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(71) Applicant: **TE CONNECTIVITY GERMANY GMBH** [DE/DE]; Amperestrasse 12-14, 64625 Bensheim (DE).

(72) Inventors: **WOLF, Marco**; Hainbachring 2a, 76879 Hochstadt (DE). **BERGER (NEE: SEHESTEDT), Christian**; Wormser Landstrasse 27, 67346 Speyer (DE).

(74) Agent: **KEANE, David**; Murgitroyd & Company, Scotland House, 165-169 Scotland Street, Glasgow Strathclyde G5 8PL (GB).

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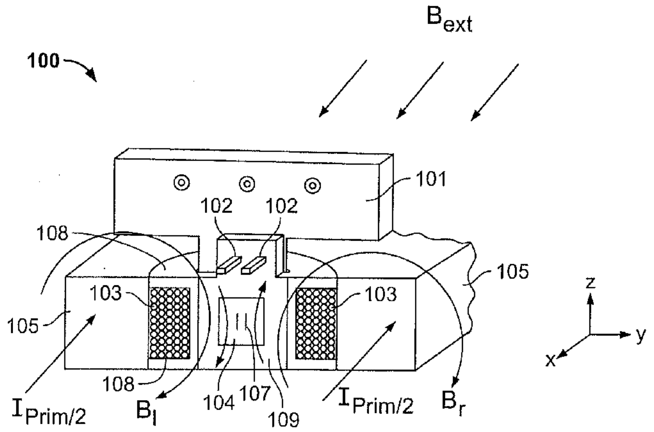

Fig. 4

(57) **Abstract**: The present invention relates to an apparatus for measuring an electric current flowing through a bus bar, which comprises the bus bar itself, a compensation coil and a magnetic field sensor. A through-hole is provided in the bus bar, which divides the electric current flowing through the bus bar into two partial currents that flow round the through-hole. In the through-hole there is provided a compensation coil for generating a compensation field which, at a predetermined position of the through-hole, compensates the magnetic fields generated by the partial currents and an external magnetic field generated outside the apparatus, so that the magnetic flux density of the resulting magnetic field at the predetermined position does not exceed a predetermined threshold. The magnetic flux density of the resulting magnetic field at the predetermined position of the through-hole is detected by the magnetic field sensor which is provided in the through-hole of the bus bar. The compensation coil has a bobbin whose inner part receives the magnetic field sensor, and which is precisely fitted in the through-hole of the bus bar.

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APPARATUS FOR MEASURING AN ELECTRIC CURRENT THROUGH A BUS BAR

The present invention relates to an apparatus for measuring an electric current through a bus bar, in particular a bus bar between a battery and a drive unit in an electrically powered vehicle, and to a battery disconnect unit in an electrically powered vehicle which, on the basis of the measurement result from the apparatus for measuring the electric current, cuts off the electric current in the bus bar if it is too high.

Figure 1 shows an apparatus known from document JP H08 136587 A for measuring the electric current I, which flows through the bus bar 5. The bus bar 5 of this known apparatus has a rectangular cross-section transverse to the propagation direction of the electric current, and has a continuous box-shaped slot 6 which is situated symmetrically relative to the axis of the bus bar 5. The electric current I flowing through the bus bar 5 is divided by the slot 6 into two substantially identical partial currents having the strength of current I/2. These partial currents which flow respectively above and below round the slot join together again into an electric current of the strength I after they have passed the slot 6. Each of the two partial currents generates, in the interior of the slot 6, a magnetic field of which the magnetic flux density is located substantially perpendicular to the aperture of the slot 6. Thus, the upper partial current generates a magnetic flux density directed upwards in the interior of the slot 6, and the lower partial current generates a magnetic flux density directed downwards in the interior of the slot 6. The resulting magnetic flux density in the interior of the slot 6 thus substantially corresponds to the difference in the magnetic flux densities generated in the interior of the slot 6 by the upper and lower partial currents. The resulting magnetic flux density in the interior of the slot 6, which is proportional to the electric current I flowing through the bus bar 5, is detected by a fluxgate magnetometer 4 arranged in the interior of the slot 6 and an electric signal which corresponds to the detected magnetic flux density is formed which is available at the output of the fluxgate magnetometer 4.

A further apparatus for measuring an electric current in a bus bar, which has a design similar to the apparatus shown in Figure 1, is shown in document US 6 636 029 B1.

The mode of operation of the apparatus depicted in Figure 1 for measuring the electric current I in the bus bar 5 can be impaired by an external magnetic field which overlies the magnetic fields generated by the two partial currents. External magnetic fields, in particular those generated during the operation of electrically powered vehicles, are mostly time-constant magnetic fields, the magnetic flux density of which substantially exceeds the resulting magnetic flux density, generated by the two partial currents, in the interior of the slot 6. External magnetic fields can thus saturate the fluxgate magnetometer 4, and disrupt the unambiguous correlation/proportionality between the electric signal output by the fluxgate magnetometer 4 and the strength of current of the electric current I flowing through the bus bar 5. External magnetic fields which are time-constant are also referred to hereafter as magnetic common mode fields.

In order to reduce the effect of external magnetic common mode fields on the measuring result of the fluxgate magnetometer 4, a differential fluxgate sensor can be used to detect the magnetic flux density. This has two fluxgate magnetometers oriented to be parallel which are integrated in an IC, and is capable of compensating an undesired external magnetic common mode field to a certain extent. For example, differential fluxgate sensors are capable of compensating external magnetic common mode fields of up to 2 mT.

However, for applications in the automobile field, in particular in the case of electrically powered vehicles, the compensation of external magnetic common mode fields with a magnetic flux density of up to 3 mT is required. The effect of such magnetic common mode fields on the measurement result of the apparatus shown in Figure 1 can indeed be kept low through magnetic screening of the apparatus. However, such a solution would be very complex and expensive. There is therefore a desire for a solution which does without screening.

The problem of the present invention is to provide an apparatus for measuring an electric current through a bus bar, which detects the electric current flowing through the bus bar with the aid of a magnetic field sensor which is arranged in a recess/slot provided in the bus bar, and the apparatus is capable of compensating external magnetic common mode fields in the region of the magnetic field sensor which exceed a predetermined value, for example 2 mT. At the same time, this apparatus can be manufactured simply and inexpensively.

This problem is solved according to the features of Claim 1. Further advantageous developments of the present invention are disclosed in the dependent claims.

The present invention is based on the idea of compensating the undesired magnetic common mode field in the interior of the recess with a compensation field generated by a compensation coil with a bobbin, which compensation coil is inserted into the recess and receives the magnetic field sensor in the inner part of the bobbin.

Preferably, the magnetic field sensor is arranged at the protruding part of a circuit board, the protruding part of the circuit board is inserted into the interior of the bobbin of the compensation coil and is firmly mechanically connected to it.

The apparatus for measuring an electric current through a bus bar according to the present invention does without screening and is simple to manufacture. In particular, the present invention is advantageous when winding the compensation coil, because the bobbin of the compensation coil is freely accessible from all sides, as long as the compensation coil is not yet inserted into the recess.

To better understand the present invention, this is explained in greater detail using the exemplary embodiments depicted in the following figures. Identical parts are hereby provided with identical reference numbers and identical component names. Furthermore, some features or combinations of features from the various embodiments shown and described depict independent solutions, inventive solutions or solutions according to the invention. In the drawings:

Fig. 1 shows a known apparatus for measuring an electric current through a bus bar;

Fig. 2a shows a bus bar and an electric current which flows through the bus bar and which is meant to be measured with an apparatus according to an exemplary embodiment of the present invention;

Fig. 2b shows a cross-section through the bus bar at the position A – A shown in Fig. 2;

Fig. 3 shows an arrangement for detecting the magnetic field at a predetermined position of the through-hole located in the bus bar, which is used in the apparatus according to the first exemplary embodiment of the present invention;

Fig. 4 shows a cross-section through the apparatus for measuring an electric current through a bus bar according to the first exemplary embodiment of the present invention at the position A – A shown in Fig. 2;

Fig. 5a shows the magnetic flux densities generated at the predetermined position in the through-hole, and their relation to one another when the magnetic flux densities generated by the partial currents do not exceed the predetermined threshold;

Fig. 5b shows the magnetic flux densities generated at the predetermined position in the through-hole, and their relation to one another when the magnetic flux densities generated by the partial currents exceed the predetermined threshold;

Fig. 6 shows an arrangement for detecting the magnetic field at a predetermined position of the through-hole located in the bus bar, which is used in the apparatus according to the second exemplary embodiment of the present invention;

Fig. 7 shows a cross-section through the apparatus for measuring an electric current through a bus bar according to the second exemplary embodiment of the present invention at the position A – A shown in Fig. 2.

Figure 2a shows a perspective depiction of a bus bar 105 and the electric current I_{prim} which flows through the bus bar 105 and the strength of current of which is meant to be measured/determined with the aid of the apparatus according to the present invention. The bus bar 105 has a box-shaped shape and a longitudinal axis 113 along which the electric current I_{prim} is propagated. However, the present invention is not restricted to box-shaped bus bars. On the contrary, it also includes other forms, for example the cylindrical form. The bus bar can also have bends.

In the bus bar 105 shown in Figure 2a, a cylindrical through-hole 106 is provided between the upper and lower side faces of the bus bar 105. The axis of symmetry 114 of the through-hole 106 is situated perpendicular to the longitudinal axis 113 and intersects it. The axis of symmetry 114 is preferably also situated perpendicular to the upper and/or lower side face of the bus bar 105, so that the through-hole 106 is arranged in the centre between the left and right side faces of the bus bar 105.

However, the present invention also includes arrangements in which the axis of symmetry 114 of the through-hole 106 has any direction relative to the longitudinal axis 113 of the bus bar 105, so that the through-hole 106 has an incline compared to the upper/lower sides of the bus bar 105. The present invention also includes arrangements in which the axis of symmetry 114 of the through-hole 106 does not intersect the longitudinal axis 113 of the bus bar 105 such that the through-hole 106 is arranged offset with regard to the longitudinal axis 113. The present invention also includes arrangements in which the through-hole 106 has a form different from the cylindrical form, for example a box-shaped form. The hole 106 being a through-hole is also not absolutely necessary for the present invention.

On the contrary, the present invention also detects such arrangements, in which the bus bar has a hole/recess which is not continuous.

Figure 2b shows a cross-section through the bus bar 105, which goes through the middle of the through-hole 106 and which is perpendicular to the longitudinal axis 113 of the bus bar 105. This section is labelled A – A in Figure 2a.

The current density distribution of the electric current I_{prim} is preferably substantially symmetrical with regard to the longitudinal axis 113 of the bus bar 105. At the location of the through-hole 106, the electric current I_{prim} is divided into two identical partial currents of the strength of current $I_{prim}/2$. In this case, one of the partial currents flows through the part of bus bar 105 which is located between the through-hole 106 and the left side face of the bus bar 105, and the other partial current flows through the part of the bus bar 105 which is located between the through-hole 106 and the right side face of the bus bar 105. After the two partial currents have passed the through-hole 106, they join together again into an electric current of the strength of current I_{prim}. The electric partial current flowing through the left part of the bus bar 105 generates a magnetic field B_l which surrounds the left part of the bus bar 105 (approximately in a circle), and the electric partial current flowing through the right part of the bus bar 105 generates a magnetic field B_r which surrounds the right part of the bus bar 105 (approximately in a circle). The magnetic field lines corresponding to the two magnetic fields B_l and B_r break through/penetrate the through-hole 106 in the opposite direction such that the resulting magnetic flux density at one point of the through-hole 106 substantially corresponds to the difference in the magnetic flux densities B_l and B_r. This difference represents a measurement of the electric current I_{prim} flowing through the bus bar 105. At predetermined positions of the through-hole 106, for example in the middle, this difference is (substantially) proportional to the electric current I_{prim} flowing through the bus bar 105.

Relative to the three-dimensional coordinate system shown in Figure 2a, the longitudinal axis 113 of the bus bar 105 runs parallel to the x-axis of the coordinate system and the axis of symmetry 114 of the through-hole 106 runs parallel to the z-axis of the coordinate system. The resulting magnetic flux density of the magnetic fields B_l and B_r generated by the two partial currents is also substantially parallel to the z-axis. This essentially means that the resulting magnetic flux density of the magnetic fields B_l and B_r has a component in the z-axis which substantially exceeds the components in the x- and y-axes.

Figure 2b depicts an exemplary embodiment of the present invention in which the two partial currents, which flow through the left and right parts respectively of the bus bar 105, are identical. However, the present invention also incorporates exemplary embodiments in which the partial currents which flow through the left and right parts of the bus bar 105 respectively are different. This is the case, for example, when the current density distribution of the electric current I_{prim} is not symmetrical with reference to the longitudinal axis 113 of the bus bar 105 or the through-hole 106 is arranged offset with reference to the longitudinal axis 113. In these cases too, the resulting magnetic flux density at a point in the interior of the through-hole 106 corresponds to the electric current I_{prim} flowing through the bus bar 105.

In order to be able to deduce the strength of current of the electric current I_{prim} flowing through the bus bar 105, it is important to detect/measure/determine, at a predetermined position in the interior of the through-hole 106, the resulting magnetic flux density of the magnetic fields B_l and B_r generated by the two partial currents. This location is preferably selected such that there exists here as precise a proportionality as possible between the detected magnetic flux density and the strength of current of the electric current I_{prim} flowing through the bus bar 105.

An arrangement for detecting/measuring/determining the magnetic flux density at a predetermined position in the interior of the through-hole 106, said arrangement being used in the apparatus according to the first exemplary embodiment of the present invention, is depicted in Figure 3. This arrangement has: a circuit board 101 with a protruding part 109; a magnetic field sensor 104 arranged on the protruding part 109 of the circuit board 101; and a compensation coil 103 with a bobbin 108, on which windings for generating a (magnetic) compensation field are provided. The inner part of the bobbin 108 is suitable for receiving the part of the protruding part 109 of the circuit board 101 on which the magnetic field sensor 104 is arranged. The protruding part 109 of the circuit board 101 and the bobbin 108 are preferably positioned relative to one another such that the magnetic field sensor 104 attached onto the protruding part 109 is located in a region of the interior of the bobbin 108 in which the magnetic compensation field generated by the compensation coil 103 is homogeneous. For example the circuit board 101 has a T-shape, the base of the T-shape corresponding to the protruding part 109 of the circuit board 101, and the magnetic field sensor 104 is arranged at the lower end of the protruding part 109 (of the base of the T-shape). The bobbin 108 of the compensation coil 103 and the circuit board 101 are mechanically firmly connected to one another such that both together form a rigid unit and the magnetic field sensor 104 remains in a fixed/determined position relative to the windings of the compensation coil 103. The windings of the compensation coil 103, and the circuit board 101, are electrically connected to one another. This connection preferably occurs via press-fit pins 102. These have the advantage that, when inserting the protruding part 109 into the interior of the bobbin 108, they can be used as reference points for the (mechanical) positioning of the compensation coil 103 relative to the circuit board 101.

The magnetic field sensor 104 is, for example, a fluxgate magnetometer which provides at an output an electric signal which corresponds to the magnetic flux density detected by the fluxgate magnetometer. Fluxgate magnetometers are saturated and thus the proportionality between the output signal and the magnetic flux density to be detected is disrupted if the magnetic flux density to be detected exceeds a maximum value. This maximum value can be exceeded for example if, at the location of the fluxgate magnetometer, an external magnetic common mode field overlays the magnetic field which is generated by the two partial currents flowing around the through-hole 106, and which is a measure of the electric current I_{prim} flowing through the bus bar 105.

In order to eliminate the effect of magnetic common mode fields up to a certain strength on the measuring result of the magnetic field sensor 104, differential fluxgate magnetometers are employed as magnetic field sensors. Differential fluxgate magnetometers (hereafter referred to simply as differential fluxgate(s)) are capable of compensating external magnetic common mode fields up to a predetermined magnetic flux density, for example 2 mT. However, if the magnetic flux density of the external magnetic common mode field exceeds this predetermined value, then the output signal of the differential fluxgate is disrupted. A differential fluxgate has two fluxgate magnetometers oriented to be parallel which are preferably integrated in an integrated circuit. The output signal of the differential fluxgate is a combination of the output signals of the two fluxgate magnetometers. In this case, the output signals of the two fluxgate magnetometers are combined such that the effect of the magnetic common mode field is eliminated. As long as the magnetic flux density of the external magnetic common mode field does not exceed the predetermined value, there is an unambiguous correlation between the output signal of the differential fluxgate and the magnetic flux density to be detected.

The arrangement shown in Figure 3 for detecting the magnetic flux density at a predetermined position in the interior of a through-hole is introduced into the through-hole 106 of the bus bar 105 shown in Figure 2a and is fixed there such that the magnetic field sensor 104 is positioned at the predetermined position of the through-hole 106. For example, the protruding part 109 of the circuit board 101 with the compensation coil 103 fixed on it is inserted into the through-hole 106 until the magnetic field sensor 104 reaches the depth in which the predetermined position is located. The outer edge of the bobbin 108 preferably has the same form as the through-hole 106 such that the outer edge of the bobbin 108 fits precisely together with the inner wall of the through-hole 106. It is also advantageous if the bobbin 108 has the same height as the bus bar 105.

Figure 4 shows a cross-section through the apparatus for measuring an electric current through a bus bar according to the first exemplary embodiment of the present invention. The cross-section goes through the through-hole 106, is perpendicular to the longitudinal axis 113 of the bus bar 105, and goes through the location 107 at which the magnetic field is meant to be detected by the magnetic field sensor 104. This figure also shows an external magnetic common mode field B_{ext} which is generated from outside of the apparatus according to the present invention, and which, at the predetermined position 107, overlays the resulting magnetic field which is to be detected and which is generated by the two partial currents $I_{prim}/2$ at the predetermined position 107. Identical components in Figures 3 and 4 are equipped with identical reference symbols.

With reference to the three-dimensional coordinate system shown in Figure 4, the bus bar 105 runs in the x-direction, the depth of the through-hole 106 and the height of the bobbin 108 run in the z-direction, and the protruding part 109 of the circuit board 101 likewise runs in the z-direction. The external magnetic common mode field B_{ext}, which can have any direction with reference to the bus bar 105, also has a component in the z-direction.

The magnetic field sensor 104 located at the predetermined position 107 is a differential fluxgate, for example, the two fluxgate magnetometers of which are oriented such that they detect the z-component of the resulting magnetic flux density. In this case, the resulting magnetic flux density relates to the magnetic fields B_l and B_r generated by the two partial currents $I_{prim}/2$, to the external magnetic common mode field B_{ext} and to the compensation field B_{sp} which is generated by the compensation coil 103 and which is oriented substantially parallel to the z-axis at the predetermined position 107. The compensation field B_{sp} preferably has a (substantially) homogeneous region at the predetermined position 107.

In addition to the features specified in relation to Figure 3, the apparatus depicted in Figure 4 has the following features: the compensation coil 103 and the bobbin 108 are cylindrical and have an axis of symmetry which coincides with the axis of symmetry 114 of the through-hole 106. The bobbin 108 of the compensation coil 103 and the bus bar 105 have identical heights. In addition, the compensation coil 103 is introduced so deeply into the through-hole 106 until the upper and lower side faces of the bobbin 108 fit together with the upper and lower side faces respectively of the bus bar 105 in a flat manner. The outer edge of the bobbin 108 also fits precisely together with the inner wall of the through-hole 106. The protruding part 109 of the circuit board 101 has a longitudinal axis which is parallel to the axis of symmetry 114 of the through-hole 106 and is perpendicular to the longitudinal axis 113 of the bus bar 105. The differential fluxgate 104 is positioned on the protruding part 109 of the circuit board 101 such that it assumes the predetermined position 107 in the through-hole 106 when the compensation coil 103 is introduced.

If the external magnetic common mode field at the predetermined position 107 exceeds a certain strength, for example 2 mT, then the differential fluxgate 104 is saturated, and the output signal it provides no longer corresponds to the magnetic field available at the predetermined position 107. In order to avoid this malfunction, the compensation coil 103 generates a compensation field B_{sp}, which, at the predetermined position 107, compensates the external magnetic common mode field such that the magnetic flux density of the resulting magnetic field at the predetermined position 107 does not exceed a predetermined threshold, for example 2 mT.

The compensation coil 103 shown in Figure 4 generates at the predetermined position 107 a compensation field B_{sp} which is substantially parallel to the z-axis, i.e. substantially only has a z-component $B_{sp,z}$. The z-component of the compensation field ($B_{sp,z}$) and the z-component of the external magnetic common mode field ($B_{ext,z}$) have opposing directions.

Figure 5a shows the magnetic flux densities of the magnetic fields occurring at the predetermined position 107 if the resulting magnetic field B_l-B_r generated by the two partial currents $I_{prim}/2$ has a z-component ΔB_z which is smaller than the predetermined value 2mT, for example. The z-component of the external magnetic common mode field $B_{ext,z}$ and the z-component ΔB_z overlay one another at the predetermined position 107. The overlaying of these two magnetic flux densities would lead to their result exceeding the predetermined value of 2 mT, for example. However, the compensation field $B_{sp,z}$ compensates the z-component of the external magnetic common mode field $B_{ext,z}$ such that the sum of all magnetic fields available at the predetermined position 107 have a magnetic flux density which remains under the predetermined value of 2 mT, for example.

The external magnetic common mode field B_{ext} is not necessarily constant in time. For example, it is dependent on the exterior/local conditions in which the apparatus of the present invention is employed. In the apparatus according to the present invention, the external magnetic common mode field to be compensated, for example its z-component $B_{ext,z}$, is thus constantly detected anew, an (electric) signal is generated corresponding to the newly detected external magnetic common mode field, and, on the basis of this signal, the compensation coil 103 is activated such that it generates a compensation field which compensates the detected external magnetic common mode field. This compensation mechanism represents a closed control loop in which the current is controlled by the compensation coil 103.

According to the present invention, the compensation of the external magnetic common mode field B_{ext} takes place in a closed control circuit, wherein the strength of current of the current flowing through the compensation coil 103 is controlled such that the compensation field B_{sp} generated by the compensation coil 103 compensates the external magnetic common mode field B_{ext} at the predetermined position 107. For example, the current is controlled by the compensation coil 103 such that the z-component of the compensation field, $B_{sp,z}$, compensates the z-component of the external magnetic common mode field, $B_{ext,z}$. The control can take place by analogue or digital means.

For the magnetic field configuration shown in Figure 5a and an apparatus according to the present invention, which uses two differential fluxgate magnetometers as a magnetic field sensor, the following algorithm can be applied to control the strength of current of the current flowing through the compensation coil 103, for example. The following labels apply with regard to the foregoing:

$B_{l,mess}$, the magnetic field in the z-direction which is measured/detected by the left fluxgate at the predetermined position 107;

$B_{r,mess}$, the magnetic field in the z-direction which is measured by the right fluxgate at the predetermined position 107;

B_i, the magnetic field in the z-direction resulting at the predetermined position 107 generated by the electric current I_{prim} flowing through the bus bar 105, B_i substantially corresponds to ΔB_z from Figure 5a;

I_{sp}, the strength of current of the current (to be) flowing through the compensation coil 103;

N_{sp}, the number of windings of the compensation coil 103; and k, a constant, with the following equations applying:

$$B_{sp,z} = k\ N_{sp}\ I_{sp} \qquad \text{(equation 1)}$$

$$B_{l,mess} = +B_i + B_{ext,z} + B_{sp,z} \qquad \text{(equation 2)}$$

$$B_{r,mess} = -B_i + B_{ext,z} + B_{sp,z} \qquad \text{(equation 3)}$$

The useful signal supplied by the two differential fluxgate magnetometers which unambiguously corresponds to the electric current I_{prim} flowing through the bus bar 105 emerges from the difference between equations 2 and 3 to:

$$B_{l,mess} - B_{r,mess} = 2B_i \qquad \text{(equation 4)}$$

The resulting magnetic common mode field detected/perceived by the two differential fluxgate magnetometers emerges from the sum of equations 2 and 3 to:

$$B_{l,mess} + B_{r,mess} = 2B_{ext,\ z} + 2B_{sp,z} \qquad \text{(equation 5)}$$

Compensation of the external magnetic common mode field at the predetermined position 107 is thus achieved if $B_{l,mess} + B_{r,mess} = 0$. With the aid of equation 1 and equation 5, the following results for the strength of current I_{sp} of the current flowing through the compensation coil 103:

$$B_{ext,z} + k\ N_{sp}\ I_{sp} = 0. \qquad \text{(equation 6)}$$

In an apparatus according to the present invention which has a differential fluxgate magnetometer as a magnetic field sensor, the strength of current of the current flowing through the compensation coil 103 is preferably controlled such that the sum of the magnetic fields detected by the two fluxgates of the differential fluxgate magnetometer, $B_{l,mess} + B_{r,mess}$, does not exceed a predetermined threshold. This predetermined threshold is preferably zero.

Malfunctioning of the differential fluxgate 104 can also occur if the resulting magnetic field generated by the two partial currents has a magnetic flux density which exceeds the predetermined value of 2 mT, for example. This is the case, for example, if the through-hole 106 is not arranged in the centre with reference to the longitudinal axis 113, and if the two partial currents accordingly have very different strengths of current. The apparatus according to the present invention is capable of compensating such asymmetries by the compensation coil 103 generating a compensation field which is directed opposite the resulting magnetic field generated by the two partial currents and compensates it to such an extent that the resulting magnetic flux density at the predetermined position 107 does not exceed the predetermined threshold of 2 mT, for example. If an external magnetic common mode field is also present at the predetermined position 107, the compensation field generated by the compensation coil 103 must also compensate this.

Figure 5b shows the magnetic flux densities of the magnetic fields occurring at the predetermined position 107 if the resulting magnetic field B_l-B_r generated by the two partial currents has a z-component ΔB_z which is larger than the predetermined value of 2mT, for example. At the same time, at the predetermined position 107, an external magnetic common mode field is also available, the z-component of which is overlaid with the z-component ΔB_z. The compensation coil 103 in this case generates a compensation field $B_{sp,z}$ such that the sum of all magnetic fields available at the predetermined position 107 has a magnetic flux density which is smaller than the predetermined value of 2 mT, for example.

Figure 6 shows an arrangement 120 for detecting the magnetic field at a predetermined position of a through-hole located in a bus bar, which arrangement is used in an apparatus according to the second exemplary embodiment of the present invention. This arrangement differs from the arrangement depicted in Figure 3 only in that it has a Helmholtz coil as a compensation coil. The design and function of the arrangements depicted in Figures 3 and 6 are otherwise identical. The Helmholtz coil has two equal-size coils 110 and 111 which are wound in the same direction and which are arranged spaced apart from one another, the spacing between the coils being equal to the radius of the coils. The overlaying of the fields generated by the two coils 110 and 111 arises between the two coils, close to the coil axis a region with a largely homogeneous magnetic field. The differential fluxgate 104 is positioned in this region. Therefore, its output signal is disturbed less by the inhomogeneity of the magnetic field which is to be detected.

For the present invention, it is not absolutely necessary for the spacing between the two coils 110 and 111 to be equal to the radius of the two coils. On the contrary, the present invention relates to arrangements in which the compensation coil has two coils connected behind one another, the windings of these two coils are wound in the same direction, these two coils are arranged spaced apart from one another and the location at which the magnetic field sensor is arranged is situated between these two coils in a region of homogeneous magnetic field.

Figure 7 shows a cross-section through the apparatus for measuring an electric current through a bus bar according to the second exemplary embodiment of the present invention. The cross-section goes through the through-hole 106, is situated perpendicular to the longitudinal axis 113 of the bus bar 105, and goes through location 107 at which the magnetic field is meant to be detected by the magnetic field sensor 104. Identical components in Figures 3, 4 and 6 are equipped with identical reference signs.

Relative to the three-dimensional coordinate system shown in Figure 7, the bus bar 105 runs in the x-direction, and the depth of the through-hole 106 and the height of the bobbin 118 of the Helmholtz coil run in the z-direction. The protruding part 109 of the circuit board 101 likewise runs in the z-direction.

The apparatus for measuring an electric current through a bus bar according to the present invention does without screening and is simple to manufacture. The present invention is advantageous when winding the compensation coil. The compensation coil can be used to compensate external magnetic common mode fields which substantially exceed 2 mT which, due to the spatial limitations is not possible in an integrated circuit. Furthermore, the compensation coil can be mechanically fixed quickly and simply in the hole of the bus bar.

The apparatus for measuring an electric current through a bus bar according to the present invention can be used in a battery disconnect unit, for example, in particular in electrically powered vehicles to disconnect the operating current. Therefore, the present invention also relates to a battery disconnect unit which has an apparatus for measuring the electric current through a bus bar according to the present invention.

List of reference signs:

Reference	Description
4	Magnetic field sensor, fluxgate for example
5	Bus bar
6	Recess, slot for example
100	Apparatus for measuring the current through a bus bar
101	Circuit board
102	Press-fit pins
103	Compensation coil
104	Magnetic field sensor, or two fluxgates oriented to be parallel
105	Bus bar
106	Recess, for example through-hole
107	Region of approximately homogeneous magnetic field in the re-cess
108	Bobbin of the compensation coil
109	Protruding part of the circuit board
110	First coil of the Helmholtz coil
111	Second coil of the Helmholtz coil
112	Region of approximately homogeneous magnetic field in the Helmholtz coil
113	Longitudinal axis of the bus bar
114	Axis of symmetry of the recess
118	Bobbin of the Helmholtz coil
120	Apparatus for measuring the current through a bus bar

Claims:

1. An apparatus for measuring an electric current through a bus bar (105), which has:

the bus bar (105), in which a recess (106) is provided such that it divides the electric current (I_{prim}) flowing through the bus bar (105) into at least two partial currents flowing round the recess (106), the recess (106) preferably being a through-hole which divides the electric current flowing through the bus bar (105) into two partial currents flowing round the through-hole (106), the through-hole (106) prefereably being perpendicular to the propagation direction of the electric current (I_{prim}) in the bus bar (105),

a compensation coil (103), which is provided in the recess (106) of the bus bar (105), for generating a compensation field (B_{sp}) which, at a predetermined position (107) of the recess (106), compensates the magnetic fields (B_l, B_r) generated by the partial currents and/or an external magnetic field (B_{ext}) generated from outside of the apparatus (100, 120), to such an extent that the magnetic flux density of the resulting magnetic field at the predetermined position (107) does not exceed a predetermined threshold, and

a magnetic field sensor (104), which is provided in the recess (106) of the bus bar (105), for detecting the magnetic flux density of the resulting magnetic field at the predetermined position (107) of the recess (106) and for emitting an output signal corresponding to the detected magnetic field,

wherein the compensation coil (103) is fixed preferably precisely in the recess (106) of the bus bar (105),

the compensation coil (103) has a bobbin (108), and

the inner part of the bobbin (108) receives the magnetic field sensor (104).

2. The apparatus according to Claim 1, characterised in that the two partial currents flowing round the through-hole (106) have identical flow strengths.

3. The apparatus according to Claim 1 or 2 characterised in that the magnetic field sensor (104) is provided to detect a component of the magnetic flux density of the resulting magnetic field at the predetermined position (107), this component preferably being perpendicular to the direction of propagation of the electric current (I_{prim}) in the bus bar (105)

the output signal of the magnetic field sensor (104) corresponds to the detected component of the magnetic flux density, and

the compensation coil (103) is provided to generate a compensation field (B_{sp}) which, at the predetermined position (107) of the recess (106), compensates the magnetic fields (B_l, B_r) generated by the partial currents and/or an external magnetic field (B_{ext}) generated outside the apparatus (100, 120), so that the component of the magnetic flux density of the resulting magnetic field which has the same direction as the component detected by the magnetic field sensor (104) does not exceed a predetermined threshold at the predetermined position (107).

4. The apparatus according to one of Claims 1 to 3, characterised in that furthermore a circuit board (101) is provided with a protruding part (109)

the magnetic field sensor (104) is arranged on the protruding part (109) of the circuit board (101),

the compensation coil (103) and the circuit board (101) are mechanically firmly connected to one another,

the compensation coil (103) and the circuit board (101) are electrically connected to one another, preferably via press-fit pins (102),

the inner part of the bobbin (108) receives the protruding part (109) of the circuit board (101), and

the magnetic field sensor (104), the protruding part (109) of the circuit board (101), the bobbin (108) of the compensation coil (103) and the recess (106) of the bus bar (105) are situated relative to one another such that the magnetic field sensor (104) is positioned at the predetermined position (107) of the recess (106).

5. The apparatus according to one of Claims 1, 2 and 4, characterised in that the compensation of the magnetic fields (B_l, B_r) generated by the partial currents and/or the external magnetic field (B_{ext}) generated outside of the apparatus (100, 120) takes place in a closed control circuit, wherein the strength of current of the current flowing through the compensation coil 103 is controlled such that the compensation field (B_{sp}) generated by the compensation coil 103 compensates the magnetic fields (B_l, B_r) generated by the partial currents and/or the external magnetic field (B_{ext}) generated from outside the apparatus (100, 120) to

such an extent that the magnetic flux density of the resulting magnetic field does not exceed the predetermined threshold at the predetermined position (107).

6. The apparatus according to Claim 3 or 4, characterised in that the compensation of the magnetic fields (B_l, B_r) generated by the partial currents and/or the external magnetic field (B_{ext}) generated outside of the apparatus (100, 120) takes place in a closed control circuit, wherein the strength of current of the current flowing through the compensation coil 103 is controlled such that the component of the magnetic flux density of the resulting magnetic field, which has the same direction as the component detected by the magnetic field sensor (104), does not exceed the predetermined threshold at the predetermined position (107).

7. The apparatus according to one of Claims 1 to 6, characterised in that the magnetic field sensor (104) has a fluxgate magnetometer, and

the output signal of the magnetic field sensor (104) corresponds to output signal of the fluxgate magnetometer.

8. The apparatus according to one of Claims 1 to 6, characterised in that the magnetic field sensor (104) has two fluxgate magnetometers oriented to be parallel, and

the output signal of the magnetic field sensor (104) corresponds to a combination of the output signals of the two fluxgate magnetometers, and

the output signals of the two fluxgate magnetometers are combined such that there is an unambiguous correlation between the output signal of the magnetic field sensor (104) and the strength of current of the electric current (I_{prim}) flowing through the bus bar (105) if the magnetic flux density of the resulting magnetic field does not exceed the predetermined threshold,

the two fluxgate magnetometers are preferably integrated in an integrated circuit.

9. The apparatus according to one of Claims 1 to 8, characterised in that the output signal of one of the two fluxgate magnetometers corresponds to a first magnetic flux density,

the output signal of the other of the two fluxgate magnetometers corresponds to a second magnetic flux density, and the strength of current of the current flowing through the compensation coil 103 is controlled such that the sum of the first and second magnetic flux density does not exceed the predetermined threshold, this predetermined threshold preferably being zero.

10. The apparatus according to any one of Claims 1 to 9, characterised in that the compensation coil (103) has two coils (110, 111) connected behind one another, the windings of these two coils being wound in the same direction, and these two coils being arranged spaced apart from one another, these two coils preferably having the arrangement of a Helmholtz coil, and

the predetermined position (107) is located between these two coils (110, 111) in a region (112) of homogeneous magnetic field.

11. The apparatus according to any one of Claims 1 to 10, characterised in that the recess (106) has an axial symmetry, a cylindrical or box-shaped through-hole preferably being provided as a recess (106).

12. The apparatus according to Claim 11, characterised in that the outer edge of the compensation coil (103) has the same form as the through-hole (106) and precisely fits together with the inner wall of the through-hole (106), the through-hole (106) and the compensation coil (103) preferably having the same height.

13. The apparatus according to Claim 11 or 12, characterised in that the bus bar (105) has a longitudinal axis (113), the bus bar (105) preferably having a box-shaped cross-section transverse to the longitudinal axis (113),

the electric current flow in the bus bar (105) is parallel to the longitudinal axis (113),

the axis of symmetry (114) of the recess (106)/of the through-hole intersects the longitudinal axis (113) of the bus bar (105), both preferably being perpendicular to one another.

14. A battery disconnect unit, for example for an electrically powered vehicle, which has an apparatus (100, 120) according to any one of the preceding claims.

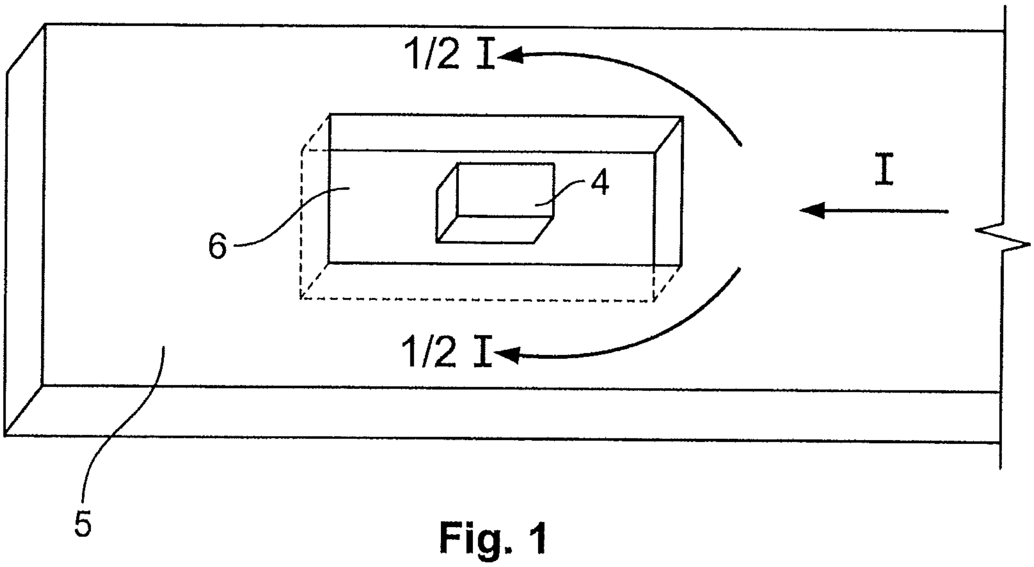


Fig. 1

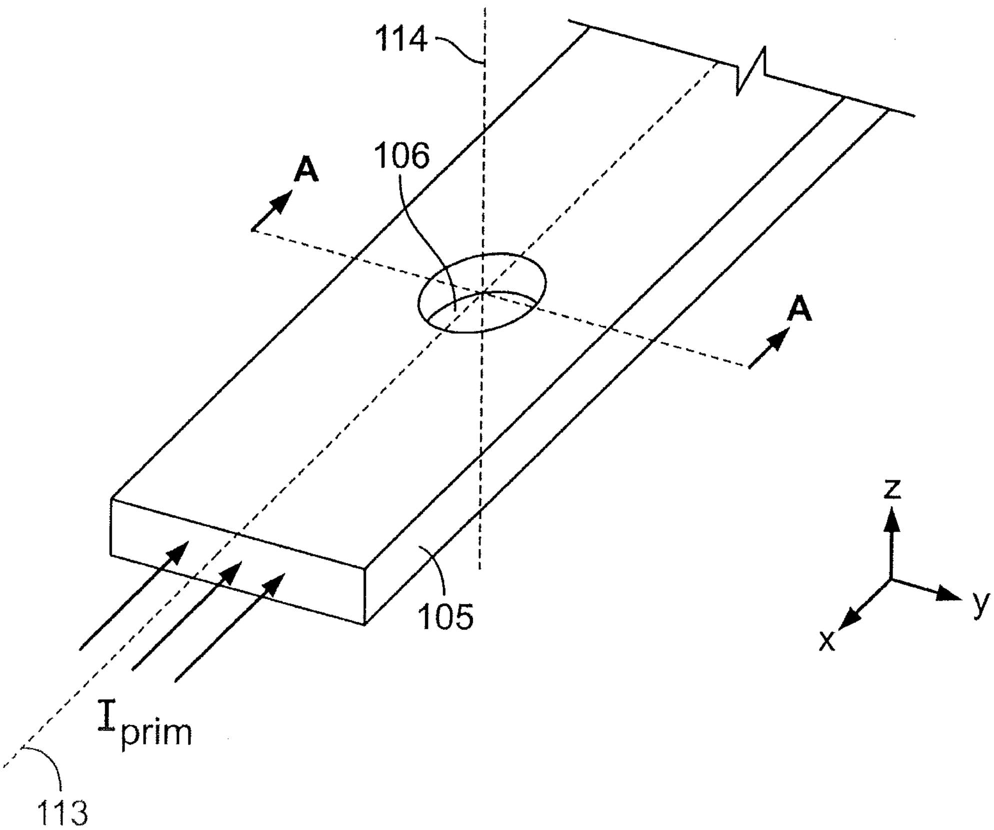


Fig. 2a

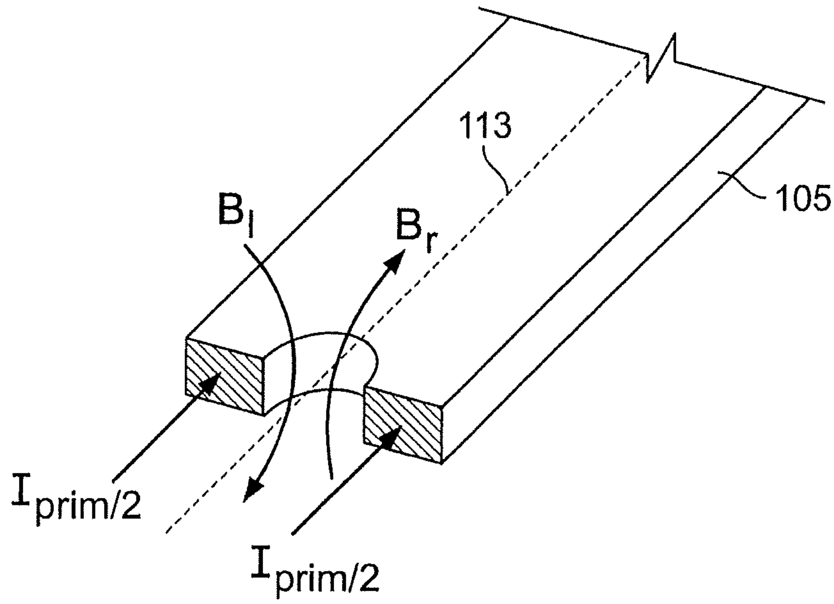


Fig. 2b

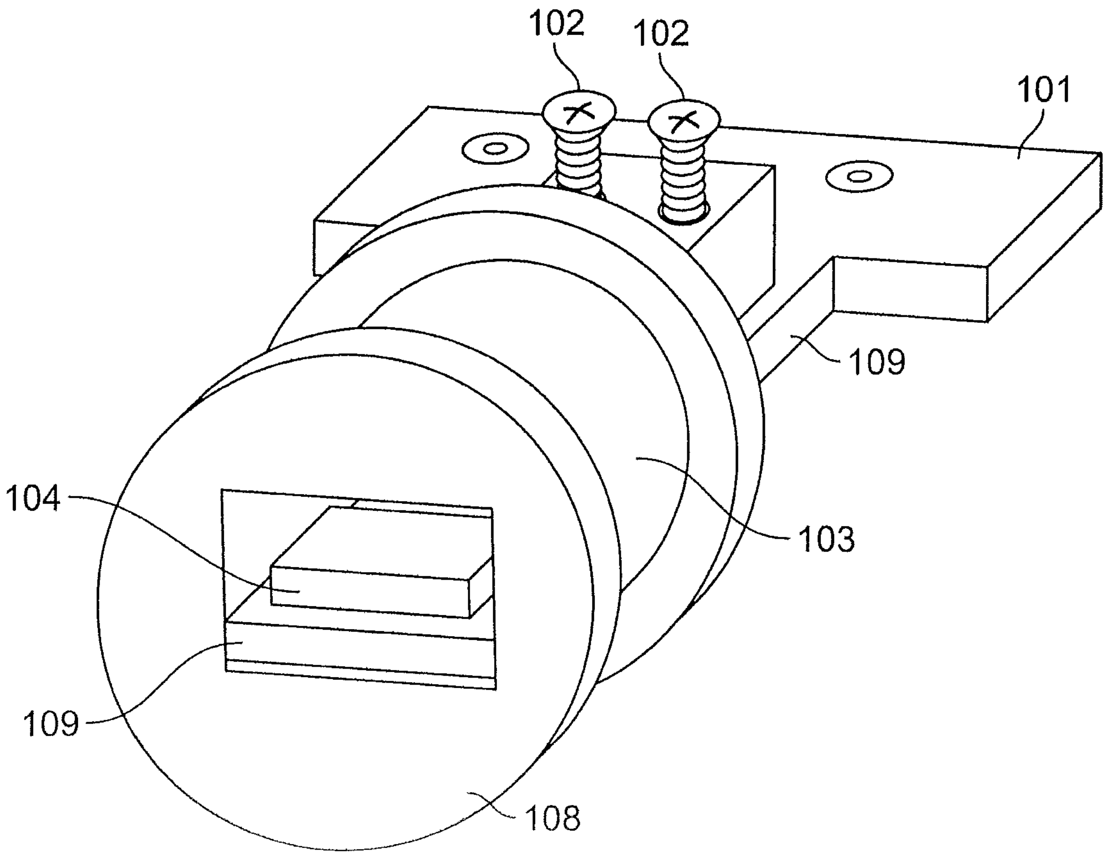
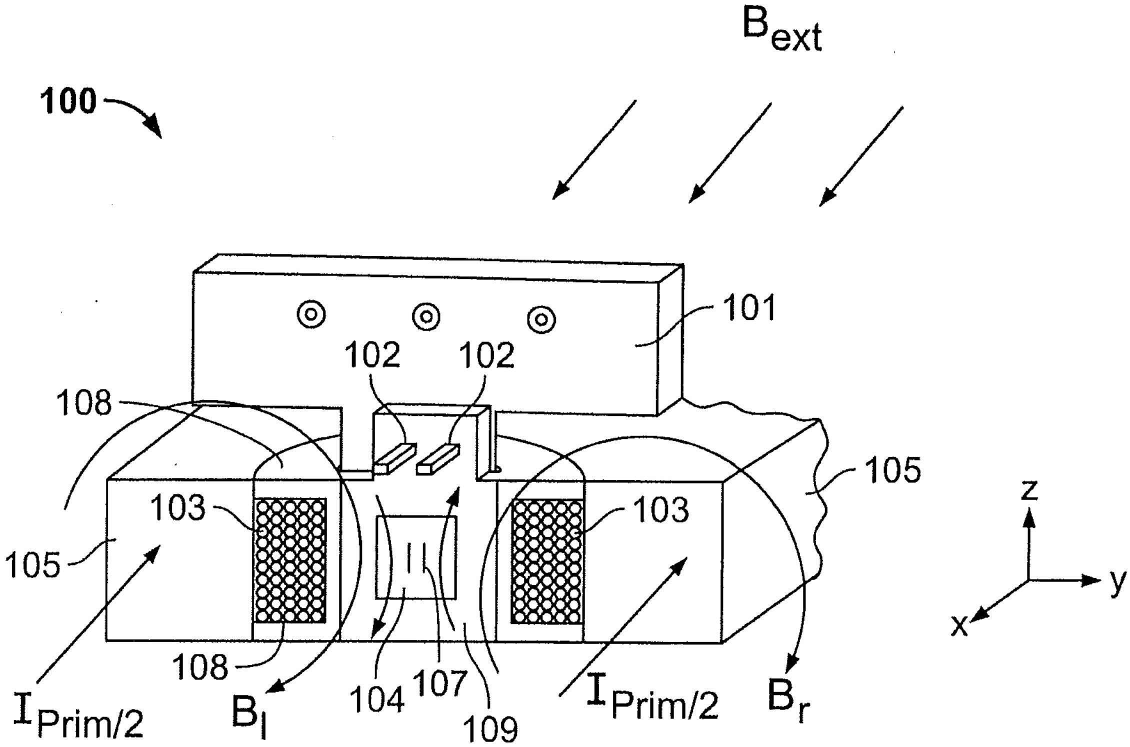


Fig. 3



B_{ext}
100
101
102
102
108
105
103
103
105
z
y
x
108
104
107
109
$I_{Prim/2}$
B_l
$I_{Prim/2}$
B_r

Fig. 4

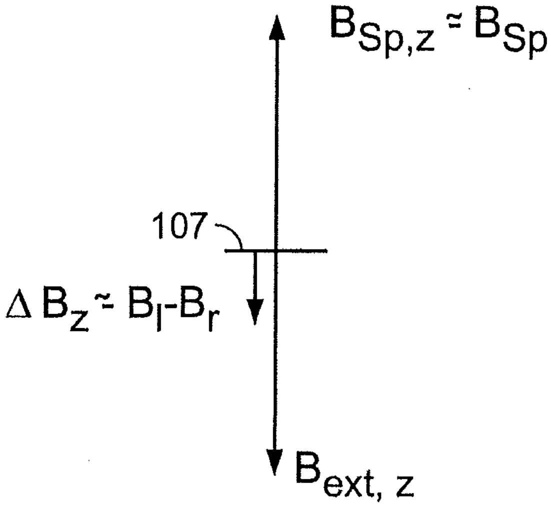


Fig. 5a

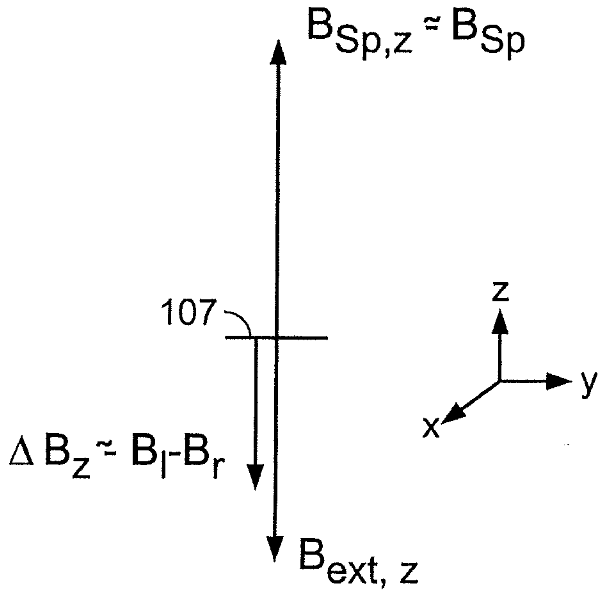


Fig. 5b

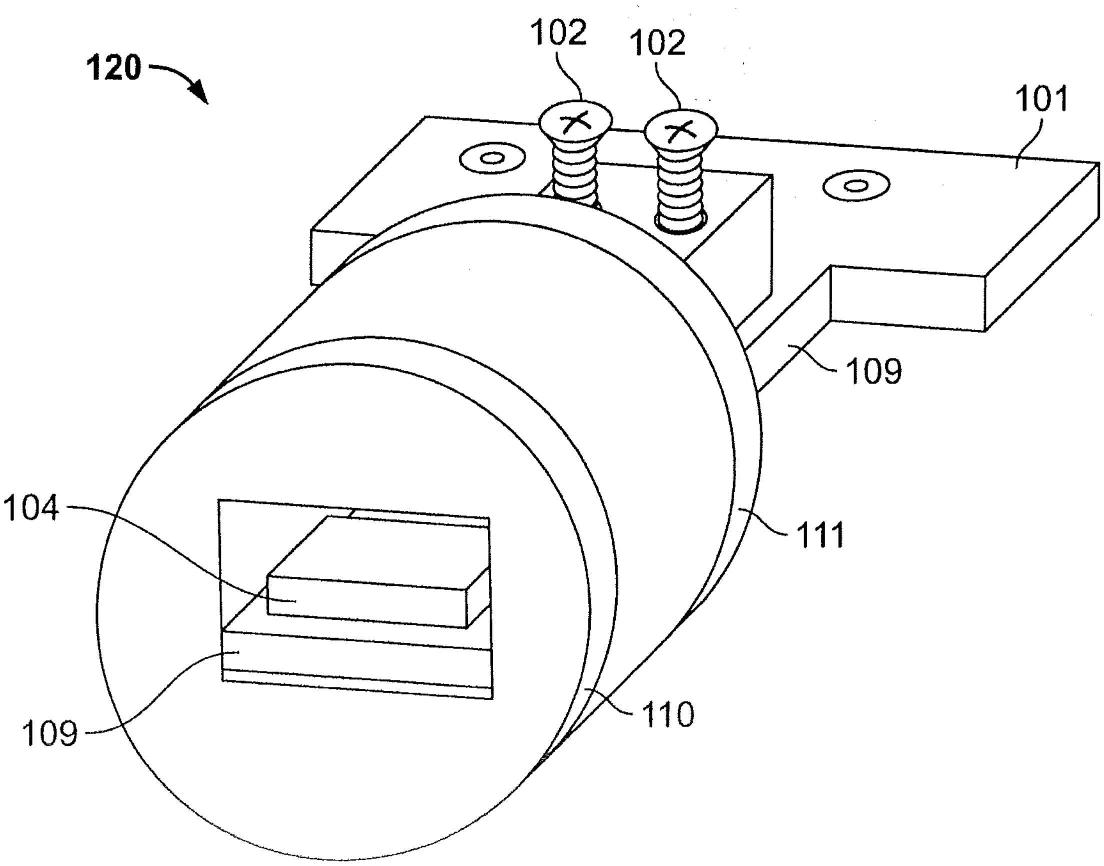


Fig. 6

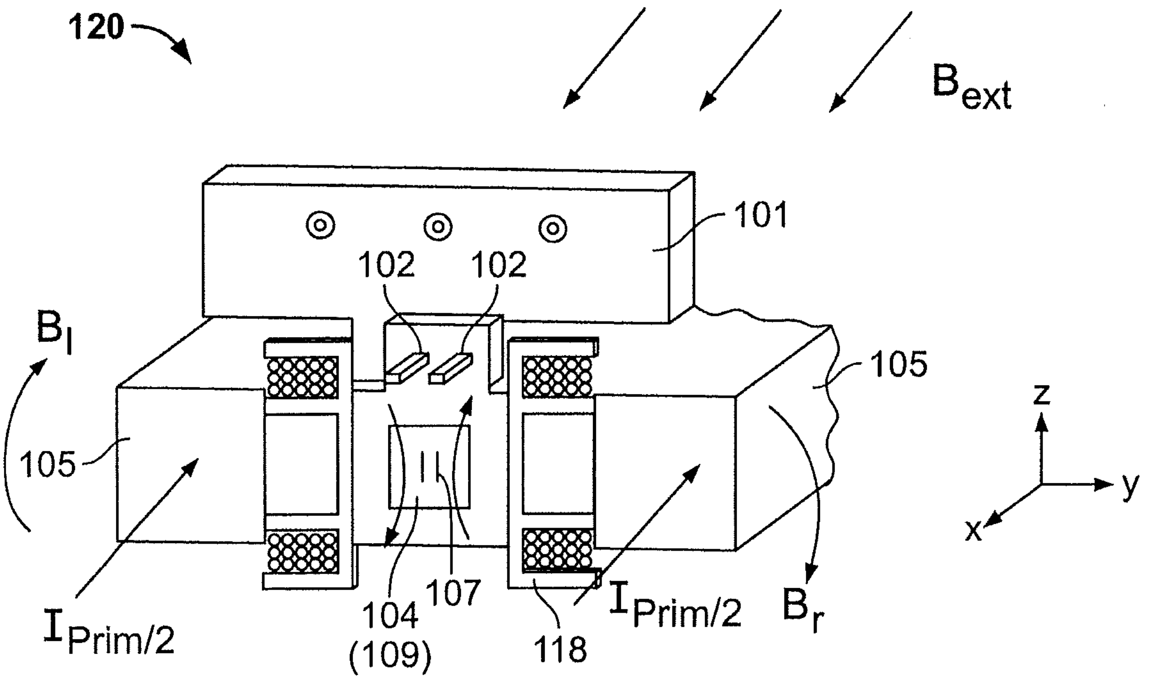

120
B_{ext}
101
102
102
B_l
105
105
z
y
x
$I_{Prim/2}$
104
(109)
107
118
$I_{Prim/2}$
B_r

Fig. 7

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2016/067586

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01R33/04 G01R15/14 G01R15/18
ADD. B60L3/04 G01R33/025

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)
G01R B60L

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

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

EPO-Internal, WPI Data

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Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2014/218018 A1 (IVANOV MIKHAIL VALERYEVICH [DE] ET AL) 7 August 2014 (2014-08-07)	1-4,7-9, 11-13
Y	figures 1-3, 6, 17 paragraph [0003] paragraphs [0033] - [0051] -----	5,6,10, 14
Y	US 5 465 012 A (DUNNAM CURT [US]) 7 November 1995 (1995-11-07)	5,6,10
A	column 3, line 37 - column 5, line 7 -----	1,3
	-/--	

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

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"E" earlier application or patent but published on or after the international filing date

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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

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
18 October 2016	03/11/2016

Name and mailing address of the ISA/
European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040,
Fax: (+31-70) 340-3016

Authorized officer

Danisi, Alessandro

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C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
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1

INTERNATIONAL SEARCH REPORT

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International application No
PCT/EP2016/067586

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