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(54) Device and method for discriminating coins

(57) A device and method for discriminating coins traveling along a track between an inlet and one or more outlets, wherein a pair of inductive sensors formed by a first inductive sensor (1) and a second inductive sensor (2) are placed facing each other. The pair of sensors (1, 2) are excited in at least two different operation modes; for each operation mode, several first measurements relating to the first inductive sensor (1) and several second measurements relating to the second inductive sensor (2) are carried out. The excitation is carried out at excitation frequencies lower than 500 kHz. And at least one compensation term (Δz) is calculated based on said first and second measurements, and said compensation term (Δz) is applied to several phase and/or counter-phase configuration measurements (z).

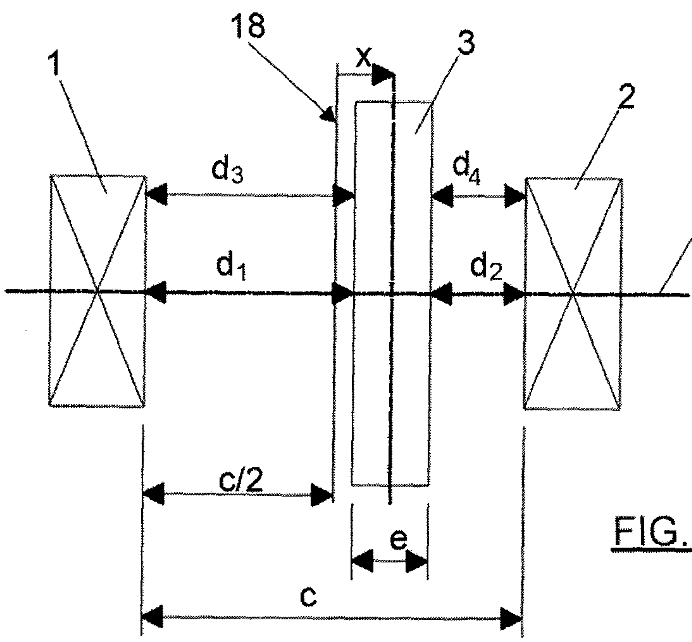

FIG. 2

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Description

Field of the invention

[0001] The present invention refers to coin selectors defining a path or track inside along which the coins run between an inlet and one or more outlets.

[0002] This type of selectors is used in machines whose operation is carried out by means of introducing one or more coins of a value sufficient for obtaining the requested product or service.

[0003] These selectors normally have sensors in the coin track that are capable of dynamically measuring different dimensional features (radius, thickness), alloy (weight, hardness) features, electrical features and magnetic features. The value and validity of the coins can thus be detected.

Background of the invention

[0004] One of the most important features of a coin is the material composing it. This is even more important in the case of bicolor or multilayer coins in which the coin is constructed combining different alloys. One of the easiest ways of characterizing a metal alloy is determining its electric features (conductivity) and/or magnetic features (permeability). The sensors used for determining said features are the inductive type, also called electromagnetic sensors.

[0005] Inductive sensors are based on inducing and measuring electric currents in the coin. By subjecting the coin to a variable magnetic field, according to Faraday's law, currents are created whose magnitude, phase and distribution for a determined exciter field depend on the electric, magnetic and dimensional features of the coin. The depth to which an electromagnetic field penetrates in the coin decreases as the excitation frequency increases. Therefore, as frequency increases, the physical properties of the material of the coin surface have a greater effect on the field than does the inner material and the thickness of the coin. For the same reason, for detecting the features of the inner material in multilayer coins, the excitation frequency must be low enough so that the electromagnetic field penetrates up to the inner material of the coin.

[0006] The inductor field is generated by means of an oscillator-fed coil. As it is not possible to directly measure the currents inducted in the coins, the magnetic field they generate is analyzed. To do so, a coil is normally used that can be the same as the one generating the exciter field, or it can be another type of sensor, such as magnetoresistance sensors or Hall effect sensors. In the case of inductor coils, the corresponding effect on the impedance of the coil is measured.

[0007] One of the intrinsic features of inductive sensors is the strong dependency of its response with the distance between the sensor and the coin. This implies a drawback in coin selectors, since along its track through the sensors, the coin does not normally circulate at a constant position regarding the sensors, but rather the position varies from one introduction to another, and even in a same introduction along the coin's path. Two phenomena associated with the instability of the coin in its track can be distinguished. The first one is the change in the distance between the sensors and the coin. This effect is commonly known as the lift-off effect in the field of non-destructive tests by induced currents. The second effect is that of the rotation of the coin, such that the angle formed by the axis of the sensors and the rotation axis of the coin varies. This effect is known as the tilt of the coin. An additional phenomenon will be described below that is associated with the changes in the distances between the coin and the sensors which occurs when, in the configuration with two facing sensors, the spacing between said sensors varies.

[0008] It is normal to deduce typical parameters of each type of coin with extreme values (maximums and minimums) or mean values from the signal produced by the sensors. These parameters have been strongly influenced by the lift-off and tilt of the coin. The decision to accept or reject a coin is made after an individual comparison of the values of the different parameters measured with their respective reference ranges, which are normally defined by upper and lower limits. The lift-off and tilt effects oblige extending the reference ranges, which worsens the discrimination quality.

[0009] Le Bihan's document ("Lift-off and tilt effects on eddy current sensor measurements: a 3-D finite element study", Y. Le Bihan, The European Physical Journal Applied Physics, 17, 25-28, 2002) presents the results of the study by means of finite elements of the lift-off and tilt effects on a sensor formed by square coils wound around a U-shaped magnetic ferrite core. It is therein shown that the lift-off and tilt effects produce similar lines in the standardized impedances plane and as a consequence, it is affirmed that a lift-off effect correction would likewise permit correcting the lateral and longitudinal tilt effects.

[0010] Another common feature of inductive sensors is that they analyze an area of the coin comparable to that of the sensor itself and which, due to the fact that its sensitivity decreases as the coin to sensor distance increases, in order to correctly measure the coin, the distance between the coin and sensor must be clearly less than the size of said sensor. The lack of precision in measurements of this type of sensors represents a difficulty for characterizing the materials of the core and crown in a bicolor coin. Furthermore, the problem of the contact resistance between the core and the crown arises in these coins, which is a very unstable parameter affecting the eddy currents, especially when said resistance is of a low value. These features have made it a tendency to use smaller inductive sensors. Coin selector devices can be found on the market which include several inductive sensors for the purpose of obtaining measurements independent of the materials of the core and crown, without the measurements being affected by the contact resistance. For example, documents WO 99/12130 belonging to Azkoyen and WO 99/23616 belonging to Coin Controls describe configurations including several, sufficiently small inductive sensors for measuring different regions of the coin when it passes through the ramp along which the sensors are arranged. On the other hand, for a same variation of the distance of a coin to a sensor, the smaller the inductive sensor is, the greater is the effect of this variation on the signal generated by the sensor. Therefore, it is becoming more necessary to find a process which compensates the lift-off and tilt effects of the coin on the measurements carried out by the selector.

[0011] The lift-off and tilt effects of the coin imply a significant worsening of the discrimination quality of the selectors, making it critical to stabilize the coin prior to its passing through said sensors and preventing obtaining a high discrimination quality in applications in which stabilization of the coin is not possible.

[0012] A basic configuration of the electromagnetic sensor is that which is constituted by a single coil. Said coil carries out excitation functions, creating an electromagnetic field inducing currents in the material of the coin, and at the same time, measurement functions of the eddy currents in the material. The magnetic field created by the eddy currents is phase shifted with regard to the exciter field, making the resulting magnetic field vary, and it is reflected in the coil as a change in its impedance. To increase the magnetic flux and focus it, the coil is normally wound in a material with high permeability, such as ceramic ferrites.

[0013] The biggest drawback of the system with a single coil is the strong dependence of the resistance R and inductance L measurements on the distance between the coil and the material (lift-off). As disclosed in documents such as the one by Susan N. Vernon "The Universal Impedance Diagram of the Ferrite Pot Core Eddy Current Transducer", (IEEE Transactions on Magnetics, VOL. 25 NO. 3, May 1989) and in patent WO 93/21608, the angle formed by the reactance variation (wL) and resistance variation of the coil in the presence of the coin with regard to its value in the absence of the coin is independent from the lift-off when Pot Core ferrite types are used. Applying this principle, it is possible to obtain a combination parameter of the resistance and reactance variation that is representative of said angle and therefore independent of the lift-off.

[0014] One way to attenuate the lift-off effect in measurements is to arrange a coil on each side of the coin pass track. Said attenuation is based in that a shift of the coin in one direction along the common axis of the coils implies a decrease of the measurement in one of the coils and an increase in the measurement of the coil on the other side, such that the sum of the measurements produces a partial compensation of this effect.

[0015] Patent application GB-2107104-A discloses a configuration with two significantly equal sensors formed by coils wound in ferrite cores, placed facing on the walls of the coin pass channel.

[0016] The two coils can be connected in series, such that the magnetic fields created are added (arrangement called "in phase") or subtracted ("counterphase" arrangement). Each one of these configurations creates currents in the coin with a different distribution, thereby providing a different characterization of the coin.

[0017] Another configuration type based on two coils is that which uses a coil as excitation, arranged on one side of the channel through which the coin passes, and the other facing the other side of the channel as a receiver, such that it measures the field reaching it. A conductor material between both attenuates and phase shifts the field depending on its conductivity, permeability and thickness. This configuration is called "emitter-receiver". An example of this configuration type is disclosed in patent application EP-0110510.

[0018] US patent number US-5337877 discloses a coin selector with a thickness sensor constituted of two coils located one on each side of the coin pass channel, characterized in that the signals of each one of the coils, indicative of the effects of the coin on an electromagnetic field, are dependent on the position of the coin in the channel with regard to each one of the coils. The signals of each one of the coils are separately processed to derive values which, combined, generate measurements indicative of the thickness of the coin which are significantly independent of the position thereof. In this case, each one of the coils is connected to an oscillator circuit operating at a relatively high frequency, for example 1 MHz. The frequencies are preferably high so that the field does not significantly penetrate in the coins and the signals of the coils are not significantly influenced by the composition of the material of the coin and are mainly dependent on the thickness thereof.

[0019] There are fundamentally two types of processes with regard to electronics associated with sensors. The first one consists of integrating the coil on an oscillator circuit. In this case, the changes in inductance of the coil are mainly translated into changes in the oscillation frequency, whereas the changes in resistance fundamentally cause changes in the oscillation amplitude. The second one is based on applying an alternating current (or voltage) with a constant value to the coil, measuring the changes in voltage (or current), and calculating from these data the changes in impedance of the coil.

[0020] Reference has previously been made to coin selectors including several pairs of inductive sensors, where each one is constituted of a coil located on one side of the coin pass channel and another second facing coil on the other side of the channel, for the purpose of having several configurations of sensors providing different coin characterizations. European patent EP-0599844-B1 discloses a device which uses a single coil pair and switching means for changing the electric configuration of the coils as the coin passes through the sensors, such that different tests are carried out on the coin from among a series of tests controlled by the different operation states of the switching means.

[0021] Furthermore, document WO 97/29460 discloses another method for detecting the diameter of the coin by means of a pair of coils coupled on the feedback path of an oscillator, such that the oscillation frequency is dependent on the inductances of the coils and on the mutual inductance between them. In this method, the mutual induction of the coils is taken as a measurement indicative of the diameter of the coin. A measurement representative of the mutual inductance of the coils is obtained by means of the difference of the oscillation frequency when the coils are in phase and when they are in a counterphase configuration. In this case, the switching of the coils is also carried out between the configuration of in phase and in counterphase currents several times during the pass of the coin between them.

[0022] Another consequence derived from the strong dependence of the response of the inductive sensors with the distance between the sensor and the coin, in addition to those described of the lift-off and tilt effect, is the change of the response of said sensors upon changing the distance between them. On one hand, the different manufacturing tolerances have the consequence that the real effective distance between sensors is different in each coin selector, which obliges a calibration process absorbing said differences. On the other hand, to date it has not been necessary to design and manufacture the selectors such that it is guaranteed that the distance between sensors in a selector is fixed (absence of clearances) and stable in the entire useful life of the selector without it being affected by environmental conditions, wear or aging. This type of requirements make manufacturing these sensors a complex and expensive process.

Summary of the invention

[0023] The invention refers to a device according to claim 1, to a method according to claim 10 and to a selector according to claim 20. Preferred embodiments of the device and of the method are defined in the dependent claims.

[0024] An object of the present invention is to provide a device for discriminating coins, comprising

- a track along which a coin runs between an inlet and one or more outlets,
- at least a pair of inductive sensors formed by a first inductive sensor and a second inductive sensor facing each other, one on each side of the coin track,
- excitation means of said first and second sensors in at least two different operation modes from the following operation modes:

    (A) exciting only the first inductive sensor,
    (B) exciting only the second inductive sensor,
    (C) exciting both first and second inductive sensors such that their electromagnetic fields are added (in phase arrangement) or subtracted (in counterphase arrangement) or that they have any known phase shift,

- means for carrying out, for each operation mode, some first measurements relating to the first inductive sensor,
- means for carrying out, for each operation mode, some second measurements relating to the second inductive sensor.

[0025] Said excitation means are configured so as to function at excitation frequencies lower than 500 kHz, such that they provide measurements indicative of the materials and constructive features of the coin.

[0026] The device further comprises:

- means for calculating at least one compensation term Δz based on said first and second measurements,
- means for applying said compensation term Δz to some phase and/or counterphase configuration measurements z, such that it at least partially corrects the effect on said measurements due to the changes in some of the distances of the coin to the sensors or between the sensors, in at least one span of the coin track as it passes through said sensors.

[0027] Said excitation frequencies are preferably approximate to each other in the at least two different operation modes.

[0028] Several pairs of inductive sensors can be placed at different heights, each pair comprising two facing inductive sensors, one on each side of the coin pass channel, such that each pair interferes in a different area of the coin, returning a signal which is characteristic of said area.

[0029] According to a preferred embodiment of the invention, the device further comprises means for calculating, for each operation mode used, the change in resistance R and inductance L in each one of the inductive sensors with regard to its value in the absence of a coin. According to this preferred embodiment, the means for calculating a compensation term Δz preferably include,

- means for calculating a first compensation term Δz_{1R} for each phase and counterphase R change value based on the change values of self-resistances of each inductive sensor,
- means for calculating a first compensation term Δz_{1L} for each phase and counterphase L change value based on the change values of self-inductances of each inductive sensor,

such that it significantly compensates the effect of the change of distances of the coin to the sensors due to lift-off and tilt in the change values in phase and counterphase resistance and inductance in at least one span of the coin track as it passes through said sensors.

[0030] The excitation means are preferably configured so as to work cyclically, such that the period of said cycle is less than the time it takes any coin to travel a distance equal to half the radius of the inductive sensor, to thus be able to reconstruct the signals of the sensors in each one of the operation modes in at least one span of the coin track as it passes through the first and second sensors, with no significant loss of information; in other words, the operation mode change frequency is significantly greater than the speed of the coin, this change frequency being quick enough in comparison to the coin speed.

[0031] In a preferred embodiment, the calculation of the resistance and inductance is carried out from the measurements of the voltage phase and amplitude and the current passing through the two inductive sensors in each one of the modes in which said sensors are excited.

[0032] The device of the invention preferably includes two capacitors, each one connected in series or in parallel with each inductive sensor, such that the ratio between the reactance and resistance variation of each inductive sensor in the presence of a coin increases with regard to the module of their impedance in the absence of the coin.

[0033] The device for discriminating coins of the invention can also include at least two resistances r_1, r_2, each one connected in series with each inductive sensor, for the purpose of increasing the dampening coefficient of the circuit.

[0034] The present invention significantly compensates the distance change effect from the coin to the sensors due to lift-off and tilt on the change values in phase and counterphase inductance and resistance with said compensation terms in at least one span of the coin track as it passes through said sensors.

[0035] Compensating the lift-off and tilt effects implies an improvement of the discrimination quality of the selectors and it opens up the possibility of new applications in which it is impossible to stabilize the coin, for example coin selectors in public transportation vehicles, or selectors with coin in free fall.

[0036] According to another preferred embodiment of the device of the invention, the device comprises means for calculating the mutual inductance L_M between the first and second inductive sensors in the absence of a coin as from said first and second measurements.

[0037] The means for calculating the compensation term Δz are in this case preferably configured for calculating a second compensation term Δz_2 from said mutual inductance L_M such that said phase and counterphase configuration measurements z to which said compensation term Δz_2 has been applied are those corresponding to a nominal distance between inductive sensors, regardless of the real distance existing between the latter, thus compensating the difference between the real and nominal distances between coils.

[0038] According to a preferred embodiment, in addition to means for calculating the mutual inductance L_M, the device comprises means for calculating the self-inductances L_1, L_2 of each inductive sensor in the absence of a coin as from said first and second measurements, means for calculating a coupling coefficient M as from the mutual inductance L_M and self-inductances L_1, L_2, means for calculating the effective distance between first and second inductive sensors as from said coupling coefficient M, and means for calculating a second compensation term Δz_2 based on said effective distance,

such that said phase and counterphase configuration measurements z to which said compensation term Δz_2 has been applied based on said effective distance are those corresponding to a nominal distance between inductive sensors. In this manner, the present invention also provides a device and method for compensating the effect of the change in the distance of the coin to the sensors due to the variation in the distance between sensors, such that the compensated phase and counterphase resistance and inductance measurements, corresponding to a fixed nominal spacing between sensors, are obtained. This distance is common for all manufactured selectors, regardless of which is the real distance between sensors in each selector and of whether this distance changes once the selector has been calibrated.

[0039] Compensating the channel width implies obtaining a greater uniformity in the manufacturing of selectors, which facilitates their calibration, lowers the clearance-free requirements in designing and manufacturing selectors and making it insensitive to conditions of aging, wear or a change in the environmental conditions affecting the spacing between the sensors. This all implies an additional improvement in the discrimination quality.

[0040] The present invention also provides a method for discriminating coins, comprising:

- arranging at least a first inductive sensor and a second inductive sensor facing each other, one on each side of a track along which a coin runs between an inlet and one or more outlets,
- exciting said first and second sensors in at least two different operation modes from among the following operation modes:

  (A) exciting only the first inductive sensor,
  (B) exciting only the second inductive sensor,
  (C) exciting both first and second inductive sensors such that their electromagnetic fields are added (in phase arrangement) or subtracted (in counterphase arrangement) or they have any known phase shift,

- carrying out, for each operation mode, some first measurements relating to the first inductive sensor,
- carrying out, for each operation mode, some second measurements relating to the second inductive sensor,
- using excitation frequencies lower than 500 kHz, such that they provide measurements indicative of the materials and constructive features of the coin,
- calculating at least one compensation term Δz based on said first and second measurements,
- applying said compensation term Δz to some phase and counterphase configuration measurements z, such that it corrects the effect on said measurements due to the changes in some of the distances of the coin to the sensors or from between the sensors, in at least one span of the coin track as it passes through said sensors.

[0041] Excitation frequencies close to each other in the at least two different operation modes are preferably used.
[0042] According to a preferred embodiment, the method further comprises:

- cyclically exciting said first and second sensors in at least two different operation modes from among the following operation modes:

  (A) exciting only the first inductive sensor,
  (B) exciting only the second inductive sensor,
  (C) exciting both first and second inductive sensors such that their electromagnetic fields are added (in phase arrangement) or subtracted (in counterphase arrangement) or they have any known phase shift,

- calculating, for each operation mode used, the change in resistance R and inductance L in each one of the inductive sensors with regard to their value in the absence of a coin,
- calculating a first compensation term Δz_{1R} for each phase and counterphase R change value based on the change values of self-resistances of each inductive sensor,
- calculating a first compensation term Δz_{1L} for each phase and counterphase L change value based on the change values of self-inductances of each inductive sensor,
  thus significantly compensating the effect of the change of distances of the coin to the sensors due to lift-off and tilt on the change values in phase and counterphase resistance and inductance in at least one span of the coin track as it passes through said sensors.

[0043] In a preferred embodiment, two excitation modes are used consisting of the individual excitation of each one of the coils, in other words, the operation modes (A) and (B).
[0044] It is also possible to use as operation modes mode (A) and exciting both first and second inductive sensors such that their electromagnetic fields are added (in phase arrangement) or subtracted (in counterphase arrangement).
[0045] It is also possible to use as operation modes: exciting both first and second inductive sensors such that their electromagnetic fields are added (in phase arrangement) and exciting both first and second inductive sensors such that their electromagnetic fields are subtracted (in counterphase arrangement).
[0046] According to a preferred embodiment, the method for discriminating coins of the invention measures the mutual inductance L_M between the first and second inductive sensors in the absence of a coin as from said first and second measurements. A second compensation term Δz_2 is preferably calculated as from said mutual inductance L_M, such that said phase and counterphase configuration measurements z to which said compensation term Δz_2 has been applied are those corresponding to a nominal distance between inductive sensors, regardless of the real distance existing between them.
[0047] The method further comprises:

- calculating the self-inductances L_1, L_2 of each inductive sensor in the absence of a coin as from said first and second measurements,
- calculating a coupling coefficient M as from the mutual inductance L_M and the self-inductances L_1, $L_{2,}$

- calculating the effective distance between first and second inductive sensors as from said coupling coefficient M,
- calculating a second compensation term Δz_2 based on said effective distance, such that said phase and counter-phase configuration measurements z to which said second compensation term Δz_2 has been applied based on the effective distance are those corresponding to a nominal distance between inductive sensors.

[0048] The present invention has the novelty that it compensates the effects that the change in the distances of the inductive sensors to the coin has on the measurements obtained with said sensors without carrying direct measurements on said distances.

[0049] The invention also refers to a coin selector comprising an inlet for the coins and a casing defining a pass channel for the coins, characterized in that it comprises a device for discriminating coins as per that previously described.

Brief description of the drawings

[0050] A series of figures are briefly described below which help to better understand the invention and which are expressly related to an embodiment of said invention, presented as a non-limiting example thereof.

[0051] Figure 1 shows a diagram of a coin selector.

[0052] Figure 2 shows a diagram of a coin in any one position between the sensors defined by the distances d_1, d_2, d_3 and d_4.

[0053] Figure 3 shows a block diagram of a possible embodiment of the cyclical excitation of the two inductive sensors.

[0054] Figure 4 shows an example of measurements carried out sequentially in a coil in two excitation modes.

[0055] Figure 5 shows the values corresponding to each one of the modes once the interpolated values necessary for the present invention are calculated.

[0056] Figure 6 shows the variation in the phase inductance depending on the decentering of a coin with regard to the sensors (lift-off) when the sensors are measuring the central region of the coin, as well as the compensation obtained.

[0057] Figure 7 shows the variation in the phase inductance depending on the rotation of a coin with regard to the sensors (tilt) when the sensors are measuring the central region of the coin, as well as its compensation.

[0058] Figure 8 shows the evolution of the inductive coupling coefficient with the distance between sensors.

[0059] Figure 9 shows the phase inductance change values depending on the distance between sensors, as well the resulting compensation values corresponding to a nominal distance between sensors.

Detailed description

[0060] As shown in the preferred embodiment of the discrimination device shown in figure 1, the track of a coin 3 runs between and inlet and one or more outlets. The coin rolls along a coin channel 8 defined by the walls 4 and 5 and the rolling ramp 6. On each side of said channel 8, there is a first coil 1 and a second coil 2 facing each other, such that their rotation axes 7 coincide.

[0061] The coin channel 8 is slightly inclined such that the coin 3 tends to stay close to the wall 4. However, this is not totally achieved, resulting in that the coin to sensors distance in the direction of the axis 7 is variable in each introduction of a coin, and even within a same introduction along the track of the coin in the channel. The measurements obtained with the inductive sensors depend on this distance.

[0062] Figure 2 shows the coin 3, with thickness "e", as it passes between the first coil 1 and second coil 2, spaced by a distance "c". The relative position between coin and sensors is defined by distances d_1, d_2, d_3 and d_4. Depending on how these distances vary, there are lift-off, tilt variations or changes in the spacing between sensors.

[0063] The lift-off variation occurs when, keeping the distance between sensors "c" constant, the distances d_1 and d_2 vary in the same manner. The change causing this variation in the sensors is known as the lift-off effect.

[0064] The tilt of the coin occurs when, keeping the distance between sensors "c" constant, and the distances d_1 and d_2, distances d_3 and d_4 vary, such that the angle formed by the axis of the sensors 7 and the rotation axis of the coin varies.

[0065] A change occurs in the channel width when the distance between sensors "c" changes, such that, for example, d_1 and d_3 are kept constant and d_2 and d_4 vary in the same manner.

[0066] As indicated in the background, it is possible that compensating the lift-off effect also achieves compensating the tilt effect of the coin. A lift-off compensation model is therefore developed which is also verified as valid for compensating the tilt.

[0067] The block diagram of figure 3 shows the impedances Z_1 and Z_2 of the coils 1 and 2, respectively, which interact between one another and with the coin 3, such that there is a mutual impedance Z_M. The coils are excited by applying a voltage generated by a voltage source Vs through the resistances Rs_1 and Rs_2 Depending on the state of the switches 12 and 13, said voltage can be applied to each one of the coils separately or to both simultaneously. When the switch 12 is open, the impedance Z_1 associated with the first coil 1 is short-circuited through the resistance Rs_1. The same occurs with the switch 13, the impedance Z_2 associated with the second coil 2 and the resistance Rs_2. This change in the excitation of the coils is carried out without changing their electric configuration.

[0068] An intrinsic feature of any inductance is that it opposes quick changes in the current circulating through it. However, in the present invention it is necessary to quickly change from one operation mode to another. To make this possible, the resistances r_1 and r_2 are introduced in series with the inductances, with the object of increasing the dampening coefficient of the circuit. The transients of the currents in the inductances when the voltage applied to them upon passing from one operation mode to another is changed are thus significantly reduced.

[0069] In a preferred embodiment (not shown), a capacitor is placed in series with each one of the coils of the sensors, such that the ratio between the reactance and resistance variation of each coil in the presence of a coin with regard to its impedance modulus in the absence of a coin increases, thus increasing the circuit signal-noise ratio.

[0070] According to the present invention, the coils are cyclically excited in at least two different operation modes from among the following:

(A) exciting only the first coil 1,
(B) exciting only the second coil 2,
(C) exciting both coils 1 and 2 such that their fields are added (in phase arrangement) or subtracted (in counterphase arrangement) or they have any known phase shift.

[0071] In all those operation modes used, a same excitation frequency is used, and the voltage and intensity in amplitude and phase of each one of the coils is measured.

[0072] In a preferred embodiment, modes A and B are used, consisting of the individual excitation of each one of the coils 1 and 2, respectively.

[0073] The equations relating the voltages and intensities measured with the self-impedances Z_1 (R_1, L_1) and Z_2 (R_2, L_2) and mutual impedances Z_M (R_M, L_M), are the following:

$$\breve{V}_{1MA} = \breve{I}_{1MA} * \breve{Z}_1 + \breve{I}_{2MA} * \breve{Z}_M$$

$$\breve{V}_{2MA} = \breve{I}_{2MA} * \breve{Z}_2 + \breve{I}_{1MA} * \breve{Z}_M$$

$$\breve{V}_{1MB} = \breve{I}_{1MB} * \breve{Z}_1 + \breve{I}_{2MB} * \breve{Z}_M$$

$$\breve{V}_{2MB} = \breve{I}_{2MB} * \breve{Z}_2 + \breve{I}_{1MB} * \breve{Z}_M$$

[0074] The subscripts of the voltages and currents refer to the sensor where it is measured and to the excitation mode used. Thus, for example, $\breve{V}_{1MA}$ refers to the voltage in coil 1 when the system is excited according to mode A.

[0075] Solving the described equations system and the impedance values calculated referring to those obtained in the absence of a coin, the following is obtained:

- the change in self-resistance and self-inductance in each coil, which are caused by the eddy currents in the coin by the field generated by the same coil,
- the change in mutual resistance and mutual inductance in each coil, which are caused by the eddy currents in the coin by the field generated by the opposite coil. Both mutual impedances are equal.

[0076] Figure 4 shows an example of measurements carried out in a coil in two excitation modes. Measured resistance or inductance values in mode A are shown on the curve 14. The values corresponding to the same parameter (R or L) of mode B are shown on curve 15. Since the measurements in the two modes are carried out sequentially, there are no measures corresponding to both modes for the same time instants. For the present invention, it is necessary to have resistance and inductance measurements in both modes corresponding to the same time instants. Therefore, the intermediate values are calculated by means of interpolation. The values corresponding to each one of the modes once the necessary values have been calculated are shown on curves 16 and 17 of figure 5.

[0077] The mode change frequency is quick enough so as to reconstruct the signals of the coils in each one of the modes along the coin track as it passes through the sensors with no significant loss of information.
[0078] The phase configuration is the result of adding the self-resistances and self-inductances, the mutual resistances and mutual inductances, respectively. The counterphase configuration is the result of subtracting the mutual resistances and mutual inductances from the sum of self-resistances and self-inductances, respectively.
[0079] The dependence of the resistance and inductance measurements on the lift-off is of the same type, therefore a single valid model for both is developed below. The self-resistance and self-inductance of each coil regarding the values thereof in the absence of a coin are generically called BOB1 for those corresponding to the first sensor and BOB2 for those of the second one. In the same manner, the mutual resistance and mutual inductance change between coils regarding the values thereof in the absence of a coin is generically called B.
[0080] In a first approach, the curves describing the change of the values BOB1 and BOB2 depending on the coin to sensor distance (lift-off) follow an expression of the type:

$$\text{BOB 1} = A_1 \exp(-k_1 d_1) \qquad [1]$$

$$\text{BOB 2} = A_2 \exp(-k_2 d_2) \qquad [2]$$

wherein A_1, A_2 (both positive for the resistances and negative for the inductances), k_1 and k_2 are constants.
[0081] The position of the coin 3 with regard to the coils 1 and 2 can be expressed as a function of its offsetting, understood as the distance "x" of the plane 18, located equally spaced from both sensors to the center of the coin, this value being positive when the coin 3 is closer to coil 2 than to coil 1 (as shown in figure 2). The resulting expressions are:

$$\text{BOB 1} = D_1 \exp(-k_1 x) \qquad [3]$$

$$\text{BOB 2} = D_2 \exp(k_2 x) \qquad [4]$$

wherein:

$$x = d_1 - 0.5(c - e) = -d_2 + 0.5(c - e),$$

$$D_1 = A_1 \exp(-0.5\, k_1\, (c - e))\ y,$$

$$D_2 = A_2 \exp(-0.5\, k_2\, (c - e))$$

[0082] The ratio "y" of the values measured in both coils BOB1, BOB2 as an offsetting function "x" can be expressed as:

$$y = \frac{\text{BOB2}}{\text{BOB1}} = \frac{D_2}{D_1} \exp[(k_1 + k_2)x] \qquad [5]$$

[0083] The expressions [1] and [2] corresponding to the values measured in each coil can be written as a function of the ratio [5], considering the constants k_1 and k_2 to be equal, such as:

$$\text{BOB 1} = \sqrt{D_1 D_2}\ \frac{1}{\sqrt{y}} \qquad [6]$$

$$\text{BOB 2} = \sqrt{D_1 D_2}\ \sqrt{y} \qquad [7]$$

[0084] The measurement values of the coils 1 and 2 in that offsetting in which both values are equal (y=1) is $\sqrt{D_1 D_2}$.

[0085] The phase and counterphase R and L measurements object of the compensation, represented by "z", are described by the following expression:

$$z = BOB1 + BOB2 \pm 2B \quad [8]$$

wherein "B" is the mutual inductance or resistance coefficient between the two coils, which is added in the case of phase configuration and subtracted in the case of a counterphase configuration. This mutual influence is practically independent of the lift-off.

[0086] The compensation term consists of the difference between the value that would be had in the coils in a phase or counterphase configuration in that offsetting of coin for which the self-impedance measurements of the two coils were the same, and the real value in said configuration during the passing of the coin corresponding to an unknown offsetting value. This compensation can be expressed as:

$$z(y = 1) = z(y) + \Delta z_1$$

$$\Delta z_1 = z(y = 1) - z(y) = BOB1(y = 1) + BOB2(y = 1) + 2B - BOB1(y) - BOB2(y) - 2B$$

$$\Delta z_1 = BOB\ 1(y)\sqrt{y} + BOB\ 2(y)\frac{1}{\sqrt{y}} - BOB\ 1(y) - BOB\ 2(y)$$

$$\Delta z_1 = 2\sqrt{BOB\ 1(y)BOB\ 2(y)} - [BOB\ 1(y) + BOB\ 2(y)] \quad [9]$$

[0087] The compensation method disclosed is based on correcting the measurements obtained during the pass of the coin in relation to the position in which the two coils measure the same (y=1), which in the case of equal sensors, is the equivalent to a coin centered between them, although sometimes, due to the selector channel dimensions and the thickness of the coin, this position is physically impossible. The compensation is obtained directly from the self-resistance and self-inductance variations of each coil. All measurements are carried out at a same working frequency.

[0088] An assumption carried out which facilitated in the calculations is that the constants k_1 and k_2 are equal. The equation reflecting the compensation to be carried out in the case of not considering these constants equal is:

$$\Delta z_1 = 2BOB1^{\frac{k_2}{k_1+k_2}}\ BOB2^{\frac{k_1}{k_1+k_2}} - [BOB1(y)+BOB2(y)] \quad [10]$$

[0089] In equation [10], it is seen that not considering the constants k_1 and k_2 equal obliges estimating their value for determining the compensation that must be carried out, it is therefore necessary to exactly define the exponential starting function for each one of the coils of each selector.

[0090] It has been empirically verified that the curves describing the change of values BOB1 and BOB2 depending on the coin to sensor distance adjust better to functions of the following type than to the previously described exponential function:

$$BOB\ 1 = D'_1\ E \exp(k'_1\ x) + D'_1(1 - E) \quad [11]$$

$$BOB\ 2 = D'_2\ E \exp(-k'_2\ x) + D'_2\ (1 - E) \quad [12]$$

[0091] Expressions analogous to the equations [3] and [4] are obtained by operating with the equations [11] and [12]. This indicates that it is possible to use the lift-off compensation for the phase and counterphase values (by means of expression [9]) if the constants cte_1 and cte_2 are subtracted from the individual values of the coil 1 and 2, respectively.

$$\text{BOB 1} - cte_1 = D'_1\, E \exp(k'_1\, x); \qquad cte_1 = D'_1\,(1 - E) \qquad [13]$$

$$\text{BOB 2} - cte_2 = D'_2\, E \exp(-k'_2\, x); \qquad cte_2 = D'_2\,(1 - E) \qquad [14]$$

[0092] The general expression for the calculation of the phase and counterphase compensated value, accepting the assumption that both coils are equal (such that $D = D'_1 = D'_2$ y $k'_1 = k'_2$) is the following:

$$\Delta z_1 = 2\sqrt{[BOB1(y)-D(1-E)][BOB2(y)-D(1-E)]} - [BOB1(y)+BOB2(y)-2D(1-E)] \qquad [15]$$

[0093] Figure 6 shows on curve 19 the variation in the phase inductance depending on the offsetting of a coin with regard to the sensors (lift-off) when the sensors are measuring the central region of the coin. On curve 20, the same inductance is shown once the compensation term is applied. It can be seen how the variation of said measurement is greatly attenuated with the lift-off. Figure 7 shows on curve 21 the variation in the phase inductance depending on the rotation of a coin with regard to the sensors (tilt) when the sensors are measuring the central region of the coin. Curve 22 shows the same inductance once the compensation term is applied. It can be seen how the variation of said measurement is greatly attenuated with the tilt of the coin. Therefore, it is verified that the lift-off compensation model is also valid for compensating the tilt of the coin.

[0094] Once the model was found predicting the behavior of an electromagnetic sensor consisting of two facing coils on either side of the path along which the coin rolls, depending on the distance between the coin and the coils, a compensation of the phase and counterphase measurements is presented in another embodiment of the present invention, such that these values are calculated at a fixed distance between coils, regardless of the real distance existing between them.

[0095] The phase and counterphase values corresponding to a nominal distance between sensors are calculated as a product of the phase and counterphase values obtained as the coin passes between the sensors and a compensation factor according to the following expression:

$$\Delta z_2 = \exp(-0.5 * k * (c_n - c))$$

$$z(c_n) = \Delta z_2 * z(c) \qquad [17]$$

wherein "c" is the real spacing between sensors in the selector, "c_n" is the nominal distance between sensors and $k=k_1=k_2$ is the constant initially included in the equations [1] and [2] which depends on the geometry of the sensor.

[0096] Figure 8 shows the evolution of the inductive coupling coefficient (M), whose expression is reflected in equation [18], with the distance between sensors. It is easy to find a function relating both variables, such that once the coupling is known, the distance between the sensors can be estimated.

$$M = \frac{L_M}{\sqrt{L_1 L_2}} \qquad [18]$$

[0097] In a preferred embodiment, the function relating the inductive coupling to the perpendicular distance between two coils is approximated by a line.

[0098] Curve 27 of figure 9 shows the phase inductance change values of the central region of a coin depending on the distance between sensors. Curve 28 shows the inductance change values after compensating said distance, such that values corresponding to a nominal distance between sensors are obtained.

Claims

1. Device for discriminating coins, comprising

- a track along which a coin (3) runs between an inlet and one or more outlets,

- at least one pair of inductive sensors formed by a first inductive sensor (1) and a second inductive sensor (2) which are facing each other one on each side of the coin track,
- excitation means of said first and second sensors (1, 2) in at least two different operation modes from among the following operation modes:

(A) exciting only the first inductive sensor,
(B) exciting only the second inductive sensor,
(C) exciting both first and second inductive sensors such that their electromagnetic fields are added (in phase arrangement) or subtracted (in counterphase arrangement) or that they have any known phase shift,

- means for carrying out, for each operation mode, some first measurements relating to the first inductive sensor (1),
- means for carrying out, for each operation mode, some second measurements relating to the second inductive sensor (2), **characterized in that**
- said excitation means are configured so as to function at excitation frequencies lower than 500 kHz, such that they provide measurements indicative of the materials and constructive features of the coin, and **in that** the device comprises
- means for calculating at least one compensation term (Δz) based on said first and second measurements,
- means for applying said compensation term (Δz) to phase and/or counterphase configuration measurements (z),

such that it at least partially corrects the effect on said measurements due to the changes in some of the distances of the coin to the sensors or between the sensors in at least one span of the coin path as it passes through said sensors.

2. Device according to claim 1, **characterized in that** said excitation frequencies are close to each other in the at least two different operation modes.

3. Device according to any of claims 1-2, **characterized in that** the device comprises:

- means for calculating, for each operation mode used, the change in resistance (R) and inductance (L) in each one of the inductive sensors with regard to its value in the absence of a coin,
and **in that** the means for calculating a compensation term (Δz) include,
- means for calculating a first compensation term (Δz_{1R}) for each phase and counterphase (R) change value based on the change values of the self-resistances of each inductive sensor,
- means for calculating a first compensation term (Δz_{1L}) for each phase and counterphase (L) change value based on the change values of self-inductances of each inductive sensor,

such that it at least partially compensates the effect of the change of distances of the coin to the sensors due to lift-off and tilt on the change values in phase and counterphase resistance and inductance in at least one span of the coin track as it passes through said sensors.

4. Device according to claim 3, **characterized in that** the excitation means are configured for working cyclically, such that the period of said cycle is less than the time it takes any coin to travel a distance equal to half the radius of the inductive sensor, to be able to reconstruct the signals of the sensors in each one of the operation modes in at least a span of the track of the coin as it passes through the first and second sensors with no significant loss of information.

5. Device according to any of the previous claims, **characterized in that** the device includes respective capacitors connected in series or in parallel to each inductive sensor, such that the ratio between the reactance and resistance variation of each inductive sensor in the presence of the coin increases with regard to the modulus of its impedance in the absence of a coin.

6. Device according to any of the previous claims, **characterized in that** the device includes respective resistances (r_1, r_2) connected in series to each inductive sensor (1, 2) for the object of increasing the dampening coefficient of the circuit.

7. Device according to any of claims 1-2, **characterized in that** the device comprises:

- means for calculating the mutual inductance (L_M) between the first and second inductive sensors in the absence of a coin as from said first and second measurements.

8. Device according to claim 7, **characterized in that** the means for calculating a compensation term are configured for calculating a second compensation term (Δz_2) as from said mutual inductance (L_M),
such that said phase and counterphase configuration measurements (z) to which said compensation term (Δz_2) has been applied are those corresponding to a nominal distance between inductive sensors, regardless of the real distance existing between them.

9. Device according to claim 7, **characterized in that** the device comprises:

- means for calculating the self-inductances (L_1, L_2) of each inductive sensor in the absence of a coin as from said first and second measurements,
- means for calculating a coupling coefficient (M) as from the mutual inductance (L_M) and self-inductances (L_1, L_2),
- means for calculating the effective distance between first and second inductive sensors as from said coupling coefficient (M),
- means for calculating a second compensation term (Δz_2) based on said effective distance,

such that said phase and counterphase configuration measurements (z) to which said compensation term (Δz_2) has been applied are those corresponding to a nominal distance between inductive sensors.

10. Method for discriminating coins, comprising:

- arranging at least a first inductive sensor (1) and a second inductive sensor (2) facing each other, one on each side of a track along which a coin (3) runs between an inlet and one or more outlet,
- exciting said first and second sensors (1, 2) in at least two different operation modes from among the following operation modes:

  (A) exciting only the first inductive sensor,
  (B) exciting only the second inductive sensor,
  (C) exciting both first and second inductive sensors such that their electromagnetic fields are added (in phase arrangement) or subtracted (in counterphase arrangement) or that they have any known phase shift,

- carrying out, for each operation mode, some first measurements relating to the first inductive sensor (1),
- carrying out, for each operation mode, some second measurements relating to the second inductive sensor (2), **characterized in that** the method comprises
- using excitation frequencies lower than 500 kHz, such that they provide measurements indicative of the materials and constructive features of the coin,
- calculating at least one compensation term (Δz) based on said first and second measurements,
- applying said compensation term (Δz) to some phase and counterphase configuration measurements (z),

such that it at least partially corrects the effect on said measurements due to the changes in some of the distances of the coin to the sensors or between the sensors in at least one span of the coin track as it passes through said sensors.

11. Method according to claim 10, **characterized in that** the method comprises using excitation frequencies that are close to each other in the at least two different operation modes.

12. Method according to any of claims 10-11, **characterized in that** the method comprises:

- calculating, for each operation mode used, the change in resistance (R) and inductance (L) in each one of the inductive sensors with regard to their value in the absence of a coin,
- calculating a first compensation term (Δz_{1R}) for each phase and counterphase (R) change value based on the change values of self-resistances of each inductive sensor,
- calculating a first compensation term (Δz_{1L}) for each phase and counterphase (L) change value based on the change values of self-inductances of each inductive sensor,

such that it at least partially compensates the effect of the change of distances of the coin to the sensors due to lift-off and tilt on the change values in phase and counterphase resistance and inductance in at least a span of the coin track as it passes through said sensors.

13. Method according to claim 12, **characterized in that** the method comprises

- cyclically exciting in the operation modes, such that the period of said cycle is less than the time it takes any coin to travel a distance equal to half the radius of the inductive sensor, to be able to reconstruct the signals of the sensors in each one of the operation modes in at least a span of the track of the coin as it passes through the first and second sensors, with no significant loss of information.

14. Method according to any of claims 12-13, **characterized in that** operation modes (A) and (B) are used.

15. Method according to any of claims 12-13, **characterized in that** it uses as operation modes operation mode (A) and exciting both first and second inductive sensors such that their electromagnetic fields are added (in phase arrangement) or subtracted (in counterphase arrangement).

16. Method according to any of claims 12-13, **characterized in that** it uses as operation modes: exciting both first and second inductive sensors such that their electromagnetic fields are added (in phase arrangement) and exciting both first and second inductive sensors such that their electromagnetic fields are subtracted (in counterphase arrangement).

17. Method according to any of claims 10-11, **characterized in that**

- the mutual inductance (L_M) between the first and second inductive sensors in the absence of a coin is calculated as from said first and second measurements.

18. Method according to claim 17, **characterized in that** a second compensation term (Δz_2) is calculated as from said mutual inductance (L_M),
such that said phase and counterphase measurements (z) to which said compensation term (Δz_2) has been applied are those corresponding to a nominal distance between inductive sensors, regardless of the real distance existing between them.

19. Method according to claim 17, **characterized in that** the method comprises:

- calculating the self-inductances (L_1, L_2) of each inductive sensor in the absence of a coin as from said first and second measurements,
- calculating a coupling coefficient M as from the mutual inductance (L_M) and the self-inductances (L_1, L_2),
- calculating the effective distance between first and second inductive sensors as from said coupling coefficient M,
- calculating a second compensation term (Δz_2) based on said effective distance,

such that said phase and counterphase configuration measurements (z) to which said second compensation term (Δz_2) has been applied are those corresponding to a nominal distance between inductive sensors.

20. A coin selector comprising an inlet for coins and a casing defining a pass channel (8) for the coins, **characterized in that** it comprises a device for discriminating coins according to any of claims 1-9.

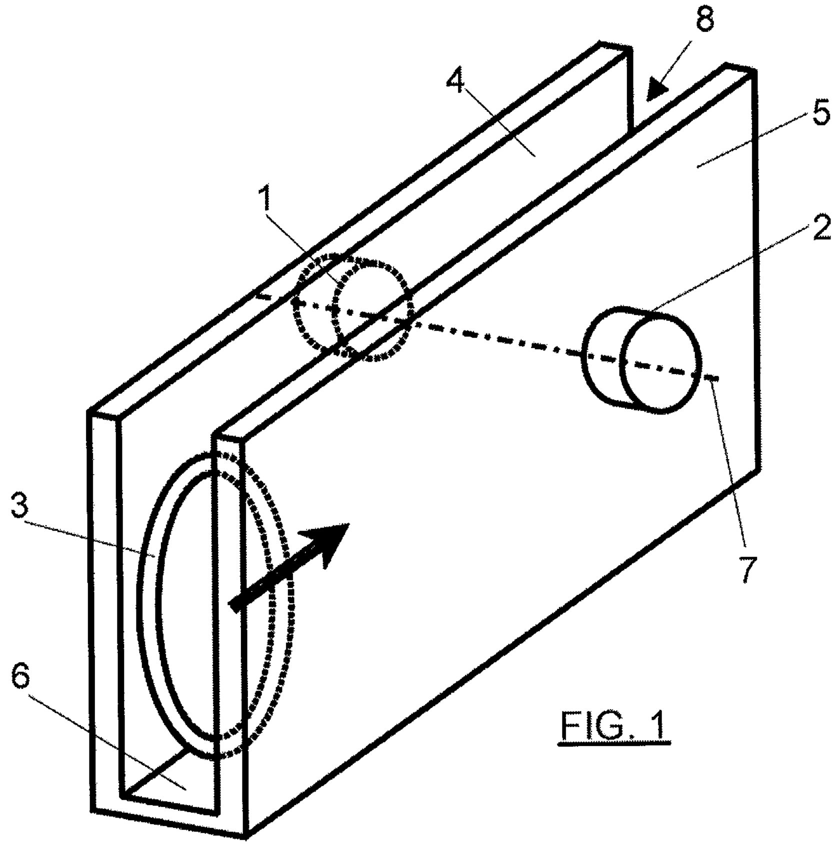


FIG. 1

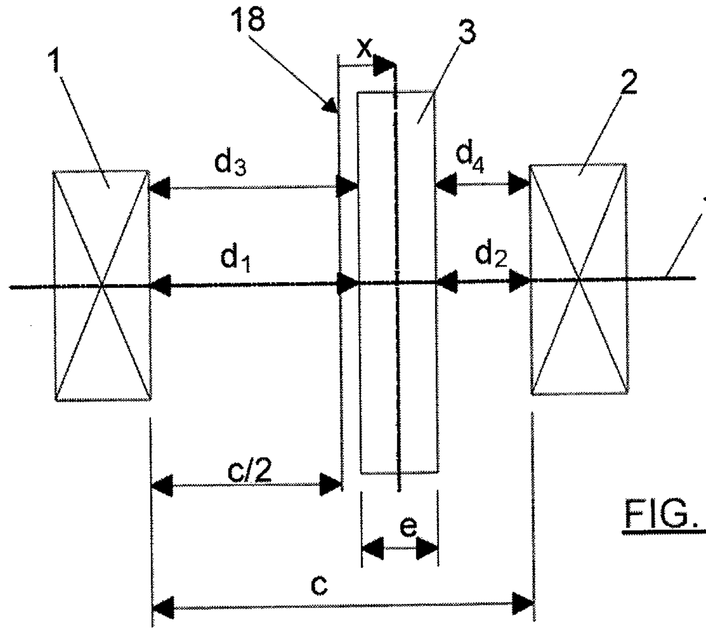


FIG. 2

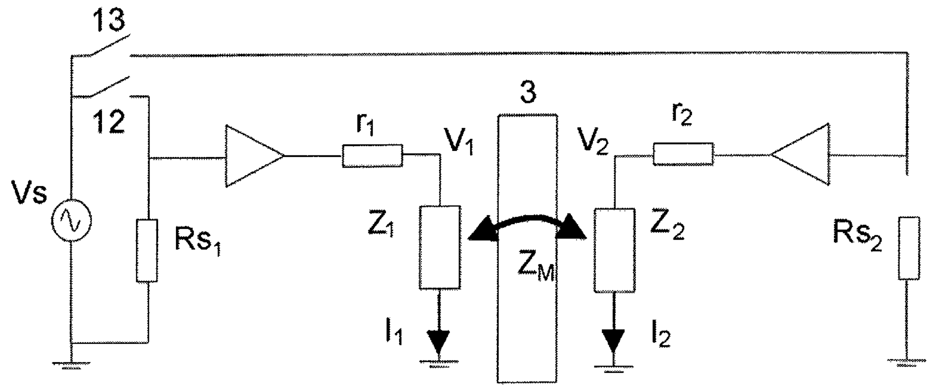


FIG. 3

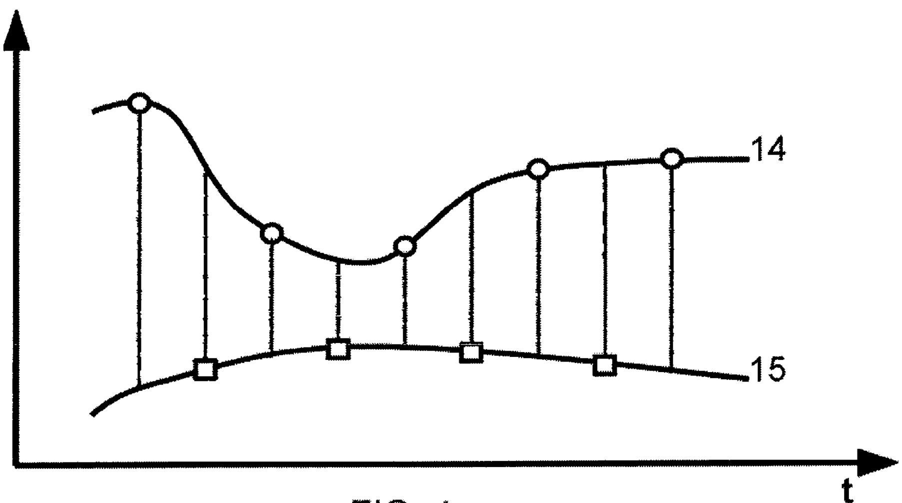


FIG. 4

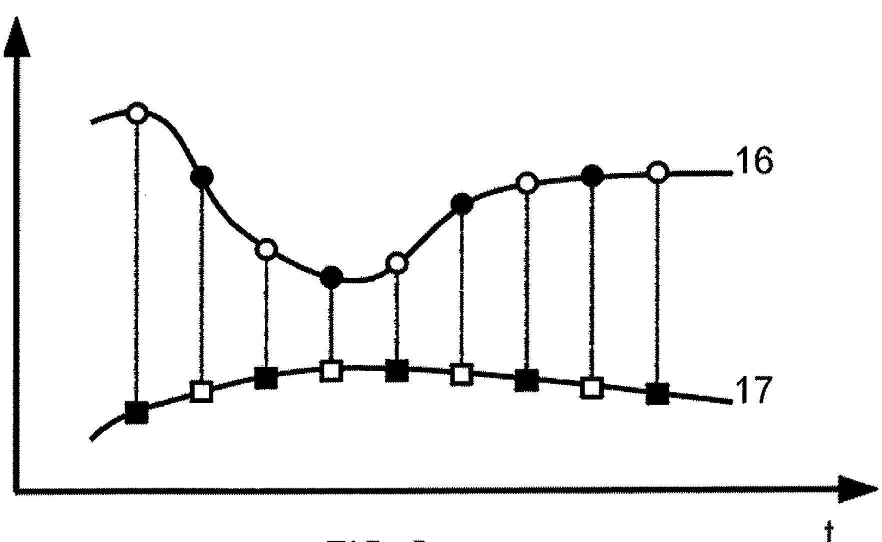
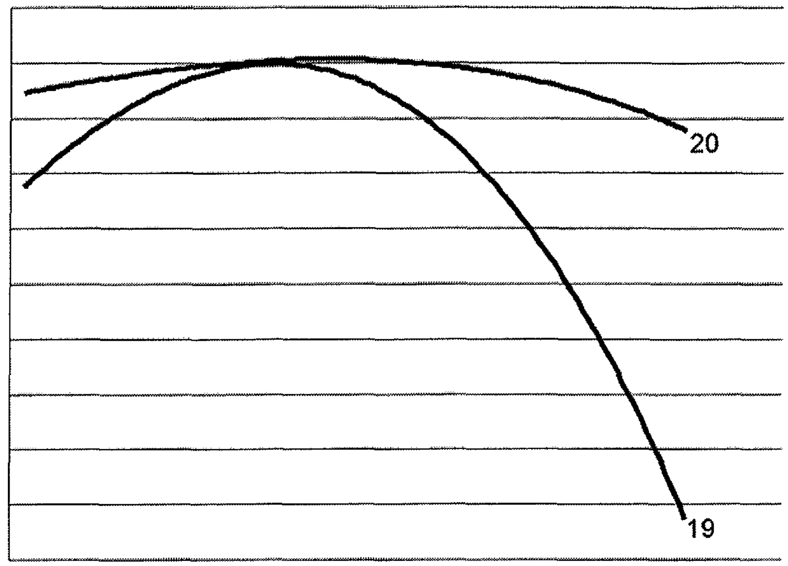


FIG. 5

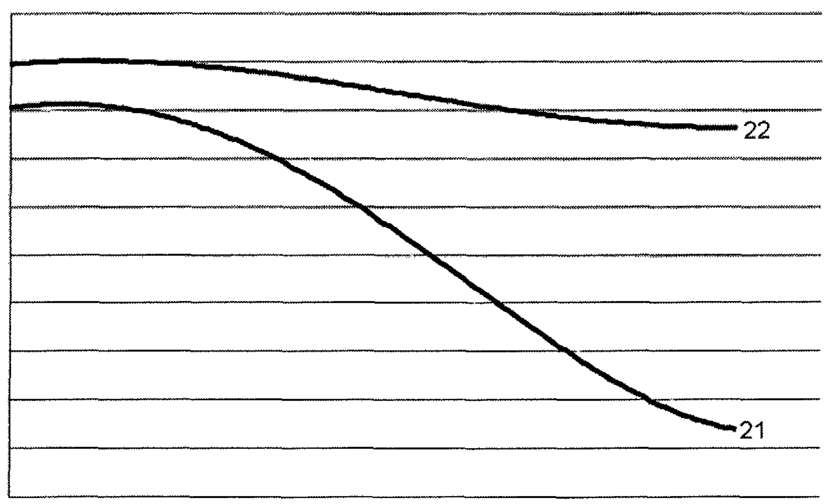
INDUCTANCE



Offsetting

FIG. 6

INDUCTANCE



Rotation Angle

FIG. 7

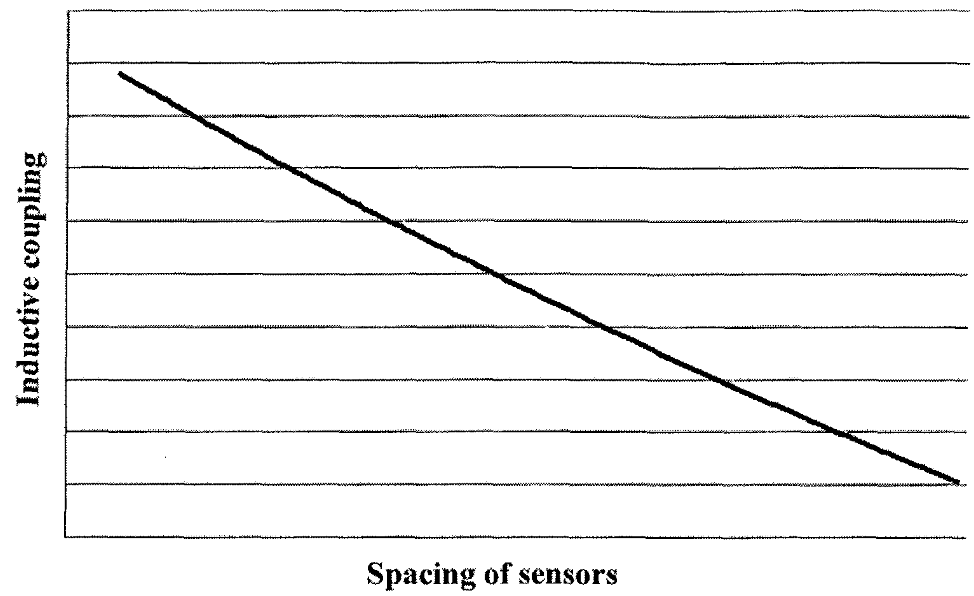

Inductive coupling
Spacing of sensors

FIG. 8

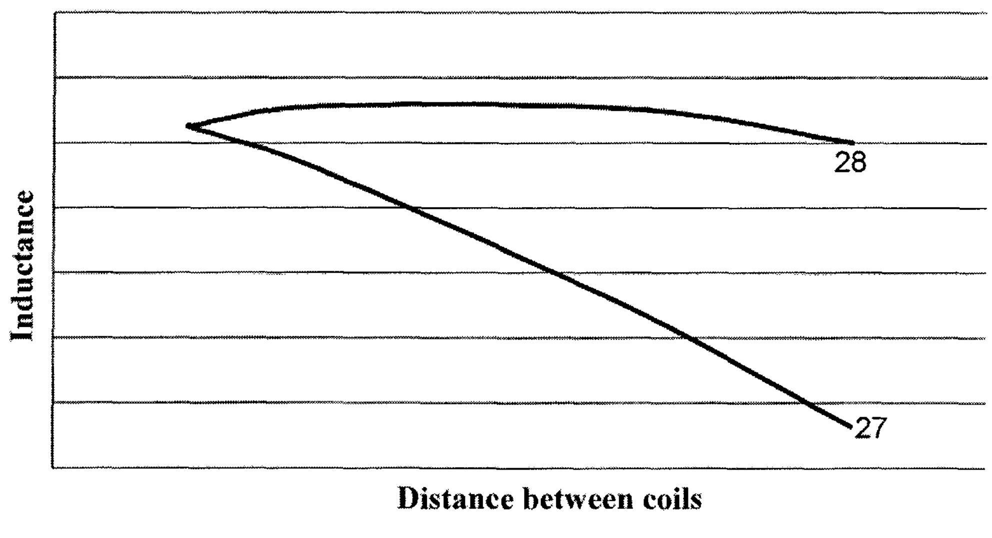

Inductance
28
27
Distance between coils

FIG. 9

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 03 38 0018

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Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.7)
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G07D
G07F

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	24 July 2003	Van Dop, E

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