of the coil wire 51.

Also, in this embodiment, the predetermined inter-convolutions gaps G are provided between each pair of the convolutions of the coil wire 51. However, the claimed subject matter is not limited to this specific
25 configuration. For example, the inter-convolutions gaps G may differ in their sizes adjusted depending on the potential difference between the

convolutions 55 and in view of the dielectric strength of the molded member 52.

In addition, the coil wire 51 of this embodiment is wound helically for multiple times. However, the claimed subject matter is not limited to this configuration, and for example, as shown in FIGS. 6A and 6B, the resonance coil may comprise a flat helical coil having (a) a flat and cylindrical molded member 52 comprising a first insulating layer 52b, a second insulating layer 52c, and a first insulating layer 52a in this order in the radial direction (the direction in which an object extends in a radial fashion away from the centre) and (b) the coil wire 51 wound in a plate-like manner for multiple times and comprise and accommodated in the molded member 52 As long as the object of the claimed subject matter is deviated from, the coil wire 51 may take a suitable shape.

15 Third Embodiment of Resonance Coil

Now referring to FIGS. 7 and 8, illustrated is a resonance coil according to a third illustrative embodiment of the claimed subject matter.

In the same manner as in the first and second illustrative embodiments, the resonance coil of the third embodiment also uses resonance phenomena (magnetic resonance coupling) and is configured to transmit the electric power to the counterpart coil disposed opposed to the resonance coil or receives electrical power transmitted by the counterpart coil. Description of the basic configuration of the coil wire 51 is not repeated here.

25 The resonance coil (indicated by the reference sign 50 in the figures) of the claimed subject matter shown in the figures includes a coil wire 51

and a cover member 53.

As shown in FIGS. 7 and 8, the coil wire 51 may comprise an air-cored helical coil having the same or similar configuration as that of the first embodiment. Accordingly, the coil wire 51 comprises a plurality of
5 circular portions (turns), i.e., convolutions 55[1] to 55[n].

Further, there are provided predetermined inter-convolutions gaps G between the one convolution 55[k] of the coil wire and the other convolution 55[k+1] (where $k = 1$ to $n-1$) adjacent the one convolution 55[k]. It should be noted here that, in contrast to the first embodiment, the
10 “any pair of the predetermined inter-convolutions gaps G” have the same or substantially the same interval therebetween).

The coil wire 51 has the same or similar voltage distribution as that of the first embodiment as shown in FIG 12. Accordingly, the potential difference between the convolutions 55 is large at the centre in the axis of
15 the coil wire 51 (i.e., along the length L of the coil wire 51), and the potential difference between the convolutions 55 is small at the both ends of the coil wire 51 along the axis.

The cover member 53 may be made of insulating synthetic resin with high withstand voltage such as PI (polyimide) and PFA
20 (Tetrafluoroethylene-Perfluoro-Alkylvinylether copolymer) such that the entire surface of the coil wire 51 is covered by the cover member 53. The AC breakdown voltage PI for the cover member 53 is in the order of 15 to 20 kV/mm. The AC breakdown voltage of the PFA for the cover member 53 is in the order of 150 kV/mm, On the other hand, the AC breakdown
25 voltage of the air is in the order of 3 kV/mm. Accordingly, the presence of the cover member 53 enables reduction in the size of the inter-convolutions

gaps G.

The configuration of the cover member 53 is illustrated in FIGS. 8A to 8C. FIG. 8A is a cross-sectional view of the coil wire 51 taken along the length thereof, where the coil wire 51 is extended straight, and FIG. 8B is a
5 cross-sectional view of the centre of the coil wire 51 in its longitudinal direction, i.e., the centre being the centre portion of the coil wire 51 along its axis when the coil wire 50 is wound helically for multiple times, and FIG. 8C is a cross-sectional view of one end of the coil wire in its longitudinal direction, i.e., the end being one of the both ends of the coil
10 wire 51 along its axis when the coil wire 50 is wound helically multiple times.

The cover member 53 is configured in accordance with the potential differences between the convolutions 55, i.e., such that the cover member 53 has the minimum thickness necessary for preventing breakdown
15 between the convolutions 55 even when this potential difference is created. The thickness of the cover member 53 is defined in accordance with the voltage distribution of the coil wire 51 in the resonant state.

In other words, the cover member 53 has a thickness adjusted in view of the above-described property of the coil wire 51, as shown in FIG. 8A to
20 8C, the thickness being gradually decreased from the centre in the longitudinal direction (i.e., the centre portion of the coil wire 51 along its axis) and toward the both ends in the longitudinal direction (i.e., with both ends of the coil wire 51 along its axis). In other words, the thickness of the cover member 53 is larger at the centre portion of the coil wire 51 along its
25 axis than at both ends of the coil wire 51 along its axis.

As has been described in the foregoing, some of the advantageous

effects achieved by the resonance coil according to the third embodiment are as follows.

The thickness of the cover member 53 is the larger at the centre portion of the coil wire 51 along its axis than at the both ends of the coil wire 51 along its axis. On the other hand, in the case of other configurations, if the cover member 53 has the thickness uniform over the entire length of the coil wire 51, the thickness will be defined in accordance with the potential difference between the convolutions 55 at the centre portion of the coil wire 51 along its axis, i.e., with reference to the largest potential difference. As a result, the thickness of the cover member 53 at the both ends of the coil wire 51 along its axis will be excessively large, failing to provide optimized resonance coil.

In contrast, according to the third illustrative embodiment, the thickness of the cover member 53 is small at the both ends of the coil wire 51 along its axis where the potential difference between the convolutions 55 is relatively small, and large at the centre portion of the coil wire 51 along its axis where the potential difference between the convolutions 55 is relatively large.

Accordingly, the cover member 53 has the thickness in accordance with the potential differences between the convolutions 55, which helps reduction of both the size and the costs of the resonance coil.

According to the third exemplary embodiment, there is provided the cover member 53 covering the coil wire 51 and having the thickness in accordance with the potential difference occurring between the one convolution 55[k] and the other convolution 55[k+1] of the coil wire 51.

It should be noted here that, if the thickness of the cover member 53

between the each pair of the convolutions 55 of the coil wire 51 is uniform, excessive dielectric strength is provided by some portions of the cover member 53.

In contrast, in this embodiment, the cover member 53 has the thickness adjusted in accordance with the potential difference occurring between the specific pair of the convolutions 55 of the coil wire 51, so that it is made possible to provide the optimal achievable thickness of the cover member 3 and eliminate excessive dielectric strength in the cover member 53, and thus provide smaller and more inexpensive resonance coils 50 free from breakdown between the convolutions of the coil wire 51.

Also, the coil wire 51 is wound helically for multiple times such that the thickness of the cover member 53 at the centre portion of the coil wire 51 along its axis is larger than that of the both ends of the coil wire 51 along its axis.

Accordingly, in the resonance coil 50 in which the potential difference occurring between the convolutions 55 of the coil wire 51 is the larger at the centre portion of the helical coil wire 51 along its axis and the smaller at the both ends thereof, it is made possible to provide a smaller and more inexpensive resonance coil 50 free from break down between the convolutions of the coil wire 51.

In this embodiment, the thickness of the cover member 53 at the centre portion of the coil wire 51 along its axis is larger than that of the both ends of the coil wire 51 along its axis. However, the claimed subject matter is not limited to this specific configuration, and as long as the object of the claimed subject matter is not deviated from, it suffices that the cover member 53 has the thickness defined in accordance with the potential

differences occurring between the one convolution 55[k] and the adjacent other convolution 55[k+1] of the coil wire 51.

Also, the predetermined inter-convolutions gap G is provided between each pair of the convolutions 55 of the coil wire 5. However, the
5 claimed subject matter is not limited to this configuration. By way of example, the inter-convolutions gaps G may have different size adjusted in view of the potential difference between the convolutions 55 and the thickness of the cover member 53.

Further, the coil wire 51 of this embodiment is wound helically
10 multiple times. However, the claimed subject matter is not limited to this configuration, and for example, the resonance coil may comprise a flat helical coil having the coil wire 51 wound in a plate-like manner for multiple times and comprise and accommodated in the molded member 52. As long as the object of the claimed subject matter is deviated from, the
15 coil wire 51 may take a suitable shape.

Exemplary Embodiment of Contactless Power transmission System

Turning now to FIGS. 9 to 11, there is depicted a contactless power transmission system incorporating the above-described resonance coil is
20 described below with reference to FIGS. 9 to 11.

FIG. 9 illustrates an exemplary configuration of the wireless power transmission system according to one embodiment of the invention. As shown in the same figure, the wireless power transmission system 10 of this embodiment includes a power-receiving device 12 provided in an
25 electric vehicle 5, and a power feeding device 11 adapted to supply alternating-current (AC) power to the power-receiving device 12. The

alternating-current (AC) power output by the power feeding device 11 is transmitted in a contactless (wireless) manner to the power-receiving device 12.

The power feeding device 11 includes a communication coil 24 for power transmission. When the alternating-current (AC) power is fed to the communication coil 24, the alternating-current (AC) power is transmitted to a communication coil 31 for electric power reception provided in the power-receiving device 12.

The power-receiving device 12 provided in an electric vehicle 5 comprises (a) a communication coil 31 for electric power reception and (b) a rectifier 33, the communication coil 31 being placed in proximity to a communication coil 24 for power transmission when the electric vehicle 5 is placed in a predetermined location of a power feeding device 11 for recharging.

Further, the power-receiving device 12 also comprises a battery 35 storing DC power; DC/DC converter 42 stepping down the voltage of the battery 35 and supplying the DC power to a sub-battery 41; an inverter 43 converting the output power output by the battery 35 into alternating-current (AC) power; and a motor 44 driven by the alternating-current (AC) power output by the inverter 43.

FIG. 10 is a block diagram of the wireless power transmission system 10 according to an illustrative embodiment of the claimed subject matter. The wireless power transmission system 10 comprises the power feeding device 11, and the power-receiving device 12 provided in the electric vehicle 5.

The power feeding device 11 comprises a carrier oscillator 21

adapted to output a carrier signal for electric power transmission; a power amplifier 23 adapted to amplify the carrier signal (i.e., alternating-current (AC) power) output by the carrier oscillator 21; and a communication coil 24 adapted to output the alternating-current (AC) power amplified by the power amplifier 23. The communication coil 24 comprises, as will be described below in more detail, a feeding coil (primary coil) L1 and a transmitter resonance coil X1. Further, the above-described resonance coil 50 serves as the transmitter resonance coil X1.

The carrier oscillator 21 is adapted to output alternating-current (AC) power having frequency in the order of, but not limited to, 1 to 100 MHz, in the form of alternating-current signal.

The power amplifier 23 is adapted to amplify the alternating-current (AC) power that has been output by the carrier oscillator 21, and output the amplified alternating-current (AC) power to the communication coil 24. The communication coil 24 is adapted, in cooperation with the communication coil 31 provided in the power-receiving device 12, to wirelessly transmit the alternating-current (AC) power to the communication coil 31 using the resonance-based power transmission techniques. The resonance-based power transmission system (i.e., resonance techniques) will be described below in more detail.

Also, the power-receiving device 12 includes a communication coil 31 for electric power reception adapted to receive alternating-current (AC) power transmitted from a communication coil 24 for power transmission, a rectifier 33 adapted to rectify the alternating-current (AC) power received by the communication coil 31 and generate a DC voltage. Also, there is provided a battery 35 adapted to supply electric power to the vehicle-drive

motor 44 (see FIG. 9), and the battery 35 is recharged by the DC power output by the rectifier 33.

The communication coil 31, as will be described below in more detail, includes a power-receiving coil L2 (primary coil) and a receiver
5 resonance coil X2. Further, the above-described resonance coil 50 is used as the receiver resonance coil X2.

Next, the resonance-based power transmission system is explained below. FIG. 11 illustrates the principles of the resonance-based power transmission systems. As shown in the same figure, the power feeding
10 device 11 includes feeding coil L1, and a transmitter resonance coil X1 (i.e., resonance coil 50) concentrically with and adjacent the feeding coil L1. It should be noted that the feeding coil L1 and the transmitter resonance coil X1 constitutes the communication coil 24 shown in FIGS. 9, 10. Also, the power-receiving device 12 includes a power-receiving coil L2, and a
15 receiver resonance coil X2 (i.e., resonance coil 50) provided concentrically with and adjacent the power-receiving coil L2. It should be noted that the power-receiving coil L2 and the receiver resonance coil X2 constitute the communication coil 31 shown in FIGS. 9, 10.

When primary current is let to flow in the feeding coil L1,
20 electromagnetic induction causes an induced current flows in the transmitter resonance coil X1, further, the inductance L_s and stray capacitance C_s of the transmitter resonance coil X1 causes the transmitter resonance coil X1 resonate at resonant frequency $\omega_s (= 1/\sqrt{L_s \cdot C_s})$. In response to this, the receiver resonance coil X2 of the power-receiving
25 device 12 provided adjacent this transmitter resonance coil X1 resonates at resonant frequency ω_s , and the secondary current flows in the, receiver

resonance coil X2. Further, the electromagnetic induction causes the secondary current to flow in the power-receiving coil L2 adjacent the receiver resonance coil X2.

As a result of the above-described operation, electric power is
5 allowed to be wirelessly transmitted from the power feeding device 11 to the power-receiving device 12.

Next, the operation of the wireless power transmission system of the claimed subject matter illustrated in FIGS. 9, 10 is described below. As shown in FIG. 8, the battery will be allowed to be recharged when the
10 electric vehicle 5 is placed at the predetermined location of the power feeding device 11, and the communication coil 24 provided in the power feeding device 11 and the communication coil 31 provided in the power-receiving device 12 of the electric vehicle 5 are each placed in positions opposed to each other.

15 When charging operation is started, alternating-current (AC) power having frequency in the order of 1 to 100 MHz is output by the carrier oscillator 21 illustrated in FIG. 10.

Further, the alternating-current (AC) power output by the carrier oscillator 21 is amplified by the power amplifier 23. The amplified
20 alternating-current (AC) power は, via the communication coils 24 ,31, in accordance with the principles of the resonance-based power transmission, will be transmitted to the power-receiving device 12.

The alternating-current (AC) power transmitted to the power-receiving device 12 is output from the communication coil 31 to the
25 rectifier 33.

Further, the rectifier 33 rectifies the alternating-current (AC) power

and converts it into a DC power with predetermined voltage, supplies the DC power to the battery 35, and charges the battery 35. In this manner, the battery 35 can be recharged.

As has been described in the foregoing, according to the claimed
5 subject matter, the above-described resonance coils 50 are used as the transmitter resonance coil X1 and the receiver resonance coil X2. Accordingly, between the one convolution 55[k] and the adjacent other convolution 55[k+1] of the coil wire 51 of the resonance coil 50, there is provided the inter-convolutions gap G having the size in accordance with
10 the potential difference occurring between the one convolution 55[k] and the other convolution 55[k+1], so that it is made possible to eliminate excessively large gaps between convolutions, and the transmitter resonance coil X1 and the receiver resonance coil X2 can be made small in a cost-effective manner, and thus one can build a smaller and more
15 inexpensive contactless power transmission system.

In this illustrative embodiment, Although the resonance coil 50 served as the transmitter resonance coil X1 and the receiver resonance coil X2, the claimed subject matter is not limited to this configuration, and it suffices that the resonance coil 50 is employed as at least either of the
20 transmitter resonance coil X1 and the receiver resonance coil X2.

While the exemplary embodiments of the invention have been described by way of example, it will be appreciated by those skilled in the art may make various modifications in the light of the above teaching and within the scope and spirit of the invention, and the scope of the invention is
25 to be defined by the claims appended hereto.

Claims

That which is claimed is:

1. A resonance coil transmitting via a resonance phenomenon an electric
5 power to a counterpart coil or receiving via the resonance phenomenon an
electrical power transmitted from the counterpart coil, the resonance coil
comprising:

a coil wire wound for multiple times so as to include a plurality of pairs
of convolutions continuing to each other, any of the pairs including one
10 convolution and an other convolution adjacent the one convolution; and

a plurality of inter-convolutions gaps each provided between
corresponding pairs of the one convolution and the other convolution of the
coil wire, sizes of the inter-convolutions gaps each being defined in
accordance with potential differences occurring between the corresponding
15 pairs of the one convolution and the other convolution.

2. The resonance coil as set forth in claim 1, wherein the coil wire is
helically wound for multiple times, the size of the inter-convolutions gap at
the centre of the coil wire along an axis of the coil wire is larger than the
20 sizes of the inter-convolutions gaps at both ends of the coil wire along the
axis.

3. The resonance coil as set forth in claim 2, wherein the coil wire includes
an insulating cover member covering a surface of the coil wire.

4. The resonance coil as set forth in claim 3, further comprising an

insulating member filling the inter-convolutions gaps such that the coil wire is contained in said insulating member.

5 5. A resonance coil transmitting via a resonance phenomenon an electric power to a counterpart coil or receiving via the resonance phenomenon an electrical power transmitted from the counterpart coil, the resonance coil comprising:

10 a coil wire wound for multiple times so as to include a plurality of pairs of convolutions continuing to each other, any of the pairs including one convolution and an other convolution adjacent the one convolution; and

15 an insulating member provided between the pairs of the one convolution and the other convolution of the coil wire, sizes of the insulating member being defined in accordance with potential differences occurring between the corresponding pairs of the one convolution and the other convolution.

6. The resonance coil as set forth in claim 5, the insulating member comprises a plurality of stacked insulating layers each having different dielectric strengths.

20 7. The resonance coil as set forth in claim 6, wherein the coil wire is helically wound for multiple times, the dielectric strength of the insulating layer at the centre of the coil wire along an axis of the coil wire is larger than the dielectric strengths of the insulating layers at both ends of the coil wire along the axis.

25 8. The resonance coil as set forth in claim 7, wherein the insulating layers

comprises a pair of first insulating layers each provided at the corresponding both ends of the coil wire along its axis, and a second insulating layer provided between the pair of first insulating layers to be disposed at the centre of the coil wire along the axis, and the dielectric
5 strength of the second insulating layer being larger than that of the pair of first insulating layers.

9. A resonance coil transmitting via a resonance phenomenon an electric power to a counterpart coil or receiving via the resonance phenomenon an
10 electrical power transmitted from the counterpart coil, the resonance coil comprising:

a coil wire wound for multiple times so as to include a plurality of pairs of convolutions continuing to each other, any of the pairs including one convolution and an other convolution adjacent the one convolution; and
15 a cover member covering the coil wire, a thickness of the cover member being defined in accordance with potential differences occurring between the corresponding pairs of the one convolution and the other convolution.

10. The resonance coil as set forth in claim 9, wherein the coil wire is
20 helically wound for multiple times, the thickness of the cover member at the centre of the coil wire along an axis of the coil wire is larger than the thickness of the cover member at both ends of the coil wire along the axis.

11. A contactless electric power transmission system comprising:
25 a transmitter resonance coil adapted to transmit an electric power via a resonance phenomenon;

a receiver resonance coil adapted to receive the electric power via the resonance phenomenon, the receiver resonance coil receiving the electric power transmitted by the transmitter resonance coil, wherein one or both of the transmitter receiving coil and the receiver resonance coil comprises the
5 resonance coil recited in any of the preceding claims.

FIG. 1

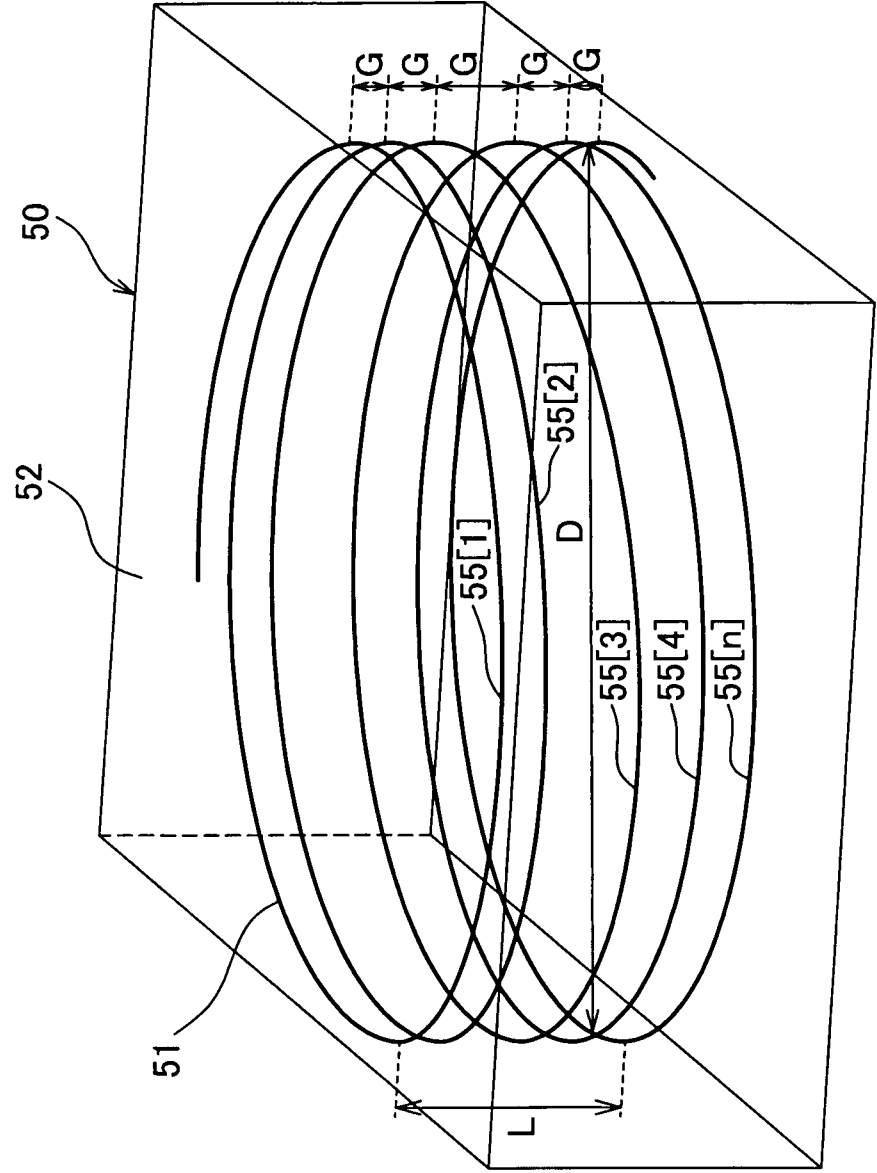


FIG. 2

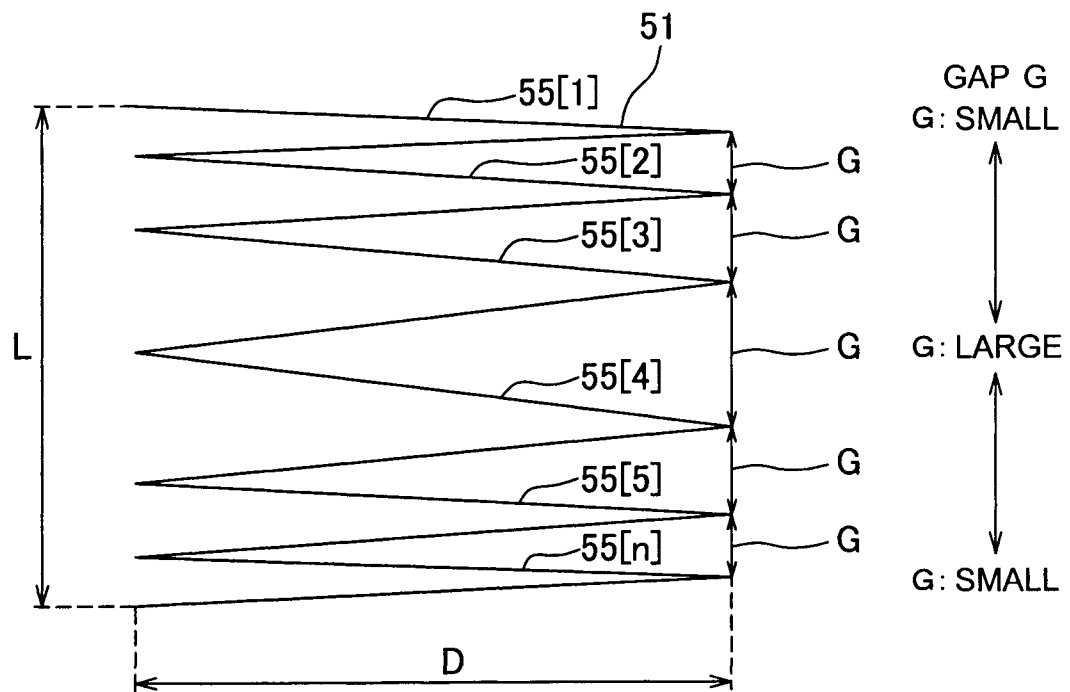


FIG. 3A

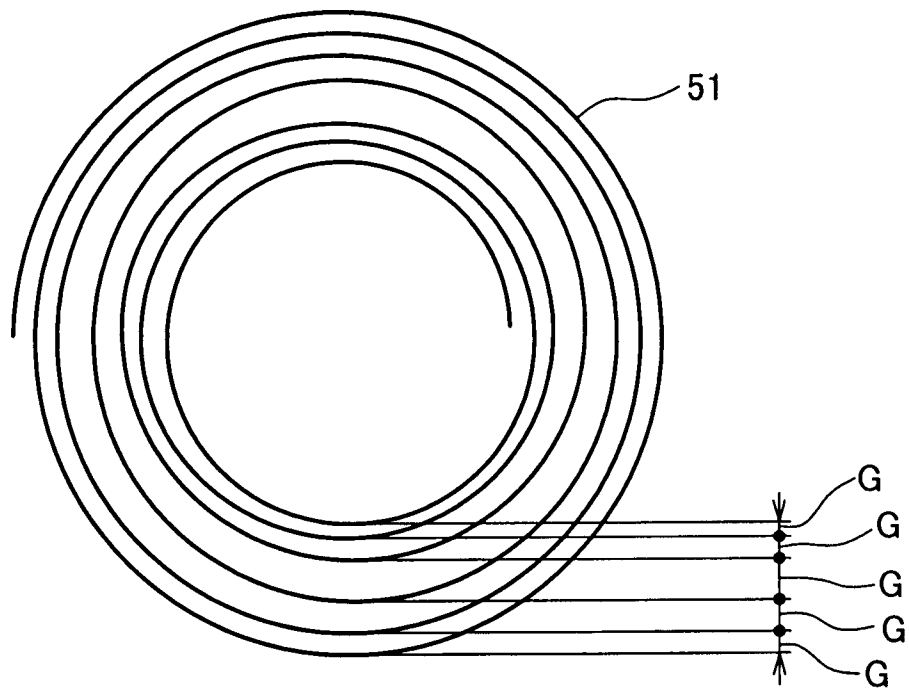


FIG. 3B

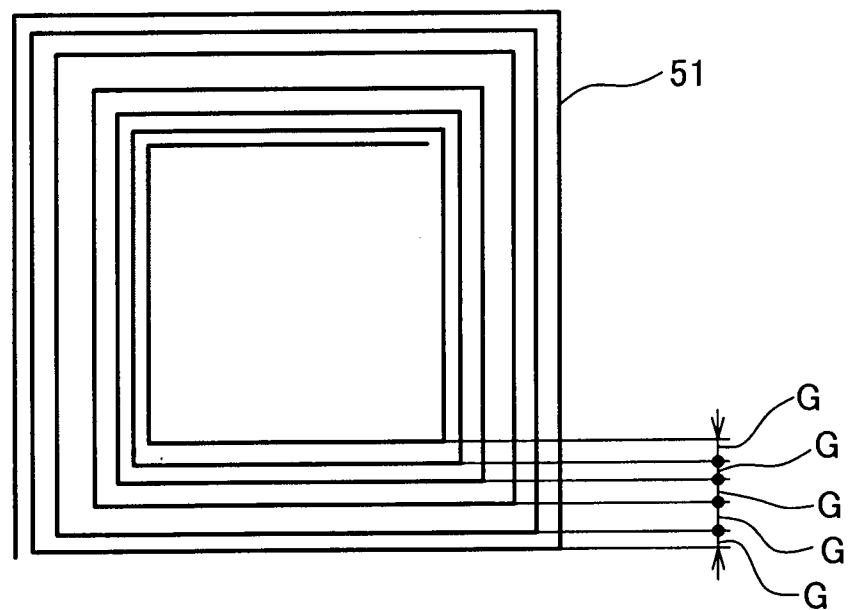


FIG. 4

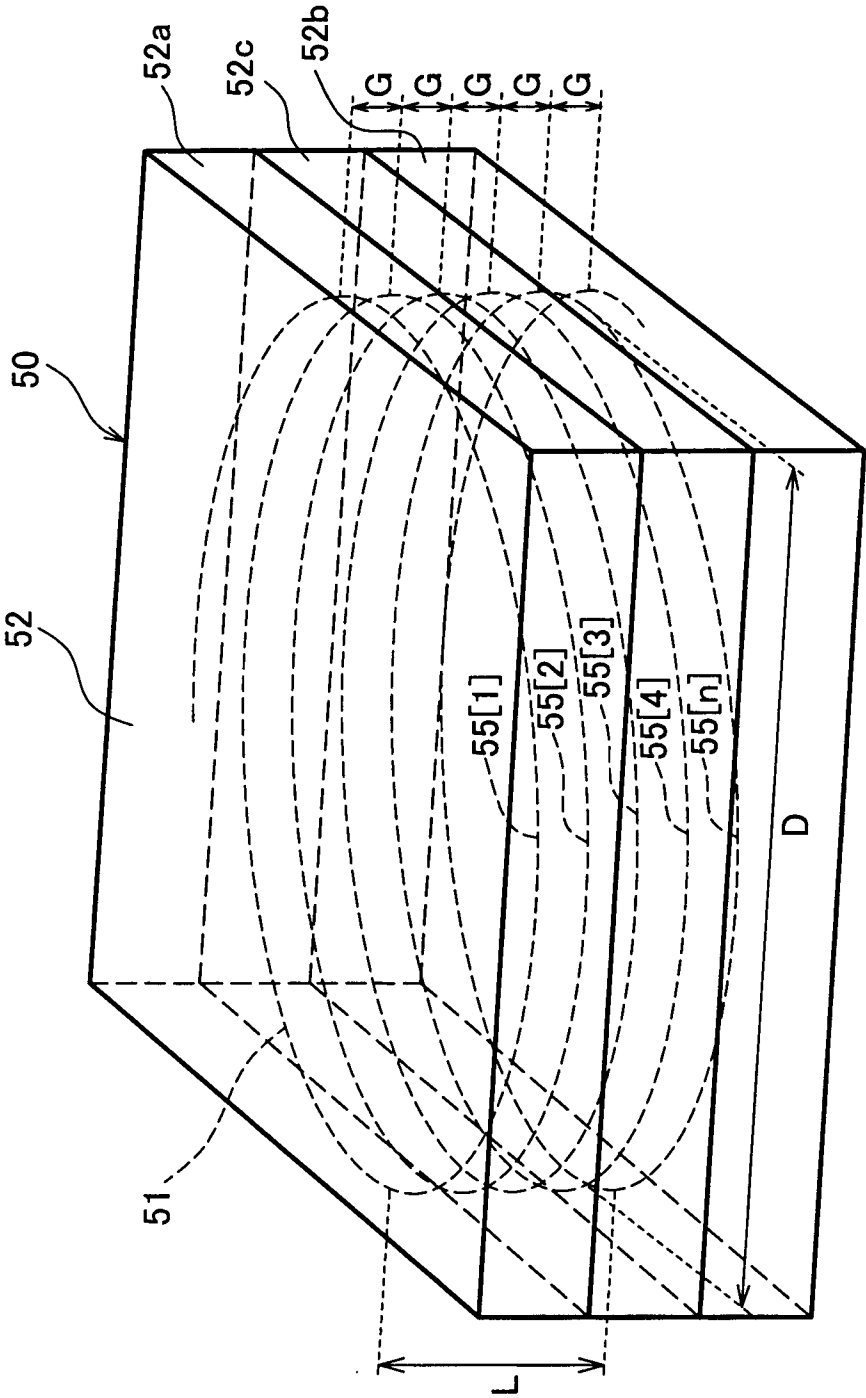


FIG. 5

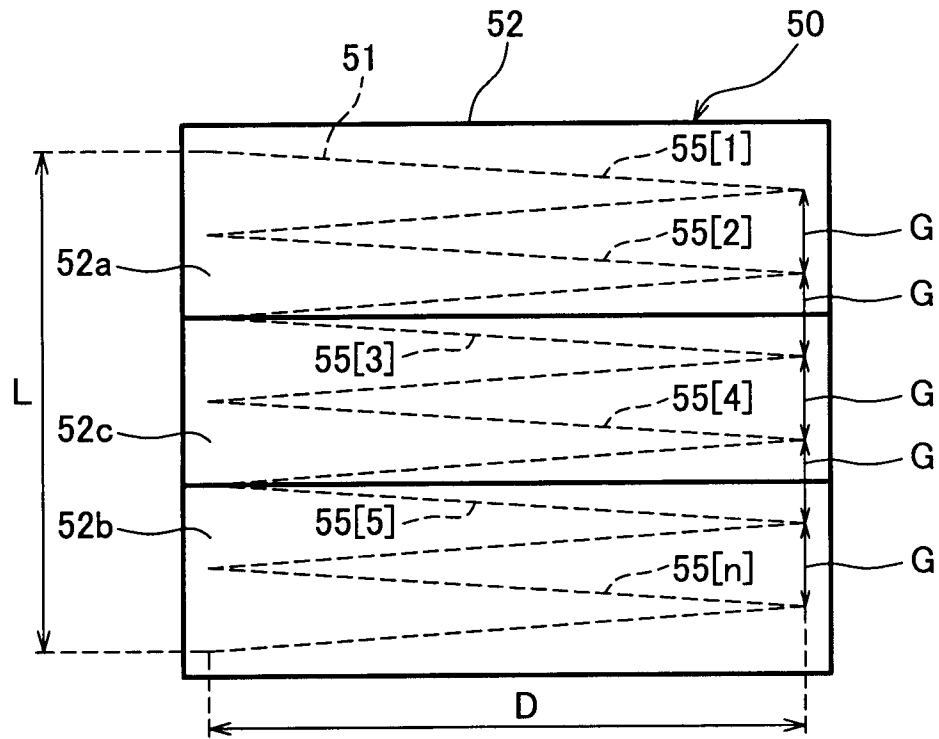


FIG. 6A

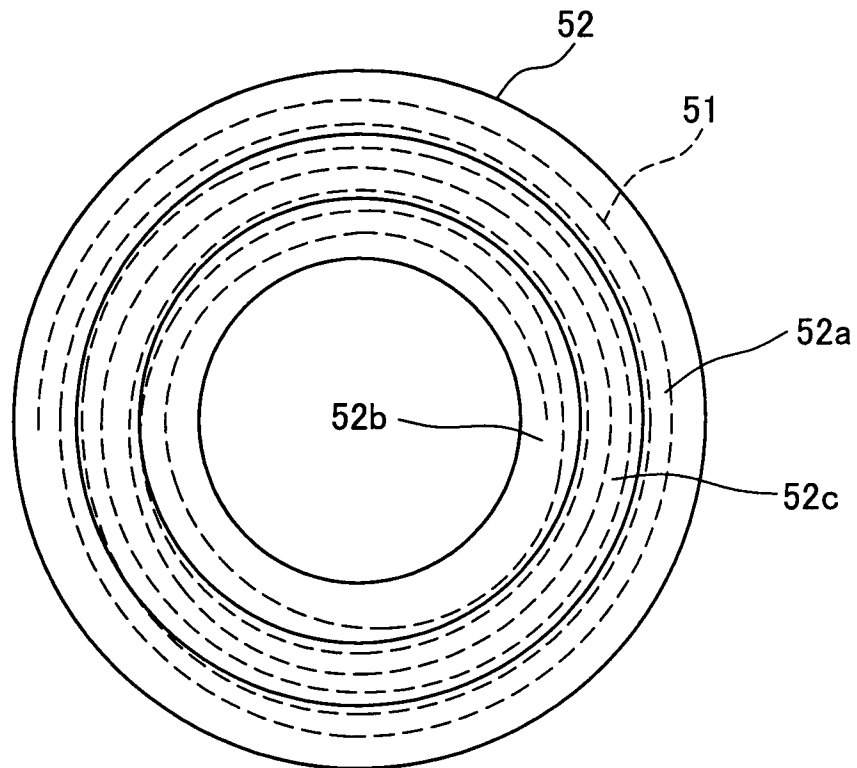


FIG. 6B

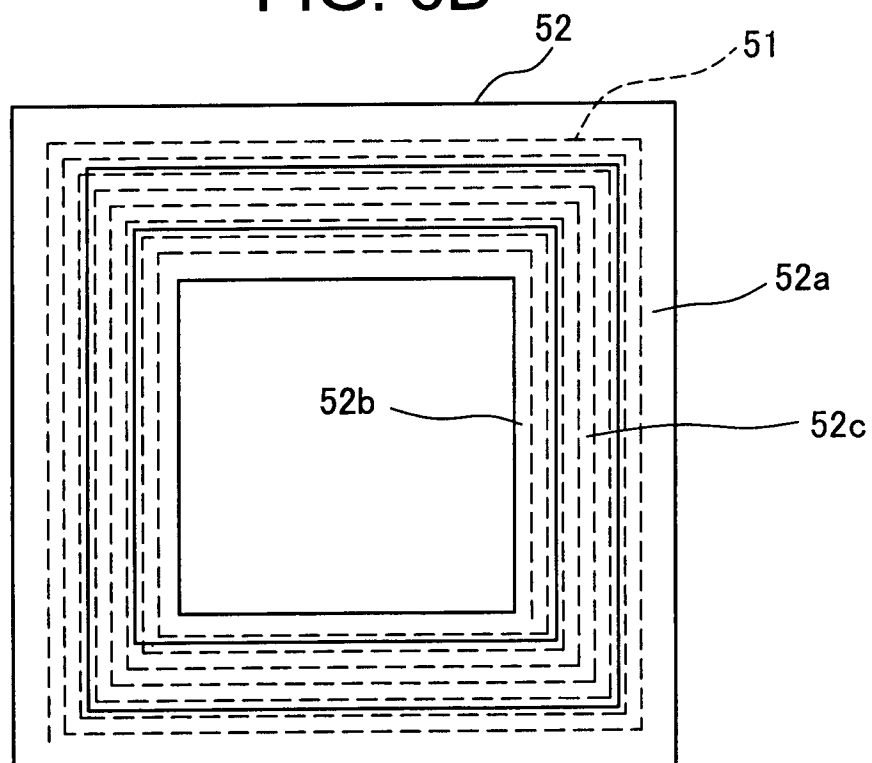


FIG. 7

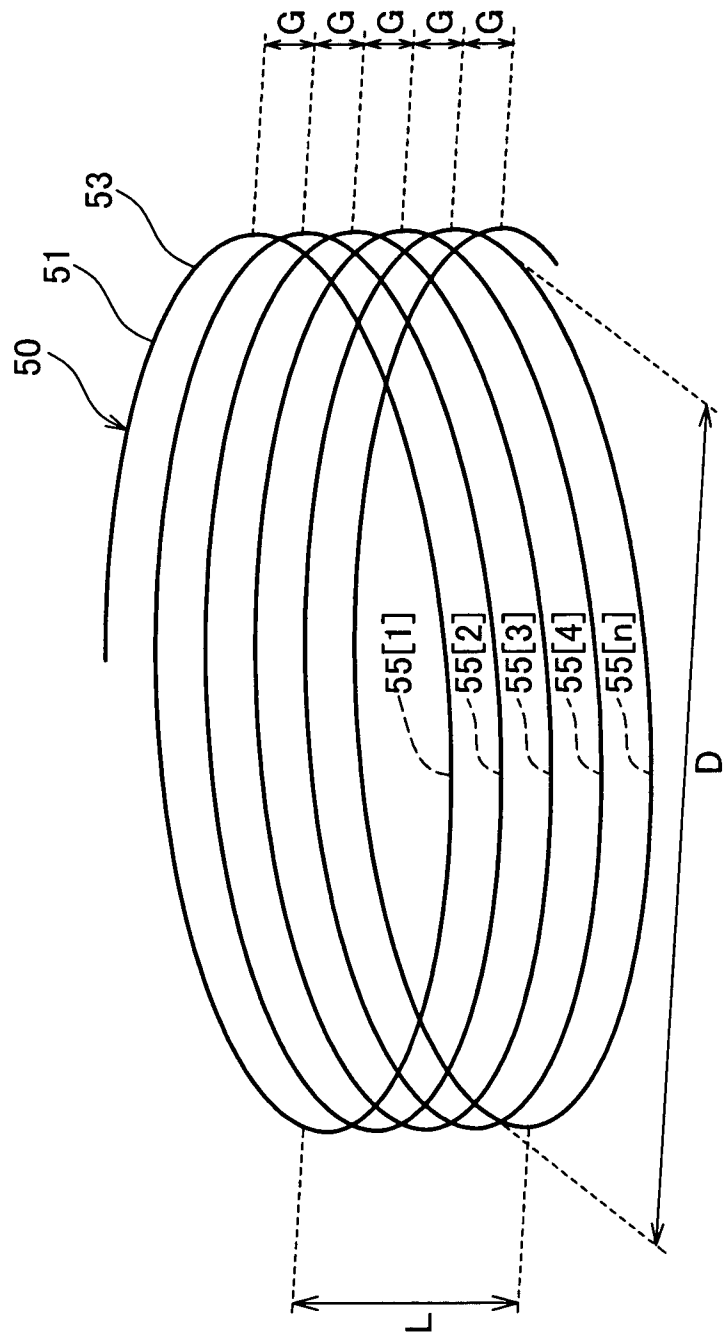


FIG. 8A

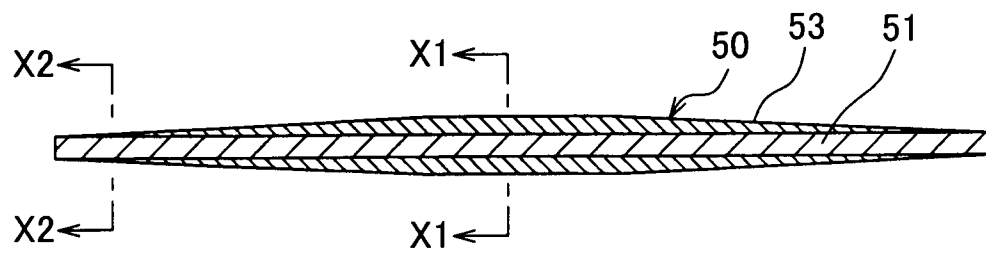


FIG. 8B

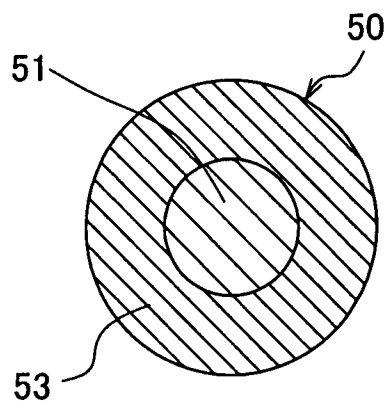


FIG. 8C

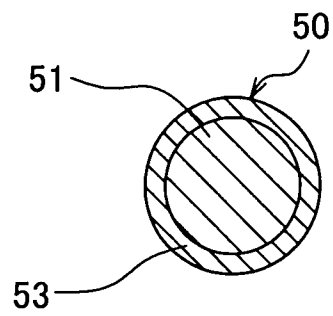


FIG. 9

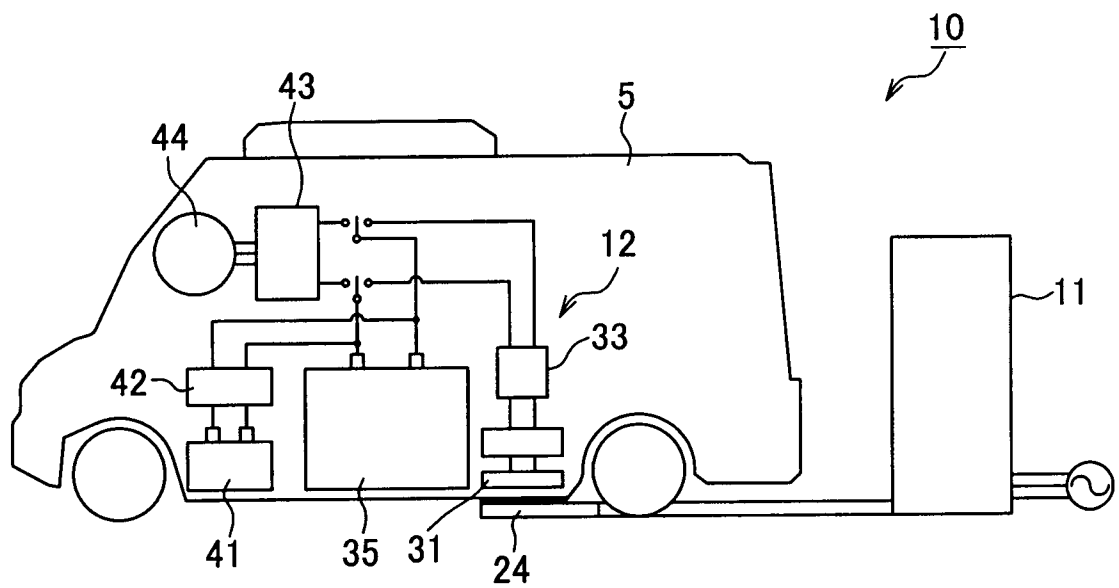


FIG. 10

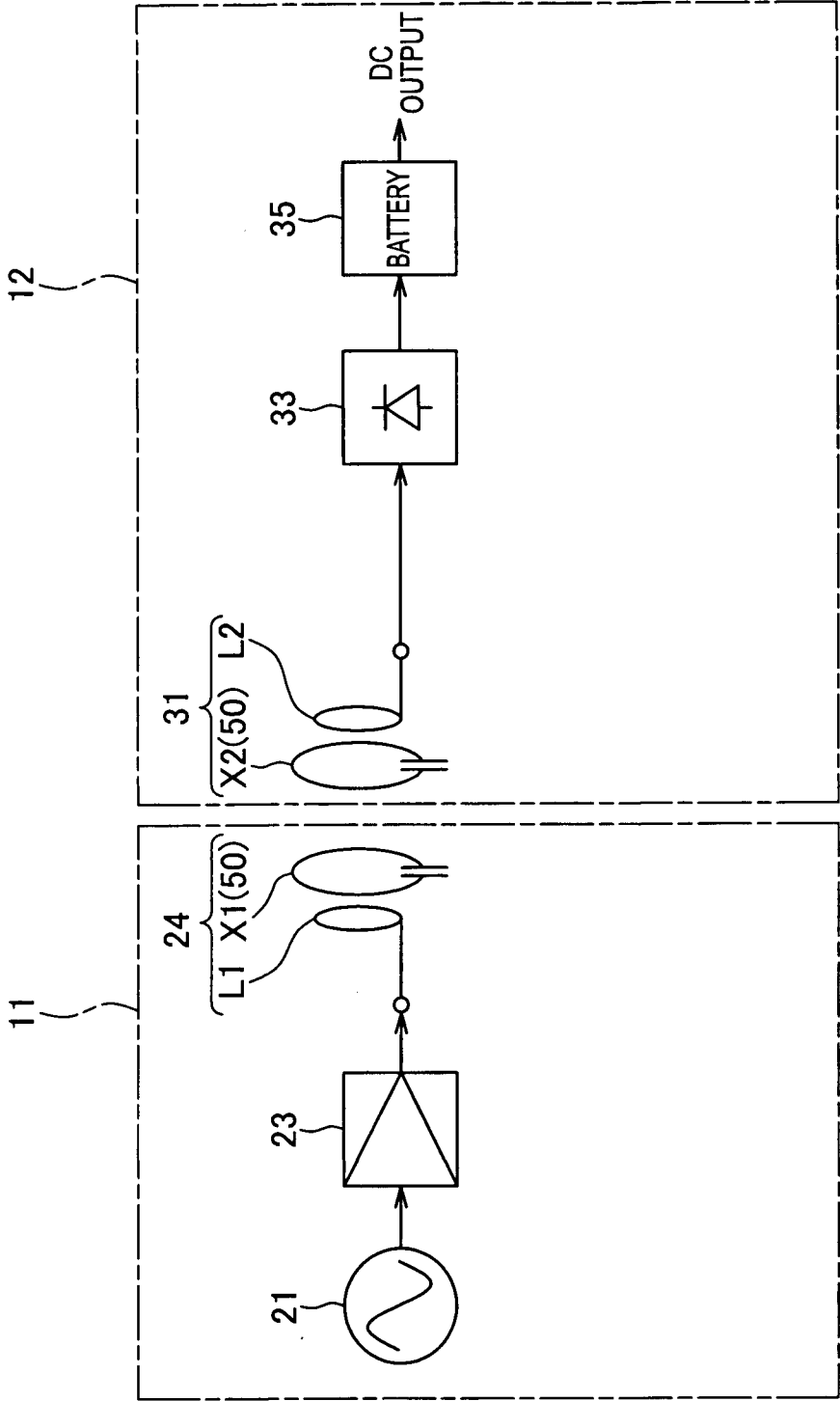


FIG. 11

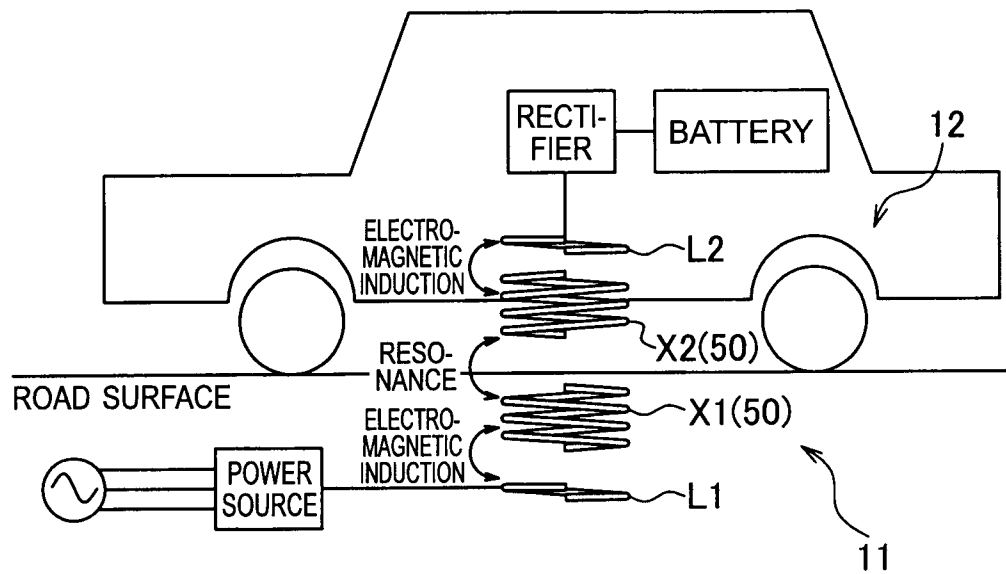


FIG. 12

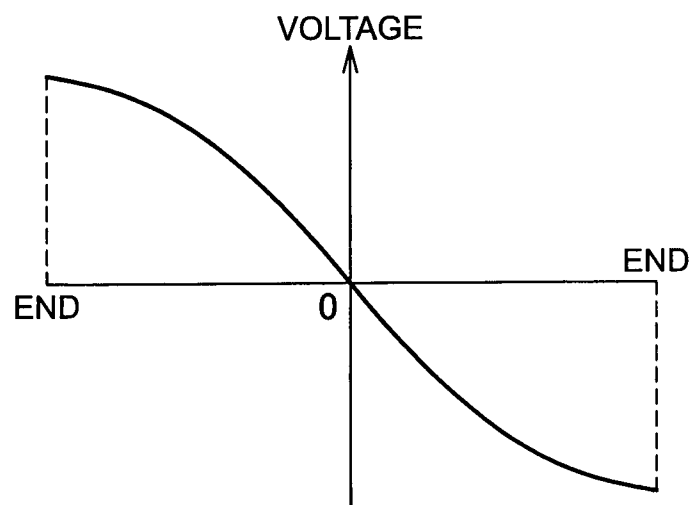
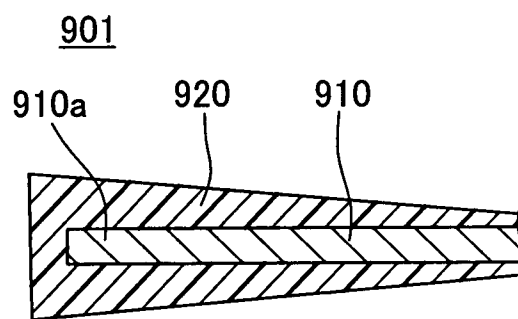


FIG. 13



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2011/078843

A. CLASSIFICATION OF SUBJECT MATTER

Int.Cl. H01F38/14 (2006.01) i, H02J7/00 (2006.01) i, H02J17/00 (2006.01) i,
B60L5/00 (2006.01) n, B60L11/18 (2006.01) n, B60M7/00 (2006.01) n

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

Int.Cl. H01F38/14, H02J7/00, H02J17/00, B60L5/00, B60L11/18, B60M7/00

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Published examined utility model applications of Japan 1922-1996
Published unexamined utility model applications of Japan 1971-2012
Registered utility model specifications of Japan 1996-2012
Published registered utility model applications of Japan 1994-2012

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y A	JP 2010-130878 A (TOYOTA INDUSTRIES.INC. & TOYOTA MOTOR.INC.) 2010.06.10, paragraph 10-33, Fig1-5 Family:WO 2010/064584 A1	1-4, 11 5-10
Y	JP 2007-43527 A (MURATA MANUFACTURING.INC.) 2007.02.15, paragraph 9-18 Family:none	1-4, 11
A	JP 2010-73885 A (TOYOTA MOTOR.INC.) 2010.04.02, paragraph 35-42, Fig1-6 Family:none	5-8, 11

☒ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

08.03.2012

Date of mailing of the international search report

19.03.2012

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5R 4 4 4 3

INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2011/078843

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 2010-73976 A (YAZAKI.INC.) 2010.04.02, paragraph 19-62, Fig1-13 Family:none	1-11
A	JP 2010-68657 A (YAZAKI.INC.) 2010.03.25, paragraph 15-18 Family:none	1-11
E,A	JP 2012-23299 A (EQUOS RESEARCH.INC.) 2012.02.02, paragraph 51-55, Fig7,8 Family:none	1-4,11