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(54) METHOD AND APPARATUS FOR DETECTING PRESENCE OF TRAINS

(57) Method for detecting presence of a train on a track section inserted in a track circuit, comprising an initial step of acquiring (300) the local voltage Vin_L and the field voltage Vin_C, equal to the sum of a periodic signal $VC(t)$ and a noise $N(t)$, for an integration interval T, wherein the method: calculates (340, 345) the effective values of the local voltage Vin_L and field voltage Vin_C; determines (330) a phase shift φ of the field voltage Vin_C with respect to the local voltage Vin_L on the basis of a cross-correlation at the origin of the local voltage Vin_L and field voltage Vin_C and its derivative at the origin; compares (335) the phase shift φ with a predetermined maximum phase shift threshold R and, if it exceeds the predetermined maximum phase shift threshold R, signals (390) the presence of a train on said track section, otherwise it executes the following steps; calculates (370) an effective value VC_{eff} of the periodic field signal $VC(t)$ on the basis of a maximum value C_{max} of the cross-correlation normalised to the product $VL_{eff\_mis} * VC_{eff\_mis}$ of the effective values, depending on the phase shift φ, and on the effective value VL_{eff_mis} of the local voltage Vin_L; compares (380) the effective value VC_{eff} of the periodic field signal VC (t) with the effective value VL_{eff_mis} of the local voltage Vin_L acquired in the initial phase and, if they differ by more than a predetermined maximum effective value difference threshold S, signals (390) the presence of a train on said track section.

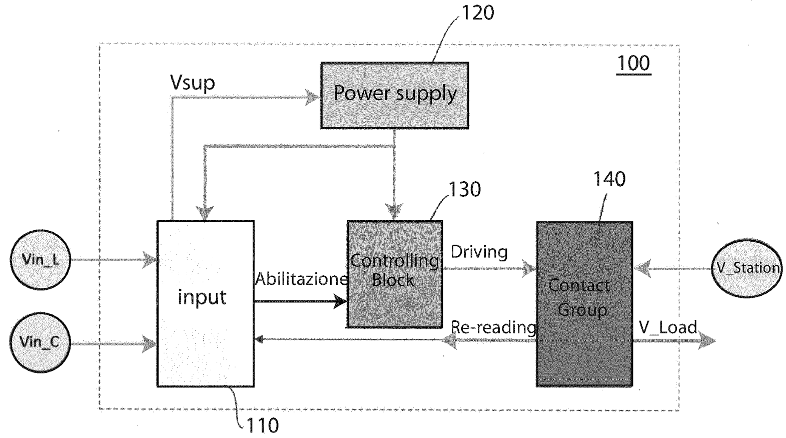

Fig. 1

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Description

[0001] The present invention relates to a method, and the related apparatus, for detecting presence of a train on a track section, that allows in a simple, fast, reliable, efficient and inexpensive way to correctly identify the occupation of a track section by a train even in presence of possible signal disturbances.

[0002] In the following of the present description reference will be made to the presence of a train on a track section, intending the presence of any railway vehicle or train, including individual railway vehicles, such as locomotives or carriages.

[0003] Moreover, in the following of the present description reference will be mainly made to an application of the apparatus according to the invention, that is configured to carry out the method according to the invention, to the detection of presence of a train on a track section inserted in a track circuit. However, it should be noted that the apparatus according to the invention can be used also in other applications in which the energisation or de-energisation of (at least one) main relay of the apparatus according to the invention are dependent on the mutual relationship of two input signals of the apparatus, still remaining within the scope of protection of the present invention.

[0004] It is known that on railway lines checks are carried out on each track section to detect and signal the possible presence of a train occupying a certain section, in order to prevent other trains from reaching the same section and causing accidents.

[0005] Prior art detection and signaling systems are based on disc relays. The traditional implementation of a disc relay is an electromechanical relay with two windings on which two alternating voltages are injected. The electromechanical construction is such that when one of the two voltages differs from the other, over certain limits, in amplitude and/or phase, the relay is de-energized opening a contact switch and interrupting a downstream circuit. When the two voltages are again similar in amplitude and phase, the relay is energized again, closing the contact switch. Prior art electromechanical disc relays are disclosed, for instance, in documents US 1066081, US 1987144, US 4564829 and GB 2275572 A.

[0006] In the most recent implementations, the electromechanical part has been at least partially replaced with electronic circuits which measure electrical quantities and, under the same conditions as the traditional relay, drive the output contact switch. Examples of such electronic relays are disclosed in documents US 6463337 B1, DE 102013003766 B3, EP 2100792 A1 and GB 2100902 A.

[0007] In both the electronic and electromechanical construction, in their railway use the disc relays have the function of identifying the presence of a railway vehicle or train on a certain track section.

[0008] In particular, the tracks are subdivided into sections, including track sections suitably connected to each other and isolated from ground and from other sections; each of such sections is inserted in a corresponding electrical circuit known as "Circuit of track", hereinafter also referred to as "Cot". Each Cot comprises a signal emitter, usually positioned at one end of the track section that is part of the Cot, and a signal receiver, usually positioned at the other end of the track section that is part of the Cot.

[0009] The railway system generates a so-called "Local" voltage that is sent to a first winding of the relay and simultaneously injected into the Circuit of track. By imposing a voltage upstream of the Cot (i.e. at the input of the Cot) through the signal emitter, a current circulation is generated on the Cot itself. Downstream of the Cot (i.e. at the output of the Cot), the voltage is again drawn and sent to a second winding of the relay through the signal receiver.

[0010] The output voltage from the Cot is called the "field voltage" and is compared by the relay with the local voltage. In particular, the field voltage and the local voltage have the same frequency f_L and, as previously described, when the two voltages differ in phase or amplitude over certain limits, the relay is de-energised by disconnecting a load.

[0011] This mechanism permits to identify the presence of a train on a Cot section. In fact, when a railway vehicle or train occupies the track circuit, it creates a short circuit (or in any case it lowers the impedance a lot) between the two rails through the wheels and the axis that joins them, bringing the field voltage down to zero or strongly reducing it. This condition causes the relay to be de-energised and to turn on a (red) signal, through a signaling circuit connected to the relay output, that signals to other trains that the track section is occupied and, thus, no other train is authorised to pass on this already occupied track section. When the railway vehicle or train clears the (track section belonging to the) Cot, the field voltage returns to its usual level, and the relay is re-engaged by turning on the (green) signal, through the signaling circuit, that authorises the transit of another train over the same track section.

[0012] In real applications, the non-idealities of the Cot, the disturbances deriving from railway traffic (e.g., other trains in the vicinity of the Cot) and the effects of atmospheric and environmental conditions causes the capability to discriminate the differences between local voltage and field voltage to possibly decrease. In particular, situations in which the relay is not capable to correctly signal the presence of a railway vehicle or train on the track section, i.e. when it is not correctly de-energised or it is unduly re-energised, are dangerous.

[0013] In particular, such situation occurs when the disturbances coupled to the field voltage are very close to the frequency band of the local signal and, at the same time, the phase shift levels which are present are such as not to allow the relay to correctly discriminate the actual differences between local voltage and field voltage.

[0014] For instance, it is quite common that, even in the absence of particular conditions on the track section, a predetermined phase shift (or phase offset) exists between local voltage and field voltage. To compensate for such phase shift, in traditional electromechanical relays it is necessary to insert phase shift correction capacitors, while the electronic relays are capable to acquire such phase offset during installation and to automatically compensate it.

[0015] Typically, sinusoidal signals with a frequency of 50 Hz and/or (substantially) 83.3 Hz (that is actually the frequency corresponding to a period of 12 milliseconds, whereby "3" after the decimal point is a recurring decimal) are used on the track circuits. Also, in the case of frequency of 83.3 Hz this is obtained through PSK type phase modulation. The disc relay is thus capable to manage track circuits operating at the two frequencies.

[0016] Compared to traditional electromechanical relays, electronic relays have improved the operation of the Cot occupancy detection and signaling systems. For instance, the electronic relays offer the possibility of:

- automatically compensating for possible predetermined phase shifts present between the two voltages, namely the local voltage and the field voltage, which are not attributable to the presence of a train on the Cot;
- introducing programmable energisation/de-energisation thresholds, so as to introduce a hysteresis with respect to the intervention thresholds in relation to the measured amplitude values of the two voltages;
- measuring the frequencies of the signals at the relay input;
- and recognising the PSK modulation and, hence, distinguishing between a signal generated by the system and possible external disturbances in a safer way,

[0017] However, even the prior art electronic relays still suffer from some drawbacks.

[0018] In particular, the prior art electronic relays have not reliably solved the problem of correctly measuring the phase shift between the local voltage and the field voltage and of recognising possible disturbances superimposed on the field voltage.

[0019] In fact, the signal processing methods used by the prior art electronic relays exploit the measurement of the time difference between two edges of the two signals at the relay input to estimate the phase shift. However, these methods are affected by errors in the presence of band disturbances determining the appearance of zero crossing edges not due to the original signal (considered free of disturbances).

[0020] Moreover, the signal processing methods used by prior art electronic relays are based on a traditional approach to measuring the amplitude of the two voltages that is affected by confounding effects due to disturbances which are typically present, in particular upon passage of a train. In particular, the presence of a disturbance with frequencies close to those of the signals generated by the emitter and fed into the Cot, i.e. 50 Hz and/or (substantially) 83.3 Hz, modifies the shape of the generated signals until they in turn appear as disturbances and confound the decision-making process of the electronic relay.

[0021] Therefore, it is an object of the present invention to correctly identify the occupancy of a track section by a train even in presence of possible signal disturbances, so as to detect presence of a train on a track section in a simple, fast, reliable, efficient and economical way.

[0022] It is specific subject matter of the present invention a computer-implemented method for detecting a presence of a train on a track section inserted in a track circuit, at one end of which a local voltage Vin_L, equal to a local periodic signal having frequency f_L, is sent and that produces at the other end of which a field voltage Vin_C, wherein the field voltage Vin_C is equal to the sum of a field periodic signal $VC(t)$ having frequency f_L and a noise $N(t)$, whereby Vin_C = $VC(t) + N(t)$, comprising the following steps:

S-A. acquiring (300) the local voltage Vin_L and the field voltage Vin_C of the track circuit for an interval T of integration having a start time assumed as time origin;

S-B. calculating (320) a cross-correlation at the time origin $C_{mis}(0)$ of the local voltage Vin_L and the field voltage Vin_C acquired in step S-A and the derivative of said cross-correlation at the time origin $C'_{mis}(0)$;

S-C. determining (330) a phase shift φ of the field voltage Vin_C with respect to the local voltage Vin_L according to the formula

$$\varphi = -arctg\left(\frac{C'_{mis}(0)}{C_{mis}(0)}\right)$$

S-D. comparing (335) the phase shift φ determined in step S-C with a predetermined maximum phase shift threshold R;

S-E. if the phase shift φ determined in step S-C exceeds the predetermined maximum phase shift threshold R, then signaling (390) the presence of a train on said track section, otherwise executing the following steps;

S-F. calculating (340) a product

$$VL_{eff\_mis} * VC_{eff\_mis}$$

of the effective values of the local voltage Vin_L and field voltage Vin_C acquired in step S-A in the interval T of integration, and calculating (345) the effective value VL_{eff_mis} in the interval T of integration of the local voltage Vin_L acquired in step S-A and the effective value VC_{eff_mis} in the interval T of integration of the field voltage Vin_C acquired in step S-A;

S-G. normalising (350) the cross-correlation at the time origin $C_{mis}(0)$ with respect to the product $VL_{eff\_mis} * VC_{eff\_mis}$ of the effective values calculated in step S-F, obtaining a normalised cross-correlation at the time origin $C_{mis\_norm}(0)$;

S-H. calculating (360) a maximum value C_{max} of said cross-correlation normalised to the product $VL_{eff\_mis} * VC_{eff\_mis}$ of the effective values calculated in step S-F through the formula

$$C_{max} = \frac{C_{mis\_norm}(0)}{cos\varphi}$$

S-J. calculating (370) an effective value VC_{eff} of the field periodic signal *VC(t)* in the interval T of integration through the formula

$$VC_{eff} = C_{max} * VC_{eff\_mis}$$

S-K. comparing (380) the effective value VC_{eff} of the field periodic signal *VC(t)* with the effective value VL_{eff_mis} of the local voltage Vin_L acquired in step S-A;

S-L. if the effective value VC_{eff} of the field periodic signal *VC(t)* differs from the effective value VL_{eff_mis} of the local voltage Vin_L acquired in step S-A over a predetermined maximum effective value difference threshold S, then signaling (390) the presence of a train on said track section.

[0023] According to another aspect of the invention, the computer-implemented method may further comprise the following step after step S-C:

S-M. determining whether the field voltage Vin_C has one or more jumps in phase and/or amplitude in the current interval T of integration and/or in one or more consecutive intervals T of integration preceding the current interval T of integration which do not correspond to similar jumps in phase and/or amplitude of the local voltage Vin_L, then signaling (390) the presence of a train on said track section,
wherein step S-M is optionally executed before step S-F, more optionally before step S-D.

[0024] According to a further aspect of the invention, the local voltage Vin_L may be phase modulated, optionally with a phase modulation of PSK type.

[0025] According to an additional aspect of the invention, the interval T of integration may be equal to one period corresponding to the frequency f_L multiplied by a coefficient J ≥ 1, i.e.

$$T = J \cdot f_L \ ,$$

wherein optionally J > 1, wherein more optionally 2 ≤ J ≤ 10.

[0026] According to another aspect of the invention, when the computer-implemented method is executed in a current interval T of integration after that in step S-E executed in a preceding interval T of integration the presence of a train on said track section has been signalled and such signaling is still in progress, step S-E executed for the current interval T of integration may terminate to signal the presence of a train on said track section if the phase shift φ of the field voltage Vin_C with respect to the local voltage Vin_L is lower than a predetermined minimum phase shift threshold H not greater than the predetermined maximum phase shift threshold R, wherein the predetermined minimum phase shift threshold H is optionally lower than the predetermined maximum phase shift threshold R, whereby step S-E executed for the current interval T of integration introduces a signaling phase shift difference hysteresis.

[0027] According to a further aspect of the invention, when the computer-implemented method is executed in a current interval T of integration after that in step S-L executed in a preceding interval T of integration the presence of a train on said track section has been signalled and such signaling is still in progress, step S-L executed for the current interval T of integration may terminate to signal the presence of a train on said track section if the effective value VC_{eff} of the field periodic signal *VC(t)* differs from the effective value VL_{eff_mis} of the local voltage Vin_L acquired in step S-A by less than a predetermined minimum effective value difference threshold G not greater than the predetermined maximum effective value difference threshold S, wherein the predetermined minimum effective value difference threshold G is optionally lower than the predetermined maximum effective value difference threshold S, whereby step S-L executed for the current interval T of integration introduces a signaling effective value difference hysteresis.

[0028] According to an additional aspect of the invention, the local periodic signal and the field periodic signal *VC(t)* may be sinusoidal signals.

[0029] According to another aspect of the invention, in step S-A, the acquired local voltage Vin_L and field voltage Vin_C may be sampled and discretised at a sampling frequency f_s, optionally equal to 10 kHz, whereby method steps following step S-A are executed in discrete time starting from a number N of discrete time samples of the local voltage Vin_L:

VL[i], per i = 0,1,..., N-1

and from a number N of discrete time samples of the field voltage Vin_C

VC[i], per i = 0, 1,..., N-1.

[0030] According to a further aspect of the invention, the frequency f_L may be equal to 50 Hz and T = 80 milliseconds, or the frequency f_L may be substantially equal to 83,3 Hz (that is actually the frequency corresponding to a period of 12 milliseconds, whereby "3" after the comma is a recurring decimal) and T = 96 milliseconds.

[0031] It is also specific subject matter of the present invention an apparatus configured to detect a presence of a train on a track section inserted in a track circuit, configured to receive a local voltage Vin_L and a field voltage Vin_C of the track circuit and to control a signaling circuit, wherein the apparatus comprises one or more processing units configured to execute the computer-implemented method for detecting a presence of a train on a track section inserted in a track circuit as previously described.

[0032] According to another aspect of the invention, the apparatus may comprise:

- an input processing block, provided with said one or more processing units, by means of which the apparatus is configured to receive the local voltage Vin_L and the field voltage Vin_C of the track circuit and to execute said computer-implemented method for detecting a presence of a train on a track section inserted in a track circuit, wherein the input processing block is configured to generate one or more output signals enabling driving one or more main relays;
- a power supply configured to receive the local voltage Vin_L from the input processing block and to supply the apparatus;
- a controlling block configured to receive said one or more output signals enabling driving one or more main relays from the input processing block and to generate, on the basis of said one or more output signals enabling driving one or more main relays, corresponding one or more driving signals configured to control one or more main relays; and
- a block provided with one or more main relays configured to receive said one or more driving signals, so as to be controlled by said one or more driving signals to selectively output at corresponding one or more output terminals a station voltage V_Station that said one or more main relays are configured to receive at a respective input terminal, wherein said one
  or more output terminals are configured to be connected to said signaling circuit; wherein said one or more output terminals optionally comprise a first output terminal that is normally closed and a second output terminal that is normally open with respect to the respective input terminal configured to receive the station voltage V_Station.

[0033] According to a further aspect of the invention, said one or more processing units may consist of two processing units, and wherein the apparatus may be configured to signal through said signaling circuit the presence of a train on said track section for an interval T of integration only when both the processing units execute step S-E or step S-L of said computer-implemented method.

[0034] According to an additional aspect of the invention, the apparatus may comprise at least one low-pass filter configured to cut signals having frequency *f* higher than a cut-off frequency equal to the sum of a maximum frequency f_{L_max} of the local voltage Vin_L that the apparatus is configured to receive and an observation frequency f_c corresponding to the interval T of integration, whereby f_c = 1/T, whereby said cut-off frequency is equal to:

$$f \leq f_{L\_max} + f_c$$

[0035] According to another aspect of the invention, the apparatus may comprise at least one band-pass filter configured to cut signals having frequency *f* outside a passband ranging from a lower cut-off frequency equal to the difference of a minimum frequency f_{L_min} of the local voltage Vin_L that the apparatus is configured to receive and an observation frequency f_c corresponding to the interval T of integration, whereby $f_c = 1/T$, and an upper cut-off frequency equal to the sum of a maximum frequency f_{L_max} of the local voltage Vin_L that the apparatus is configured to receive and the observation frequency f_c, whereby said passband is equal to

$$f_{L\_min} - f_c \leq f \leq f_{L\_max} + f_c$$

[0036] It is further specific subject matter of the present invention a set of one or more computer programs comprising instructions which, when executed by one or more processing units, cause said one or more processing units to execute the computer-implemented method for detecting a presence of a train on a track section inserted in a track circuit as previously described.

[0037] It is additional specific subject matter of the present invention a set of one or more computer-readable media having stored thereon the set of one or more computer programs just described.

[0038] In fact, the method and the apparatus according to the invention overcome the disadvantages of the prior art by adopting an alternative technique to measure the phase and, starting from this measurement, obtain the amplitude of the field signal cleared of external disturbances.

[0039] Moreover, the method and the apparatus according to the invention are capable to discriminate the presence of disturbances with frequencies very close to the working ones and with amplitudes comparable to those of actual signals.

[0040] In some embodiments, by implementing a 2-on-2-type architecture (i.e. 2 processing units operating simultaneously) and using independent driving channels for the energisation of the relay outputs, the apparatus according to the invention reaches the safety level SIL4 required in railway applications.

[0041] In this regard, it must be noted that the apparatus according to the invention can also be used in other applications, still remaining within the scope of protection of the present invention. By way of example, and not by way of limitation, the apparatus according to the invention can be used, in the railway sector, for the so-called "integrity check" of signals, wherein the apparatus according to the invention receives the power supply voltage of the primary of a transformer as local voltage Vin_L, and the voltage on the secondary of the transformer as field voltage Vin_C, and wherein the output of the apparatus according to the invention signals whether the transformer is operating correctly or not since, in the event of phase shifts of the voltage on the secondary with respect to the voltage on the primary of the transformer above a certain threshold, or in the event of incorrect absorption of the transformer, (at least) one main relay of the apparatus according to the invention is de-energised. Alternatively, the apparatus according to the invention can be used to safely drive loads only in the presence of two suitable input signals, received by the apparatus according to the invention as local voltage Vin_L and field voltage Vin_C; namely, by using two input signals in phase with each other it is possible to turn on (or off) an output signal controlling an external circuit connected to the output terminal of said (at least one) main relay of the apparatus according to the invention, while sending signals in opposition of phase to each other it is possible to turn off (or on) such output signal. In general, the apparatus according to the invention and the method carried out by it can be used in all applications in which the energisation or de-energisation of said (at least one) main relay of the apparatus according to the invention are dependent on the mutual relationship of the input signals of the apparatus, received by the apparatus according to the invention as local voltage Vin_L and field voltage Vin_C.

[0042] The present invention will be now described, by way of illustration and not by way of limitation, according to its preferred embodiments, by particularly referring to the Figures of the annexed drawings, in which:

Figure 1 shows a block diagram of the preferred embodiment of the apparatus according to the invention;
Figure 2 schematically shows the functional architecture of the apparatus of Figure 1; and
Figure 3 shows a flow chart of the preferred embodiment of the method according to the invention.

[0043] In the Figures, identical reference numerals will be used for alike elements.

[0044] In the following of the present description, reference will be mainly made to an application of the apparatus according to the invention, that is configured to carry out the method according to the invention, to the detection of the presence of a train on a track section inserted in a track circuit. However, it should be noted that the apparatus according to the invention can also be used in other applications in which the energisation or de-energisation of said (at least one) main relay of the apparatus according to the invention are dependent on the mutual relationship of two input signals of the apparatus, still remaining within the scope of protection of the present invention.

[0045] With reference to Figure 1, it can be observed that the apparatus 100 according to the invention, similarly to a traditional prior art electromechanical disc relay, is used in railway signaling systems. To this end, the apparatus 100 is inserted in the track circuit for detecting the occupancy of a respective specific track section.

[0046] In particular, the apparatus 100 is configured to receive the local voltage Vin_L and the field voltage Vin_C of the track circuit and to determine the amplitude of these voltages Vin_L and Vin_C and the phase shift between the local voltage Vin_L and the field voltage Vin_C . Also, the apparatus 100 is configured to receive an external voltage, namely a station voltage V_Station. The apparatus 100 is configured to connect the station voltage to (at least) one output terminal configured to be connected to the load when both input voltages, Vin_L and Vin_C, are present and are in a certain phase relationship, more precisely when the amplitudes of the voltages Vin_L and Vin_C and/or their phase shift assume values within respective predetermined ranges. In other words, the output voltage V_Load on said (at least one) output terminal configured to be connected to the load is alternatively zero or equal to the station voltage V_Station as a function of the values of the amplitudes of the voltages Vin_L and Vin_C and/or their phase shift determined by the apparatus 100. In the preferred embodiment shown in Figure 1, the apparatus 100 comprises two sets of output terminals driven by (at least) one main relay: the output terminals of a first set are normally open or NO with respect to the input terminal that receives the station voltage V_Station, while the output terminals of a second set are normally closed or NC with respect to the input terminal that receives the station voltage V_Station. The NO output terminals of the first set are used for safety functions (e.g., they drive the signaling circuit), so that in the absence of power supply they are certainly open; the NC output terminals of the second set are used for auxiliary functions (e.g., they are used by the railway network management company for diagnostic purposes). Moreover, in the preferred embodiment shown in Figure 1, the apparatus 100 further comprises (at least) one service relay used to internally re-read the state of the output terminals of said (at least one) main relay and to signal possible inconsistencies between driving and state of said (at least one) main relay.

[0047] Referring to the schematic block diagram of Figure 1, it can be observed that the preferred embodiment of the apparatus 100 comprises an input processing block 110, configured to receive and process the local voltage Vin_L and the field voltage Vin_C of the track circuit and to generate output signals for enabling the driving of the relays.

[0048] The local voltage Vin_L is also used to supply the apparatus 100 through a power supply 120; in Figure 1, a supply voltage indicated as Vsup is shown that is sent by the input processing block 110 to the power supply 120, since in general the supply voltage Vsup could also be only a portion of the local voltage Vin_L and, thus, it could be not coinciding with this.

[0049] A controlling block 130, in the presence of the enabling signals from the input processing block 110, is configured to generate the driving signals for controlling the contact switches of said (at least one) main relay contained in the contact group block 140 (wherein said - at least one - main relay that hence has the two sets of output terminals, one of which is the normally closed one and the other is the normally open one with respect to the input terminal that receives the station voltage V_Station, as mentioned above).

[0050] Moreover, the input processing block 110, through the output terminals of said (at least one) service relay, also contained in the contact group block 140, re-reads the driving signal to self-maintain the energisation of said (at least one) main relay, in order to verify that the contact group block 140 operates correctly and to detect possible malfunctions, for instance due to two contacts switches welded by overcurrents.

[0051] In the preferred embodiment of the apparatus 100, the input processing block 110 is based on a double microprocessor architecture such that each one of two processing and control units, each based on a respective microprocessor, is configured to independently generate the signals enabling the driving of said (at least one) main relay. The activation of said (at least one) main relay of the contact group block 140 is the result of both processing by the two processing and control units, whereby only when both processing and control units generate an activation signal said (at least one) main relay is actually activated (e.g., through a logic AND of the driving signals). In particular, some functions are executed only by one of the two processing and control units.

[0052] While the local voltage Vin_L is always present, and is also used to supply the apparatus 100 through the power supply 120, the energisation of said (at least one) main relay, i.e. the condition of Cot free from trains, and the de-energisation of said (at least one) main relay, i.e. the condition of Cot occupied by a train, depend on the presence or absence of the field voltage Vin_C and/or on the phase shift between the local voltage Vin_L and the field voltage Vin_C; in particular, said (at least one) main relay is energized in the condition where the local voltage Vin_L and the field voltage Vin_C have both amplitude and phase similar, while it is de-energized in the condition where the local voltage Vin_L and the field voltage Vin_C have at least one between amplitude and phase that is dissimilar.

[0053] In this regard, in the following of this description it is defined:

- as energisation time (of said - at least one - main relay) the time that elapses between the rise of the amplitude of the field voltage Vin_C over a certain threshold S1 and the closure of the normally open contact switches of the relay (or that elapses between the reduction of the phase shift between local voltage Vin_L and field voltage Vin_C below a certain threshold PO1 and the closure of the normally open contact switches of the relay);
- as de-energisation time (of said - at least one - main relay) the time that elapses between the fall of the amplitude of the field voltage Vin_C below a certain threshold S2 and the opening of the normally open contact switches of

the relay (or that elapses between the reduction of the phase shift between the local voltage Vin_L and the field voltage Vin_C below a certain threshold PO2 and the opening of the normally open contact switches of the relay); and

- as de-energisation ratio the ratio between the de-energisation voltage and the energisation voltage, that is a characteristic parameter of disc relays.

[0054] With reference to Figure 2, it can be observed that the functional architecture of the apparatus according to the invention comprises a processing section 1100, an input acquisition section 1120 and an input section 1140, the functions of which are executed by the input processing block 110. The function of the processing section 1100 is to process the information coming from the input acquisition section 1120 to generate the enabling signals to be sent to the controlling block 130. At the input, the processing section 1100 further receives the signals coming from the output terminals of said (at least one) service relay relating to the state of said (at least one) main relay of the contact group block 140 to check whether the latter is operating correctly or not. The input acquisition section 1120 performs the function of acquiring the signals from the input section 1140 and supplying them to the analog-digital (A/D) converters of the microprocessors of the input processing block 110 for their processing. The input section 1140 performs the function of an interface that receives the local voltage Vin_L and the field voltage Vin_C of the Cot and executes their hardware conditioning through low voltage conversion transformers which adapt them to the use inside (the electronic boards of) the apparatus 100.

[0055] The functional architecture of the apparatus according to the invention further includes an activation section 1300 the function of which is executed by the controlling block 130. In particular, the activation section 1300 performs the function of controlling the activation of said (at least one) main relay by providing the driving signals to the contact group block 140 on the basis of the enabling signals received at the input from the processing section 1100.

[0056] The functional architecture of the apparatus according to the invention still comprises a section 1400 of the contact group the function of which is executed by the contact group block 140. In particular, the contact group section 1400 performs the function of an interface that provides the terminals towards the railway system which are driven by the driving signals provided by the activation section 1300 in accordance with the processing outcome by the processing section 1100. Moreover, the contact group section 1400 also provides the processing section 1100 with the state of the driven terminals at the output.

[0057] Finally, the functional architecture of the apparatus according to the invention comprises a power supply section 1200, that performs the function, executed by the power supply 120, of receiving the local voltage Vin_L at the input and generating the supply voltages for all the blocks of the apparatus, and a user interface section 1160, that performs the function, executed by the input processing block 110, of supplying data and information to an operator and allowing the operator to interact with the apparatus 100 for configuration and maintenance purposes.

[0058] The input processing block 110 executes a preferred embodiment of the method for detecting the presence of a train on a track section according to the invention schematically shown in Figure 3, the starting step 300 of which is receiving the local voltage Vin_L and the field voltage Vin_C of the Cot for an integration interval T. In particular, the input processing block 110 is configured to measure the effective values (also known as RMS - Root Mean Square - values) of the local voltage Vin_L and field voltage Vin_C, to compare them with each other and at the same time to measure the phase shift between the two voltages Vin_L and Vin_C.

[0059] In general, the method according to the invention solves the problems of safe identification of both phase shift and amplitude from which the traditional approach suffers since it is based on the direct measurement of the RMS value and on the separate measurement of the phase shift based on a measurement of the time elapsing between two wave fronts of the two signals (i.e. of the voltages Vin_L and Vin_C) leading to problems of safe identification of both phase shift and amplitude.

[0060] Differently, the method according to the invention carries out the analysis of the phase shift between the two input voltages Vin_L and Vin_C, having a certain frequency, by searching for the maximum cross-correlation calculated in a time interval ranging from 2 periods to 10 periods of the local voltage Vin_L. In the preferred embodiment of the method according to the invention, the maximum cross-correlation is calculated every 80 milliseconds in the case of frequency f_L of the input local voltage Vin_L equal to 50 Hz (i.e., in a time interval equal to 4 periods of the local voltage Vin_L) or every 96 milliseconds in the case of frequency f_L of the input local voltage Vin_L equal to (substantially) 83.3 Hz (that is actually the frequency corresponding to a period of 12 milliseconds, so "3" after decimal point is a recurring decimal, whereby the maximum cross-correlation is calculated in a time interval equal to 8 periods of the local voltage Vin_L).

[0061] The phase value is calculated by examining the cross-correlation function, its derivative and carrying out the arctangent of their ratio. Once the phase shift is found, i.e. the phase difference, between the local voltage Vin_L and the field voltage Vin_C, it is possible to obtain the maximum cross-correlation between the two voltages by carrying out the ratio between the instant cross-correlation and the cosine of the phase difference just found. In the case where an operator has set a phase calibration value (phase shift correction), the analysis of the phase shift takes this factor into account.

[0062] Based on the calculated phase shift value and with respect to the operating specifications, the apparatus 100 does or does not control the energisation of said (at least one) main relay.

[0063] As known, the cross-correlation represents a measure of similarity of two signals. In greater detail, cross-correlation is not used to measure the phase shift or for point evaluations on the quantities under examination, but to statistically determine how similar a signal is to another one. In the method according to the invention, the field voltage Vin_C and the local voltage Vin_L are substantially the same signal measured upstream and downstream of the track circuit. When the correlation is applied to the replication of a signal, as in this case, it is called autocorrelation, that is, the correlation of a signal with itself. For this reason, the terms correlation, autocorrelation and cross-correlation in relation to the pair of voltages Vin_L and Vin_C will be used indifferently in the following description.

[0064] The autocorrelation has particular properties which are exploited by the method according to the invention to obtain both the phase shift between the voltages Vin_L and Vin_C, and the amount of distortion and/or noise present in the spectrum of the field voltage Vin_C. In particular, the main properties of the autocorrelation used by the method are the following:

- the autocorrelation function has the maximum at the origin;
- the autocorrelation of an entirely real signal, as in the application of the method according to the invention, has even symmetry.

[0065] In general, given two sinusoidal signals having the same frequency and a phase difference φ (as the local voltage Vin_L and the field voltage Vin_C):

$$a(t) = A\,sin(\omega t)$$

$$b(t) = B\,sin(\omega t + \varphi)$$

the correlation C(t) is defined as:

$$C(t) = \frac{1}{T}\int_0^T A\,sin(\omega\tau) * B\,sin(\omega(t+\tau)+\varphi)d\tau \qquad [1]$$

whereby, solving the integral, it is

$$C(t) = \frac{AB}{2}\cos(\omega t + \varphi) \qquad [2]$$

[0066] By calculating the correlation C(t) at the origin, it is:

$$C(0) = \frac{A}{\sqrt{2}}\frac{B}{\sqrt{2}}\,cos(\varphi) = A_{eff}\,B_{eff}\;cos(\varphi) \qquad [3]$$

[0067] As shown by formula [1], the value of the correlation *C*(*t*) calculated at the origin is maximum for zero phase shift (i.e., for $\varphi = 0$) and at that point it depends only on the effective value of the two sinusoidal signals:

$$C(0)|_{\varphi=0} = A_{eff}B_{eff} \qquad [4]$$

[0068] Formula [4] can be normalized by dividing it by the product of the effective values of the two sinusoidal signals to ensure that the maximum value is one. If a disturbing signal (e.g. harmonic distortions) is superimposed on the second sinusoidal signal *b*(*t*), the disturbed signal *bo(t)* is given by:

$$b_D(t) = B\,sin(\omega t + \varphi) + n(t) \qquad [5]$$

where the disturbing signal $n(t)$ can be still generically expressed as a series of sinusoidal functions, i.e. as follows:

$$n(t) = \sum_{k=2}^{N} N_k \sin(k\omega t + \varphi_k) \qquad [6]$$

[0069] Now, even in case of presence of a disturbing signal n(t), the cross-correlation is a sinusoidal function of the step of the type:

$$C(0) = K\cos(\varphi) \qquad [7]$$

where the factor K, besides depending on the effective value of the two undisturbed sinusoidal signals (as in formula [4]), also strongly depends on the degree of distortion introduced by the disturbing signal $n(t)$; in particolare, in particular, the factor K is proportional to the effective values of the local voltage Vin_L and field voltage Vin_C and it is inversely proportional to an effective value N_{eff} of the disturbing signal n(t) superimposed on the field voltage according to a relationship not known a priori.

[0070] In fact, by applying formula [1] to the local voltage Vin_L = VL (t) and to the field voltage Vin_C = VC (t), assuming that the two voltages are sinusoidal (or cosine):

The method according to the invention exploits these properties to calculate the phase difference φ of the field voltage Vin_C with respect to the local voltage Vin_L by calculating the arctangent function. In this way, on the basis of only the cross-correlation at the origin and calculating its derivative, it is possible to obtain the phase shift with the great advantage of not having any need to know the effective values of the local voltage Vin_L and the field voltage Vin_C.

[0071] In fact, by applying formula [1] to the local voltage Vin_L = VL (t) and to the field voltage Vin_C = *VC(t),* assuming that the two voltages are sinusoidal (or cosinusoidal):

$$VL(t) = Acos(\omega t) \qquad [8]$$

where

$$A = \sqrt{2} * VL_{eff}$$

and

$$VC(t) = Bcos(\omega t + \varphi) \qquad [9]$$

where

$$B = \sqrt{2} * VC_{eff}$$

it is

$$C(0) = 2 * VL_{eff} * VC_{eff} * cos(\varphi) \qquad [10]$$

[0072] The derivative of the cross-correlation at the origin is hence equal to:

$$C'(0) = \frac{dC(0)}{d\varphi} = -2 * VL_{eff} * VC_{eff} * sen(\varphi) \qquad [11]$$

[0073] The ratio between the derivative C'(0) and the primitive C(0) calculated at the origin is equal to:

$$\frac{C'(0)}{C(0)} = -\frac{sen(\varphi)}{\cos(\varphi)} = -tg(\varphi) \qquad [12]$$

whereby, when the values of the cross-correlation C(0) and its derivative *C'*(0) at the origin are known, the phase difference φ of the field voltage Vin_C with respect to the local voltage Vin_L is equal to:

$$\varphi = -arctg\left(\frac{C'(0)}{C(0)}\right) \qquad [13]$$

[0074] In other words, the method according to the invention uses the arctangent formula [13] to determine the phase shift φ of the field voltage Vin_C with respect to the local voltage Vin_L, without any need to separately measure the effective value VL_{eff} of the local voltage Vin_L and the effective value VC_{eff} of the field voltage Vin_C.

[0075] It should be noted that, although for phase shifts φ close to or equal to 90° the value of the tangent would tend to infinity, making the data unmanageable, nevertheless for the purposes of the method according to the invention this is irrelevant. In fact, the resolution required is such that for values of the tangent greater than 100 (a value of 57 already corresponds to a phase shift equal to 89°) the phase is automatically assumed equal to 90°.

[0076] What has been illustrated is valid in the absence of disturbance. In the presence of a disturbance signal *N(t)* superimposed on the field voltage Vin_C, whereby the field voltage Vin_C is equal to the sum of the pure sinusoidal signal *VC(t)* and the disturbance *N(t):*

$$\text{Vin\_C} = VC(t) + N(t)$$

the cross-correlation is equal to:

$$C(\tau) = \frac{1}{T}\int_0^T VL(t) * VC(t+\tau)dt + \frac{1}{T}\int_0^T VL(t) * N(t)dt \qquad [14]$$

[0077] The disturbance signal *N(t)* can be decomposed into a sum of one or more disturbing sinusoids, so that the product

$$\mathrm{VL(t)} * N(t) \qquad [15]$$

argument of the second integral of formula [14] is a sum of (one or more) products of sinusoidal functions of the type

$$cos\beta * cos\alpha \qquad [16]$$

that, as known from Werner's formulas, is equal to:

$$cos\beta * cos\alpha = \frac{1}{2}\ [(\cos(\beta + \alpha) + (\cos(\beta - \alpha)] \qquad [17]$$

[0078] In other words, the presence of a disturbance (i.e. noise) signal *N(t)* causes two new sinusoidal contributions to appear for each disturbing sinusoid into which the same disturbance signal *N(t)* can be decomposed: a first contribution at a sum frequency and a second contribution at a difference frequency (beat) with respect to the frequencies of the source signals, namely the frequency f_L of the local voltage Vin_L and the frequency of (the sinusoid of) disturbance.

[0079] Consequently, the presence of noise becomes a problem if (the disturbing sinusoid under consideration of) this produces a non-zero contribution in the integration interval T of the cross-correlation that, in the method according to the invention, is equal to a period of the local voltage Vin_L or a multiple thereof. This implies, considering the sinusoidal contributions (given by formula [17]) originating from the presence of noise, that all the integer periods of these sinusoidal contributions included in the integration interval T give a zero contribution, since the positive and negative half-waves cancel each other out reciprocally; differently, all the non-integer sub-multiples of period of such sinusoidal contributions give a non-zero contribution, in different proportions depending on the integration interval T and the amount of the residual time of the period of such sinusoidal contributions with respect to the integration interval T. Obviously, the longer the integration interval T, the less weight the non-zero contributions have.

[0080] For instance, if the first sinusoid (e.g. the disturbing sinusoid) has a frequency of 125 Hz and the second sinusoid (e.g. the local voltage Vin_L) has a frequency of 50 Hz, there is a sum contribution at 175 Hz that in an integration interval T of 20 milliseconds gives rise to 3,5 oscillations. The three complete oscillations give a zero contribution, while the residual 0,5 can give a maximum contribution only if it does not change its sign in the observation interval: in this worst case only 0,5/3,5, i.e. only 14 %, gives a contribution. Under the same assumptions, if the integration interval T is extended up to 80 milliseconds, there will be 14 oscillations and none give contribution.

[0081] Differently, if the first sinusoid (e.g. the disturbing sinusoid) has a frequency of 120 Hz and the second sinusoid (e.g. the local voltage Vin_L) has a frequency of 50 Hz, there is a sum contribution at 170 Hz that in an integration interval T of 20 milliseconds gives rise to 3,4 oscillations. The three complete oscillations give a zero contribution, while the residual 0,4 can give a maximum contribution only if it does not change its sign in the observation interval: in this worst case only 0,4/3,4, i.e. only 12 %, gives contribution. Under the same assumptions, if the integration interval T is extended up to 80 milliseconds, there will be 13,4 oscillations 13 of which give no contribution while the residual 0,4 can give a maximum contribution only if it does not change its sign in the observation interval: in this worst case only 0,4/13,4, i.e. only 3%, gives contribution.

[0082] Thus, in general, the sum contribution gives a marginal contribution in terms of disturbance. Conversely, the difference contribution can give rise to an important noise contribution. In particular, the difference contribution is not a problem as long as the frequencies of the (at least one) disturbing sinusoid and the local voltage Vin_L are sufficiently distant and provided that the integration interval T is long. In the two previous examples, the difference contribution is 75 Hz and 70 Hz, respectively:

- the difference contribution at 75 Hz in an integration interval T of 20 milliseconds gives rise to 1,5 oscillations, whereby there is a maximum contribution of 33% (0,5/1,5) in the integration interval T; in an integration interval T of 80 milliseconds this contribution difference at 75 Hz gives rise to 6 oscillations and zero contribution;
- the difference contribution at 70 Hz in an integration interval T of 20 milliseconds gives rise to 1,4 oscillations, whereby there is a maximum contribution of 28,5% (0,4/1,4) in the integration interval T; in an integration interval T of 80 milliseconds this difference contribution at 70 Hz gives rise to 5,6 oscillations and a maximum contribution of only 7% (0,4/5,6) in the integration interval T.

[0083] The difference contribution, even with a long integration interval T, can become extremely important if the frequencies of the (at least one) disturbing sinusoid and the local voltage Vin_L are very close. By way of example, if the local voltage Vin_L has a frequency f_L of 50 Hz and the disturbing sinusoid has a frequency of 50,5 Hz, the difference contribution is a wave at a frequency of 0,5 Hz. Even with integration interval T equal to 1 second, there is the risk of having a contribution that always remains of the same sign and that, hence, gives a contribution of 100%.

[0084] In general, the closer the frequency of the disturbance is to the frequency of the signal that is disturbed, the more the amplitude of the disturbance itself affects the amplitude of the resulting signal (sum of the disturbance and the signal that is disturbed) and the less the contribution of the disturbance is distinguishable from that of the "true" signal (i.e. the signal on which the disturbance is superimposed). This contribution causes the cross-correlation (given by formula [14]) to vary, decreasing it if the disturbance is in counterphase, increasing it if it is in phase. It is observed that the extent of this variation will depend, almost linearly, on the relationship between disturbance and field voltage Vin_C.

[0085] The method according to the invention selects the integration interval T on the basis of a parameter that is called in this description "critical band". As mentioned in the previous examples, noises with frequencies close to that of the signal to be measured contribute to a greater extent to interfere and consequently to confuse the measurement apparatus. Since the apparatus according to the invention is configured to operate for local voltages Vin_L having different frequencies selectable in an allowed band, the inventors have implemented the apparatus according to the invention avoiding the use of hardware filters; by way of example, and not by way of limitation, in the case where the apparatus according to the invention is configured to operate with a local voltage Vin_L having a frequency f_L up to (substantially) 83,3 Hz, any filter that selects only the frequency of 50 Hz would not allow the measurement of any legitimate signals (i.e. signals not disturbed by an external disturbance signal). Considering the non-idealities of the Cot, it is very likely that the waveform of the signals is very different from a sinusoid, whereby a hardware filtering would attenuate the signals which, although disturbed by the mere fact of running along the Cot, are actually legitimate, that is not disturbed by an external disturbance signal (and this is another disadvantage of the prior art solutions).

[0086] The critical band for the preferred embodiment of the method according to the invention is determined as follows. The integration interval T (that is the observation period) corresponds to an observation frequency f_c (equal to 1/T and that represents the number of cross-correlations that can be calculated in the unit of time), and the frequencies of the disturbances which give zero contribution in terms of noise to the measured signal are those outside the critical band the lower limit of which is equal to the difference between the frequency f_L of the local voltage Vin_L and the observation frequency f_c and the upper limit of which is equal to the sum of the frequency f_L of the local voltage Vin_L and the observation frequency f_c. Differently, the critical frequencies of the disturbances are those which belong to such critical band, in which

$$f_L - f_c \le f \le f_L + f_c \qquad [18]$$

[0087] For instance, operating on a local voltage Vin_L having a frequency f_L equal to 50 Hz and choosing an integration interval T of 80 milliseconds, i.e. an observation frequency f_c of 12,5 Hz, the critical frequencies will be included in the critical band 50 ± 12,5 Hz, i.e. between 37,5 Hz and 62,5 Hz. Outside this interval, upon the same integration interval T, the other frequencies will give less and less significant contributions in percentage terms.

[0088] Similarly, in the case where the local voltage Vin_L has a frequency f_L (substantially) equal to 83,3 Hz (that is actually the frequency corresponding to a period of 12 milliseconds, whereby "3" after the decimal point is a recurring decimal) and choosing an integration interval T of 96 milliseconds, i.e. an observation frequency f_c of 10,4 Hz, the critical frequencies will be included in the critical band 8,3 ± 10,4 Hz, i.e. between 72,9 Hz and 93,7 Hz.

[0089] In this regard, the more the integration interval T widens, the more the critical band around the frequency f_L of the signal to be detected (i.e. the field voltage Vin_C) narrows. All disturbances having a frequency that is distant from the frequency f_L of the signal to be detected by a multiple of the observation frequency f_c give rise to zero contributions in terms of noise; disturbances having a frequency outside the critical band (i.e., for which the frequency $f < f_L - f_c$ or for which the frequency $f > f_L + f_c$), give rise to insignificant and decreasing contributions as the distance from the critical band increases.

[0090] However, the method according to the invention takes account of the fact that it is not possible to indefinitely increase the integration interval T, to reduce the critical band down to zero, since this is in contrast with the constraint of the so-called de-energisation time.

[0091] In fact, the railway application requires that within a maximum interval of electromechanical de-energisation, that according to the current regulations valid in Italy is equal to 400 milliseconds, from the moment at which a railway vehicle or train occupies the track section belonging to the Cot said (at least one) main relay of the contact group block 140 is de-energised. The maximum electromechanical de-energisation interval is given by the sum of a mechanical intervention time of said (at least one) main relay of the contact group block 140 and an electronic intervention time of the apparatus 100 according to the invention, wherein such electronic intervention time is equal to the time necessary for the apparatus 100 according to the invention to measure, process and decide the possible de-energisation of said (at least one) main relay. Since the mechanical intervention time is equal to about 150 milliseconds, the electronic intervention time is equal to about 250 milliseconds. Also, since the arrival of a train is random with respect to the processing process executed by the apparatus 100 according to the invention, the first integration interval T coinciding with the arrival of the train on the Cot will on average contain samples with the signal (i.e. the field voltage Vin_C) that is maximum before the arrival of the train, and samples with signal that is attenuated after the arrival of the train; thus, this first integration interval T could not be significant in the calculation of the cross-correlation and it is certainly to be discarded for the calculation of the effective value VC_{eff} of the field voltage Vin_C. Consequently, the method according to the invention takes account of the fact that it may be necessary to consider two entire integration intervals T in the electronic intervention time to allow the apparatus 100 a correct detection of the presence of a train on the track section belonging to the Cot.

[0092] By way of example, in the case of the preferred embodiment of the method according to the invention, on the basis of the considerations on the critical band and on the maximum electromechanical de-energisation interval, as already mentioned, the integration interval T to obtain the cross-correlation is equal to the period corresponding to the frequency f_L of the local voltage Vin_L multiplied by a coefficient J ≥ 1, wherein if J > 1 the cross-correlation is averaged over J periods of the local voltage Vin_L. Namely, in the case of the preferred embodiment of the method according to the invention, the maximum cross-correlation (according to formula [14] calculated at the origin) is calculated every 80 milliseconds in the case of frequency f_L of the input local voltage Vin_L equal to 50 Hz (i.e., in a time interval equal to J = 4 periods of the local voltage Vin_L) or every 96 milliseconds in the case of frequency f_L of the input local voltage Vin_L (substantially) equal to 83,3 Hz (i.e. , in a time interval equal to J = 8 periods of the local voltage Vin_L). With these choices, the theoretical electromechanical intervention margin is reduced, compared to the maximum electromechanical de-energisation interval of 400 milliseconds established by the current regulations valid in Italy, down to 90 milliseconds (equal to 400-150-80-80) in the case of frequency f_L of the local voltage Vin_L equal to 50 Hz, and 58 milliseconds (equal to 400-150-96-96) in the case of frequency f_L of the local voltage Vin_L (substantially) equal to 83,3 Hz.

[0093] It should be noted that other embodiments of the method according to the invention can determine the maximum cross-correlation in an integration interval T equal to the period corresponding to the frequency f_L of the local voltage Vin_L multiplied by any coefficient J (with J ≥ 1), still remaining within the scope of protection of the present invention.

[0094] In the preferred embodiment of the apparatus according to the invention, that is configured to operate with frequencies f_L of the local voltage Vin_L selected between 50 Hz and (substantially) 83,3 Hz, it is possible to use hardware filtering outside the critical band for the frequency f_L (substantially) equal to 83.3Hz which cuts off the highest frequencies without affecting the operation of the apparatus according to the invention.

[0095] As stated above, disturbances at frequencies close to the frequency f_L of the local voltage Vin_L are the critical ones because, if they are in phase with the local voltage Vin_L, they can lead to an over-evaluation of the correlation and this is particularly influential for the determination of the effective value of the field voltage Vin_C. The extent of this over-evaluation depends a lot on the relationship between disturbance and field voltage Vin_C, that in turn depends on the disturbance current.

[0096] After the starting step (300) of receiving the local voltage Vin_L and the field voltage Vin_C of the Cot for an integration interval T, the method according to the invention (in step 320) calculates the cross-correlation at the origin $C_{mis}(0)$ of the local voltage Vin_L and the field voltage Vin_C received (i.e. measured), by means of formula [14], and its derivative at the origin $C'_{mis}(0)$.

[0097] At the end of the integration interval T, on the basis of the calculated values of the cross-correlation $C_{mis}(0)$ and its derivative $C'_{mis}(0)$, the input processing block 110 calculates (in step 330) the value of the phase shift φ of the field voltage Vin_C with respect to the local voltage Vin_L according to formula [13]:

$$\varphi = -arctg\left(\frac{C'_{mis}(0)}{C_{mis}(0)}\right) \qquad [19]$$

[0098] As stated, in the case where a phase calibration value (phase shift correction) has been set by an operator, the value of the phase shift φ of the voltage obtained through [19] is corrected by such phase calibration value, whereby in the following method steps the phase shift φ thus corrected is taken into account.

[0099] Subsequently, the method according to the invention compares (in step 335) the value of the phase shift φ of the field voltage Vin_C (possibly corrected by the phase calibration value) with a predetermined maximum phase shift threshold R: when the phase shift value φ of the field voltage Vin_C exceeds the predetermined maximum phase shift threshold R, the method according to the invention de-energises said (at least one) main relay (in step 390) to signal the presence of a train occupying the Cot.

[0100] Optionally, the method according to the invention introduces (more optionally programmable) phase shift thresholds for energisation/de-energisation, so as to introduce a hysteresis with respect to the intervention thresholds in relation to the measured phase shift values of the field voltage Vin_C with respect to the local voltage Vin_L. In other words, when the method is executed in a current integration interval T after that the presence of a train has been signaled in a preceding integration interval T because the phase shift value φ of the field voltage Vin_C (possibly corrected by the phase calibration value) exceeded the predetermined maximum phase shift threshold R and such signaling is still in progress, the method terminates to signal the presence of a train in step 390 executed for the current integration interval T only if the phase shift value φ of the field voltage Vin_C (possibly corrected by the phase calibration value) is lower than a predetermined minimum phase shift threshold H not greater than the predetermined maximum phase shift threshold R, wherein the predetermined minimum phase shift threshold H is optionally lower than the predetermined maximum phase shift threshold R, whereby step 390 executed for the current integration interval T introduces a signaling phase shift hysteresis.

[0101] The preferred embodiment of the method according to the invention also exploits the PSK type phase modulation, according to a predetermined pattern, of the local voltage Vin_L having a frequency f_L (substantially) equal to 83,3 Hz to recognise the presence of disturbing signals at a frequency close to the frequency f_L of the local voltage Vin_L. In particular, if the value of the phase shift φ of the field voltage Vin_C does not exceed the predetermined maximum phase shift threshold R, when the method detects the presence of repeated and/or anomalous phase jumps in the field voltage Vin_C with respect to those corresponding to phase changes dictated by the predetermined pattern of the local voltage Vin_L, then the presence of a disturbance is recognized. In fact, these repeated and/or anomalous phase jumps are maximum in presence of the disturbance alone, they are absent if the field voltage Vin_C is present and the disturbance is either absent or at a frequency far from the frequency f_L of (substantially) 83,3 Hz, while there is an intermediate situation when the disturbances are at a frequency close to the frequency f_L of (substantially) 83,3 Hz: in this case the extent of the jump is basically determined by the relationship between disturbance and field voltage Vin_C. In this regard, a predetermined pattern is a sequence of phase values in a corresponding sequence of periods of the local voltage Vin_L; by way of example, and not by way of limitation, a BPSK modulation can have as predetermined pattern a sequence of 52 periods comprising a first series of 7 periods with phase modulation "1", a second series of 7 periods with phase modulation "0", a third series of 23 periods with phase modulation "1" and a fourth series of 15 periods with phase modulation "0".

[0102] In the preferred embodiment of the method according to the invention, at each integration interval T, the phase shift φ of the field voltage Vin_C (possibly corrected by the phase calibration value) is calculated (in step 330) and possible phase jumps and their extent from one integration interval to the next one are monitored by updating a phase jump counter according to the extent of the possible phase jump: when the counter reaches or exceeds an (adjustable) maximum counting threshold, the method according to the invention interprets this as presence of a significant disturbance and executes a step 390 of signaling occupation of the Cot wherein it determines the de-energisation of said (at least one) main relay of the contact group block 140.

[0103] In the case of PSK type phase modulation, the phase jumps of the field voltage Vin_C are determined in comparison with the expected phase jumps of the local voltage Vin_L according to the predetermined pattern, namely through calculation of the phase shift φ of the field voltage Vin_C in step 330. It should be noted that this determination of the phase jumps is also applicable to the case where the local voltage Vin_L has no phase modulation, whereby the phase jumps of the field voltage Vin_C are determined in comparison with the phase of the field voltage Vin_C in the preceding integration interval T (again through calculation of the phase shift φ of the field voltage Vin_C in step 330).

[0104] By way of example, in the case where the local voltage Vin_L has no phase modulation, in the current integration interval T the method calculates in step 330 the phase shift φ of the field voltage Vin_C with respect to the local voltage Vin_L and, if it detects a phase variation (i.e. a phase shift φ) with respect to the measured phase (i.e. to the calculated phase shift φ) in the preceding integration interval T greater than an (adjustable) tolerance threshold of phase jumps (e.g. equal to 10°), it increases the phase jump counter proportionally to the magnitude of the phase variation, while if the phase variation (i.e. the phase shift φ) does not exceed the tolerance threshold of phase shift with respect to the phase (i.e. the phase shift φ) in the preceding integration interval T, the phase jump counter is decreased (optionally proportionally to the number of consecutive integration intervals T in which no phase variation greater than the tolerance threshold of phase jumps has been detected). For instance, the phase jump counter is increased by Q units if the phase jump PJ from the preceding integration interval T to the current integration interval T is greater than Q·10° and not greater than (Q+1)·10°, that is if

$$Q \cdot 10° < PJ \leq (Q+1) \cdot 10°$$

[0105] As stated, when the counter reaches or exceeds an (adjustable) maximum counting threshold, the method according to the invention interprets this as a detection of presence of a significant disturbance and executes step 390 of signaling the occupation of the Cot wherein it determines the de-energisation of said (at least one) main relay of the contact group block 140. In other words, the method according to the invention recognises that the more the disturbance is important, the more it causes important phase rotations.

[0106] What has just been illustrated with reference to the detection of presence of repeated and/or anomalous phase jumps in the field voltage Vin_C with respect to (those in correspondence with the phase changes dictated by the predetermined pattern of) the local voltage Vin_L is also immediately applicable to a detection of presence of repeated and/or anomalous amplitude jumps in the field voltage Vin_C with respect to the local voltage Vin_L.

[0107] In general, as shown in Figure 3 with reference to step 310, for any value of the frequency f_L of the local voltage Vin_L, in particular at both 50 Hz and (substantially) 83,3 Hz, the presence of repeated and/or anomalous phase and/or amplitude jumps in the field voltage Vin_C, even if included within the limits allowed by the specifications of the signals used in the railway system (e.g. when the value of the phase shift φ of the field voltage Vin_C does not exceed the predetermined maximum phase shift threshold R), is interpreted by the method according to the invention as presence of a significant phase and/or amplitude disturbance, whereby a step 390 of signaling the occupation of the Cot is then executed wherein the method according to the invention determines the de-energisation of said (at least one) main relay of the contact group block 140. In other words, when the method detects that the field voltage Vin_C has one or more phase and/or amplitude jumps (in one or more integration intervals T including the current integration interval T and possibly one or more consecutive integration intervals T preceding the current integration interval T, i.e. in the current integration interval T and/or in one or more consecutive integration intervals T preceding the current integration interval T) which do not correspond to similar phase and/or amplitude jumps of the local voltage Vin_L, it executes a step 390 of signaling the occupation of the Cot wherein the method according to the invention determines the de-energisation of said (at least one) main relay of the contact group block 140.

[0108] It should be noted that the possible de-energisation of said (at least one) main relay of the contact group block 140 on the basis of the detection of the presence of a significant phase and/or amplitude disturbance superimposed on the field voltage Vin_C, i.e. of a disturbance that causes the presence of repeated and/or anomalous phase and/or amplitude jumps, is not an essential feature for the invention.

[0109] If the method according to the invention does not detect any significant disturbance, then (in step 340) it calculates the product of the effective values of the received (i.e. measured) local voltage Vin_L and field voltage Vin_C using the following formula:

$$VL_{eff\_mis} * VC_{eff\_mis} = \frac{1}{T}\sqrt{\int_0^T [VL(t)]^2\,dt * \int_0^T [VC\ (t) + N(t)]^2\,dt} \qquad [20]$$

[0110] Subsequently, the preferred embodiment of the method according to the invention executes (in step 350) the normalization of the cross-correlation $C_{mis}(0)$ at the origin, dividing it by the product of the effective values of the measured signals, given by formula [20], obtaining the normalized cross-correlation $C_{mis\_norm}[0]$ at the origin:

$$C_{mis\_norm}(0) = {C_{mis}(0)}\Big/{VL_{eff\_mis} * VC_{eff\_mis}} \qquad [21]$$

[0111] Optionally, where necessary for specific implementations of the method according to the invention (e.g., when the product of the effective values of the measured signals is calculated according to formula [20] before the value of the phase shift φ of the field voltage Vin_C with respect to the local voltage Vin_L according to formula [19], whereby this value of the phase shift φ can be calculated as the ratio between the normalized cross-correlation $C_{mis\_norm}(0)$ given by formula [21] and its normalized derivative with respect to the product of the effective values of the measured signals), in step 350 the normalization of the derivative $C'_{mis}(0)$ of the cross-correlation at the origin can also be executed, again dividing it by the product of the effective values of the measured signals, given by formula [20], obtaining the normalized derivative $C'_{mis\_norm}(0)$ of the cross-correlation at the origin:

$$C'_{mis\_norm}(0) = {C'_{mis}(0)}\Big/{VL_{eff\_mis} * VC_{eff\_mis}}$$

[0112] The method according to the invention controls said (at least one) main relay on the basis of the effective values of the local voltage Vin_L and field voltage Vin_C. However, the measured value of the field voltage Vin_C is affected by noise.

[0113] The method according to the invention again isolates such noise through the correlation, that assumes a maximum value at the origin for a phase shift equal to zero (e.g., see formulas [3] and [4]). Consequently, the normalized correlation $C_{mis\_norm}(0)$ of the voltages measured at the origin is equal to

$$C_{mis\_norm}(0) = C_{max} cos\varphi \qquad [22]$$

where C_{max} is the maximum of the correlation normalized to the product of the effective values of the measured signals, that, as stated for [7], is proportional to the effective values of the two voltages and is inversely proportional to possible disturbances on the field voltage Vin_C according to a relationship not known a priori.

[0114] Known the normalized correlation $C_{mis\_norm}(0)$ of the voltages measured at the origin, given by formula [21], and the phase shift φ, given by formula [19], the method according to the invention calculates (in step 360) the maximum value C_{max} of the correlation normalized to the product of the effective values of the measured signals through the following formula

$$C_{max} = \frac{C_{mis\_norm}(0)}{cos\varphi} \qquad [23]$$

[0115] As previously stated, the term C_{max} contains the VL_{eff} and the VC_{eff} on which in general a disturbance N_{eff} is superimposed, i.e., in general, the effective value $VC_{eff\ mis}$ of the field voltage Vin_C affected by noise (i.e. the measured one) is equal to:

$$VC_{eff\_mis} = VC_{eff} + N_{eff} \qquad [24]$$

[0116] In particular, the effective value VC_{eff_mis} of the field voltage Vin_C affected by noise is calculated by the method according to the invention (step 345, that could also coincides with step 340) using the formula:

$$VC_{eff\_mis} = \sqrt{\frac{1}{T}\int_{0}^{T}[VC_{mis}(t)]^2\,dt} \qquad [25]$$

where $VC_{mis}(t)$ is the measured field voltage Vin_C that is affected by noise.

[0117] Now, the presence of the disturbance reduces the term C_{max} and thus makes the measured correlation underestimated, i.e. it makes the local voltage Vin_L and the field voltage Vin_C less similar to each other. Instead, in case of absence of disturbances, the maximum value of the correlation normalised to the product of the effective values of the measured signals is equal to 1. In other words, since the effective value of the field voltage Vin_C increases with the noise and the measured correlation reduces proportionally to the amount of disturbance superimposed on the field voltage Vin_C, the inventors have surprisingly ascertained (from results of experimental tests) that it is possible to reliably assume that the value in presence of disturbances of the product C_{max} * VC_{eff_mis} is equal to the value in absence of disturbances that, considering that the maximum value of the correlation normalised to the product of the effective values of the measured signals is equal to 1, is equal to the effective value VC_{eff} of the noise-free field voltage Vin_C, thereby

$$C_{max} * VC_{eff\_mis} = 1 * VC_{eff} \qquad [26]$$

[0118] Therefore, the method according to the invention calculates (in step 370) the effective value VC_{eff} of the field voltage Vin_C cleared of the noise component as the product of the effective value VC_{eff_mis} of the measured field voltage Vin_C affected by noise (given by formula [25]) by the maximum value C_{max} of the correlation normalised to the product of the effective values of the measured signals, given by formula [23].

[0119] Differently, the effective value VL_{eff} of the local voltage Vin_L is substantially equal to the effective value VL_{eff_mis} of the measured local voltage Vin_L since the local voltage Vin_L is generally not affected by noise. In particular, the effective value VL_{eff_mis} of the measured local voltage Vin_L is calculated by the method according to the invention (in step 345, that could also coincide with step 340) through the following formula:

$$VL_{eff} = VL_{eff\_mis} = \frac{1}{T}\sqrt{\int_{0}^{T}[VL(t)]^2\,dt} \qquad [27]$$

[0120] Subsequently, the method according to the invention compares (in step 380) the effective value VC_{eff} of the field voltage Vin_C cleared of the noise component with the effective value VL_{eff_mis} of the local voltage Vin_L: when the effective value VC_{eff} of the field voltage Vin_C cleared of the noise component differs from the effective value VL_{eff_mis} of the local voltage Vin_L measured over a predetermined maximum effective value difference threshold S, the method according to the invention de-energises said (at least one) main relay (in step 390) to signal the presence of a train occupying the Cot.

[0121] In the case where the effective value VC_{eff} of the field voltage Vin_C cleared of the noise component does not differ from the effective value VL_{eff_mis} of the local voltage Vin_L measured over the predetermined maximum effective value difference threshold S or after the signaling step (390) in which said (at least one) main relay is de-energised, the method according to the invention returns to execute the initial step 300 for the subsequent integration interval T.

[0122] Optionally, when the method is executed in a current integration interval T after the presence of a train has been signaled in a preceding integration interval T because the difference of such effective values has exceeded the predetermined maximum effective value difference threshold S and such signaling is still in progress, the method terminates to signal the presence of a train in step 390 executed for the current integration interval T only if the difference of such effective values is lower than a predetermined minimum effective value difference threshold G not greater than the predetermined maximum effective value difference threshold S, wherein the predetermined minimum effective value difference threshold G is optionally lower than the predetermined maximum effective value difference threshold S, whereby step J executed for the current integration interval T introduces a signaling effective value difference hysteresis.

[0123] Some embodiments of the apparatus 100 according to the invention can work with analog signals, i.e. signals continuous over time.

[0124] The preferred embodiment of the apparatus 100 according to the invention works with signals in discrete time which are subjected to a digital signal processing, whereby the analog signals (namely the local voltage Vin_L and the field voltage Vin_C) are sampled and discretised. Consequently, the formulas illustrated above, which are valid for signals continuous over time, remain valid as long as the integrals are replaced with summations. As known, discretisation necessarily entails an approximation depending on the number of samples acquired and sampling frequency f_s in relation to the frequencies of the signals to be sampled. For instance, at a sampling frequency f_s of 10 kHz:

- for a local voltage Vin_L having a frequency f_L equal to 50 Hz and a period of 20 milliseconds, 200 samples are acquired which cause the phase resolution to be 360°/200 = 1.8°, whereby the theoretical error is consequently equal to ± 0.9°;
- for a local voltage Vin_L having a frequency f_L (substantially) equal to 83,3 Hz and a period of 12 milliseconds, 120 samples are acquired which cause the phase resolution to be 360°/120 = 3 °, whereby the theoretical error is consequently equal to ± 1.5°.

[0125] The entity of the two errors is compatible with the application for the detection of presence of a train on a track section, also because the actual error is much smaller since the integration interval T is extended up to 80 milliseconds in case of frequency f_L equal to 50 Hz and 96 milliseconds in case of frequency f_L (substantially) equal to 83,3 Hz, as it will be illustrated in detail later. In any case, it should be noted that other embodiments of the method according to the invention used for applications in which the energisation time and the de-energisation time (of said - at least one - main relay) are different, it is also possible to further minimise such errors by extending the integration interval T and/or by increasing the sampling frequency f_s.

[0126] Also, the preferred embodiment of the method according to the invention introduces wide thresholds of voltage amplitude (i.e. wide thresholds of the difference between the amplitudes of the local voltage Vin_L and field voltage Vin_C) which are programmable for energisation/de-energisation, so as to introduce a hysteresis with respect to the intervention thresholds in relation to the measured amplitude values of the effective values of the two voltages (namely, the local voltage Vin_L and the field voltage Vin_C), which further reduce the entity of the theoretical error.

[0127] Although the preferred embodiment of the method according to the invention uses a sampling frequency f_s equal to 10 kHz and specific values of the integration interval T (namely 80 milliseconds in case of frequency f_L equal to 50 Hz and 96 milliseconds in case of frequency f_L substantially equal to 83.3 Hz), it should be noted that other embodiments of the method according to the invention can use other sampling frequencies f_s and/or other values of the integration interval T, still remaining within the scope of protection of the present invention.

[0128] Hence, in the preferred embodiment of the method according to the invention, the input processing block 110 receives (step 300 of Figure 3), or acquires by sampling the corresponding analog signals, a number N of samples of the local voltage Vin_L in discrete time:

$VL[i]$, per i = 0,1,..., N-1

and of the field voltage Vin_C in discrete time

$VC[i]$, per i = 0, 1,..., N-1

at the sampling frequency f_s of 10 kHz (i.e., 10.000 samples per second) in the integration interval T (in particular: in the case where the integration interval T is equal to 80 milliseconds, N = 800; in the case where the integration interval T is equal to 96 milliseconds, N = 960). Optionally, the input processing block 110 stores these data in a memory buffer, having a length of N elements, more optionally managed in a circular manner so that, once full, data are processed and the buffer can be filled again with other N samples of the local voltage and other N samples of the field voltage.

[0129] The input processing block 110 executes step 310 (that is not essential for the invention) to check whether there are repeated and/or anomalous phase and/or amplitude jumps in the field voltage Vin_C: in the first case, step (390) of signaling the occupation of the Cot is executed, in the second case step (320) of calculating the cross-correlation and its derivative at the origin is executed.

[0130] In particular, the cross-correlation of the local voltage Vin_L and field voltage Vin_C and its derivative are calculated at the origin using the following formulas for discrete time signals:

$$C_{LC}[0] = \sum_{m=0}^{N-1} (VL[m] * VC[m]) \qquad [28]$$

and

$$C'_{LC}[0] = \sum_{m=1}^{N-2} (VL[m] * VC[m-1] - VL[m] * VC[m+1]) \qquad [29]$$

where N is the number of samples.

[0131] In other words, at each acquisition of N samples of the local voltage Vin_L and of the field voltage Vin_C, the input processing block 110 calculates the cross-correlation thereof and its derivative at the origin.

[0132] At the end of the integration interval T, on the basis of the calculated values of the cross-correlation and its derivative, the input processing block 110 calculates (step 330 of Figure 3) the value of the phase shift φ of the field voltage Vin_C with respect to local voltage Vin_L according to the following formula:

$$\varphi = -arctg\left(\frac{C'_{LC}[0]}{C_{LC}[0]}\right) \qquad [30]$$

[0133] As stated, in the case where a phase calibration value (phase shift correction) has been set by an operator, the value of the phase shift φ of the voltage obtained through [30] is corrected by such phase calibration value, whereby in subsequent steps of the method, the phase shift φ thus corrected is taken into account.

[0134] The input processing block 110 then calculates (step 340 of Figure 3) the product of the effective values of the measured signals through the following formula:

$$\sqrt{\sum_{n=0}^{N-1} (VL[n])^2 \sum_{n=0}^{N-1} (VC[n])^2} \qquad [31]$$

[0135] Subsequently, the input processing block 110 executes (step 350 of Figure 3) the normalisation of the cross-correlation calculated at the origin, given by formula [28], dividing it by the product of the effective values of the measured signals, given by formula [31], obtaining the normalised cross-correlation $C_{LC\_norm}[0]$:

$$C_{LC\_norm}[0] = C_{LC}[0] \Big/ \sqrt{\sum_{n=0}^{N-1} (VL[n])^2 \sum_{n=0}^{N-1} (VC[n])^2} \qquad [32]$$

[0136] As stated, optionally, where necessary for specific implementations of the method according to the invention (e.g., when the product of the effective values of the measured signals is calculated according to formula [31] before the value of the phase shift φ of the field voltage Vin_C with respect to the voltage local Vin_L according to formula [30], whereby such value of the phase shift φ can be calculated as the ratio between the normalised cross-correlation

$C_{LC\_norm}[0]$ given by formula [32] and its normalised derivative with respect to the product of the effective values of the measured signals), in step 350 the normalisation of the derivative $C'_{LC}[0]$ of the cross-correlation at the origin, given by formula [29], can also be executed, again dividing it by the product of the effective values of the measured signals, given by formula [31], obtaining the normalised derivative $C'_{LC\_norm}[0]$ of the cross-correlation at the origin:

$$C'_{LC\_norm}[0] = {C'_{LC}[0]}\Big/\sqrt{\sum_{n=0}^{N-1}(VL[n])^2 \sum_{n=0}^{N-1}(VC[n])^2}$$

[0137] The input processing block 110 generates the output signals for enabling driving of said (at least one) main relay (which cause the controlling block 130 to generate the driving signals for controlling the contact switches of said - at least one - relay of the contact group block 140) on the basis of the effective values of the local voltage Vin_L and field voltage Vin_C. However, as stated, the measured value of the field voltage Vin_C is affected by noise.

[0138] As mentioned, the method according to the invention isolates such noise again through the correlation, that assumes a maximum value at the origin for a phase shift equal to zero (e.g., see formulas [3] and [4]). Consequently, the normalised correlation $C_{LC\_norm}[0]$ of the voltages measured at the origin is equal to

$$C_{LC\_norm}[0] = C_{max} cos\varphi \qquad [33]$$

where C_{max} is the maximum of the correlation normalised to the product of the effective values of the measured signals, that, as stated for [7], is proportional to the effective values of the two voltages and is inversely proportional to possible disturbances on the field voltage Vin_C according to a relationship not known a priori.

[0139] Known the normalised correlation $C_{LC\_norm}[0]$ of the voltages measured at the origin, given by formulas [28], [31] and [32], and the phase shift φ, given by formula [30], the input processing block 110 calculates (step 360 of Figure 3) the maximum value C_{max} of the correlation normalised to the product of the effective values of the measured signals using the following formula

$$C_{max} = \frac{C_{LC\_norm}[0]}{cos\varphi} \qquad [34]$$

[0140] What illustrated for the analog signals (i.e. in continuous time) with reference to formulas [24]-[27] also applies to the processing of digital signals. Consequently, the input processing block 110 calculates:

- (in phase 345 of Figure 3, possibly coinciding with phase 340) the effective value VC_{eff_mis} of the field voltage Vin_C affected by noise through the following formula:

$$VC_{eff\_mis} = \sqrt{\sum_{n=0}^{N-1}(VC[n])^2} \qquad [35];$$

- (in step 370 of Figure 3) the effective value VC_{eff} of the field voltage Vin_C devoid of noise through the following formula:

$$VC_{eff} = C_{max} * VC_{eff\_mis} \qquad [36]$$

where, the term C_{max} is given by formulas [28], [32] and [34] and the term VC_{eff_mis} is given by formula [35]; and

- (in step 345 of Figure 3) the effective value VL_{eff} of the local voltage Vin_L that coincides with the effective value VL_{eff_mis} of the local voltage Vin_L measured through the following formula:

$$VL_{eff} = VL_{eff\_mis} = \sqrt{\sum_{n=0}^{N-1}(VL[n])^2}$$

[0141] The input processing block 110 performs (in step 380 of Figure 3) a comparison of the effective value VC_{eff} of the field voltage Vin_C cleared of the noise component with the effective value VL_{eff_mis} of the local voltage Vin_L. When the effective value VC_{eff} of the field voltage Vin_C cleared of the noise component differs from the effective value VL_{eff_mis} of the local voltage Vin_L measured over a predetermined maximum effective value difference threshold S, the input processing block 110 generates (step 390 of Figure 3) the output signals for enabling driving of said (at least one) main relay which cause the controlling block 130 to generate the driving signals for de-energising said (at least one) main relay of the contact group block 140 to signal the presence of a train occupying the Cot.

[0142] In the case where the effective value VC_{eff} of the field voltage Vin_C cleared of the noise component does not differ from the effective value VL_{eff_mis} of the local voltage Vin_L measured over the predetermined maximum effective value difference threshold S or after the signaling step (390) in which said (at least one) main relay is de-energised, the input processing block 110 returns to execute the method according to the invention starting from the initial step 300 for the subsequent integration interval T; in this regard, the initial phase 300 can also be executed during the execution of the method in the preceding integration interval T.

[0143] The preferred embodiment of the method according to the invention has been described with reference to a local voltage Vin_L (and consequently to a field voltage Vin_C) having the form of a sinusoidal signal. However, it should be noted that other embodiments of the method and related apparatus according to the invention can be applied to a local voltage Vin_L (and consequently to a field voltage Vin_C) having the form of a periodic signal different from a sinusoidal signal, still remaining within the scope of protection of the present invention.

[0144] The method according to the invention is a computer-implemented method, where the term "computer" means any device for processing, through a set of one or more computer programs comprising instructions which, when executed by an apparatus 100 according to the invention (in particular by at least one microprocessor of the data input processing block 110), cause the same apparatus 100 to execute the computer-implemented method for detecting a presence of a train on a track section. Also, said one or more computer programs can be stored on a set of one or more memory media readable by a computer.

[0145] The preferred embodiments of this invention have been described and a number of variations have been suggested hereinbefore, but it should be understood that those skilled in the art can make other variations and changes without so departing from the scope of protection thereof, as defined by the attached claims.

Claims

1. Computer-implemented method for detecting a presence of a train on a track section inserted in a track circuit, at one end of which a local voltage Vin_L, equal to a local periodic signal having frequency f_L, is sent and that produces at the other end of which a field voltage Vin_C, wherein the field voltage Vin_C is equal to the sum of a field periodic signal *VC(t)* having frequency f_L and a noise *N(t),* whereby Vin_C = *VC(t)* + *N(t),* comprising the following steps:

S-A. acquiring (300) the local voltage Vin_L and the field voltage Vin_C of the track circuit for an interval T of integration having a start time assumed as time origin;

S-B. calculating (320) a cross-correlation at the time origin $C_{mis}(0)$ of the local voltage Vin_L and the field voltage Vin_C acquired in step S-A and the derivative of said cross-correlation at the time origin $C'_{mis}(0)$;

S-C. determining (330) a phase shift φ of the field voltage Vin_C with respect to the local voltage Vin_L according to the formula

$$\varphi = -arctg\left(\frac{C'_{mis}(0)}{C_{mis}(0)}\right)$$

S-D. comparing (335) the phase shift φ determined in step S-C with a predetermined maximum phase shift threshold R;

S-E. if the phase shift φ determined in step S-C exceeds the predetermined maximum phase shift threshold R, then signaling (390) the presence of a train on said track section, otherwise executing the following steps;

S-F. calculating (340) a product

$$VL_{eff\_mis} * VC_{eff\_mis}$$

of the effective values of the local voltage Vin_L and field voltage Vin_C acquired in step S-A in the interval T of integration, and calculating (345) the effective value VL_{eff_mis} in the interval T of integration of the local voltage Vin_L acquired in step S-A and the effective value VC_{eff_mis} in the interval T of integration of the field voltage Vin_C acquired in step S-A;

S-G. normalising (350) the cross-correlation at the time origin $C_{mis}(0)$ with respect to the product $VL_{eff\_mis} * VC_{eff\_mis}$ of the effective values calculated in step S-F, obtaining a normalised cross-correlation at the time origin $C_{mis\_norm}(0)$;

S-H. calculating (360) a maximum value C_{max} of said cross-correlation normalised to the product $VL_{eff\_mis} * VC_{eff\_mis}$ of the effective values calculated in step S-F through the formula

$$C_{max} = \frac{C_{mis\_norm}(0)}{cos\varphi}$$

S-J. calculating (370) an effective value VC_{eff} of the field periodic signal *VC(t)* in the interval T of integration through the formula

$$VC_{eff} = C_{max} * VC_{eff\_mis}$$

S-K. comparing (380) the effective value VC_{eff} of the field periodic signal *VC(t)* with the effective value VL_{eff_mis} of the local voltage Vin_L acquired in step S-A;

S-L. if the effective value VC_{eff} of the field periodic signal *VC(t)* differs from the effective value VL_{eff_mis} of the local voltage Vin_L acquired in step S-A over a predetermined maximum effective value difference threshold S, then signaling (390) the presence of a train on said track section.

2. Computer-implemented method according to claim 1, further comprising the following step after step S-C:

S-M. determining whether the field voltage Vin_C has one or more jumps in phase and/or amplitude in the current interval T of integration and/or in one or more consecutive intervals T of integration preceding the current interval T of integration which do not correspond to similar jumps in phase and/or amplitude of the local voltage Vin_L, then signaling (390) the presence of a train on said track section,
wherein step S-M is optionally executed before step S-F, more optionally before step S-D.

3. Computer-implemented method according to claim 1 or 2, wherein the local voltage Vin_L is phase modulated, optionally with a phase modulation of PSK type.

4. Computer-implemented method according to any one of the preceding claims, wherein the interval T of integration is equal to one period corresponding to the frequency f_L multiplied by a coefficient J ≥ 1, i.e.

$$T = J \cdot f_L \ ,$$

wherein optionally J > 1, wherein more optionally 2 ≤ J ≤ 10.

5. Computer-implemented method according to any one of the preceding claims, wherein, when it is executed in a current interval T of integration after that in step S-E executed in a preceding interval T of integration the presence of a train on said track section has been signalled and such signaling is still in progress, step S-E executed for the current interval T of integration terminates to signal the presence of a train on said track section if the phase shift φ of the field voltage Vin_C with respect to the local voltage Vin_L is lower than a predetermined minimum phase shift threshold H not greater than the predetermined maximum phase shift threshold R, wherein the predetermined minimum phase shift threshold H is optionally lower than the predetermined maximum phase shift threshold R, whereby step S-E executed for the current interval T of integration introduces a signaling phase shift difference hysteresis.

6. Computer-implemented method according to any one of the preceding claims, wherein, when it is executed in a current interval T of integration after that in step S-L executed in a preceding interval T of integration the presence of a train on said track section has been signalled and such signaling is still in progress, step S-L executed for the current interval T of integration terminates to signal the presence of a train on said track section if the effective value VC_{eff} of the field periodic signal *VC(t)* differs from the effective value VL_{eff_mis} of the local voltage Vin_L acquired in step S-A by less than a predetermined minimum effective value difference threshold G not greater than the predetermined maximum effective value difference threshold S, wherein the predetermined minimum effective value difference threshold G is optionally lower than the predetermined maximum effective value difference threshold S, whereby step S-L executed for the current interval T of integration introduces a signaling effective value difference hysteresis.

7. Computer-implemented method according to any one of the preceding claims, wherein the local periodic signal and the field periodic signal *VC(t)* are sinusoidal signals.

8. Computer-implemented method according to any one of the preceding claims, wherein, in step S-A, the acquired local voltage Vin_L and field voltage Vin_C are sampled and discretised at a sampling frequency f_s, optionally equal to 10 kHz, whereby method steps following step S-A are executed in discrete time starting from a number N of discrete time samples of the local voltage Vin_L:
VL[i], per i = 0,1,..., N-1
and from a number N of discrete time samples of the field voltage Vin_C
VC[i], per i = 0, 1,..., N-1.

9. Apparatus (100) configured to detect a presence of a train on a track section inserted in a track circuit, configured to receive a local voltage Vin_L and a field voltage Vin_C of the track circuit and to control a signaling circuit, wherein the apparatus (100) comprises one or more processing units configured to execute the computer-implemented method for detecting a presence of a train on a track section inserted in a track circuit according to any one of claims 1 to 8.

10. Apparatus (100) according to claim 9, comprising:

- an input processing block (110), provided with said one or more processing units, by means of which the apparatus is configured to receive the local voltage Vin_L and the field voltage Vin_C of the track circuit and to execute said computer-implemented method for detecting a presence of a train on a track section inserted in a track circuit, wherein the input processing block (110) is configured to generate one or more output signals enabling driving one or more main relays;
- a power supply (120) configured to receive the local voltage Vin_L from the input processing block (110) and to supply the apparatus (100);
- a controlling block (130) configured to receive said one or more output signals enabling driving one or more main relays from the input processing block (110) and to generate, on the basis of said one or more output signals enabling driving one or more main relays, corresponding one or more driving signals configured to control one or more main relays; and
- a block (140) provided with one or more main relays configured to receive said one or more driving signals, so as to be controlled by said one or more driving signals to selectively output at corresponding one or more output terminals a station voltage V_Station that said one or more main relays are configured to receive at a respective input terminal, wherein said one or more output terminals are configured to be connected to said signaling circuit;

wherein said one or more output terminals optionally comprise a first output terminal that is normally closed and a second output terminal that is normally open with respect to the respective input terminal configured to receive the station voltage V_Station.

11. Apparatus (100) according to claim 9 or 10, wherein said one or more processing units consist of two processing units, and wherein the apparatus (100) is configured to signal through said signaling circuit the presence of a train on said track section for an interval T of integration only when both the processing units execute step S-E or step S-L of said computer-implemented method.

12. Apparatus (100) according to any one of claims 9 to 11, comprising at least one low-pass filter configured to cut signals having frequency f higher than a cut-off frequency equal to the sum of a maximum frequency f_{L_max} of the local voltage Vin_L that the apparatus (100) is configured to receive and an observation frequency f_c corresponding to the interval T of integration, whereby f_c = 1/T, whereby said cut-off frequency is equal to:

$$f \leq f_{L\_max} + f_c$$

13. Apparatus (100) according to any one of claims 9 to 11, comprising at least one band-pass filter configured to cut signals having frequency f outside a passband ranging from a lower cut-off frequency equal to the difference of a minimum frequency f_{L_min} of the local voltage Vin_L that the apparatus (100) is configured to receive and an observation frequency f_c corresponding to the interval T of integration, whereby $f_c = 1/T$, and an upper cut-off frequency equal to the sum of a maximum frequency f_{L_max} of the local voltage Vin_L that the apparatus (100) is configured to receive and the observation frequency f_c, whereby said passband is equal to

$$f_{L\_min} - f_c \leq f \leq f_{L\_max} + f_c$$

14. Set of one or more computer programs comprising instructions which, when executed by one or more processing units, cause said one or more processing units to execute the computer-implemented method for detecting a presence of a train on a track section inserted in a track circuit according to any one of claims 1 to 8.

15. Set of one or more computer-readable media having stored thereon the set of one or more computer programs according to claim 14.

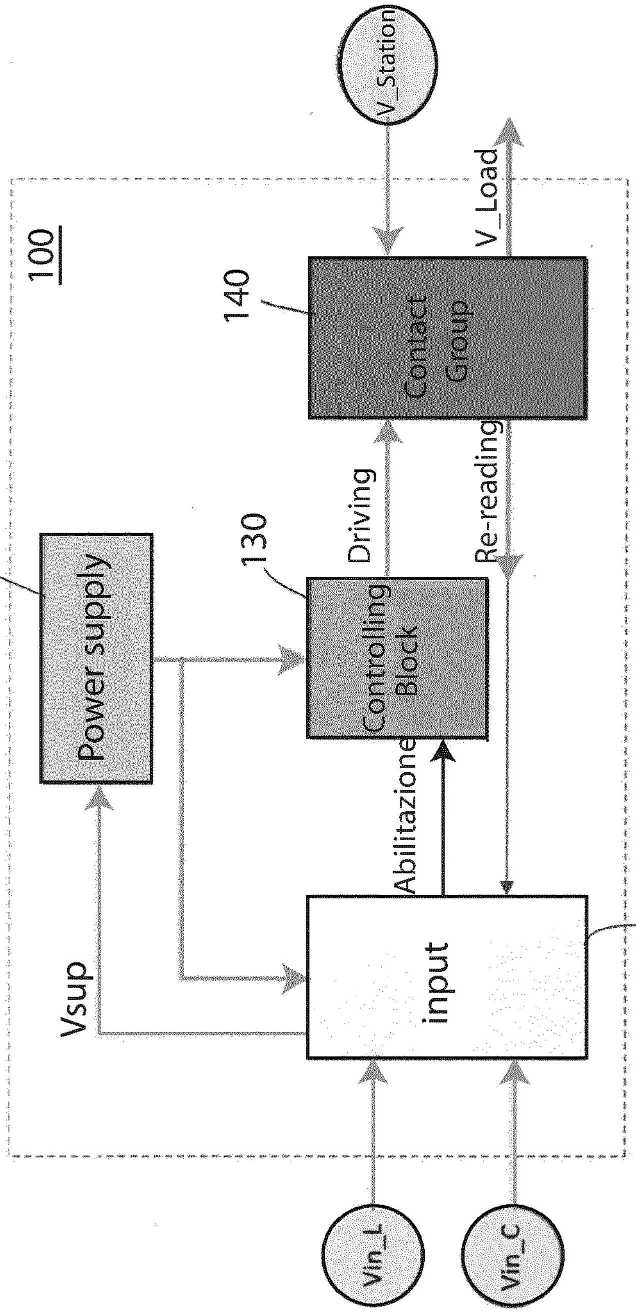

100
120
Power supply
Vsup
130
Controlling Block
Driving
140
Contact Group
V_Station
V_Load
Re-reading
Abilitazione
input
110
Vin_L
Vin_C

Fig. 1

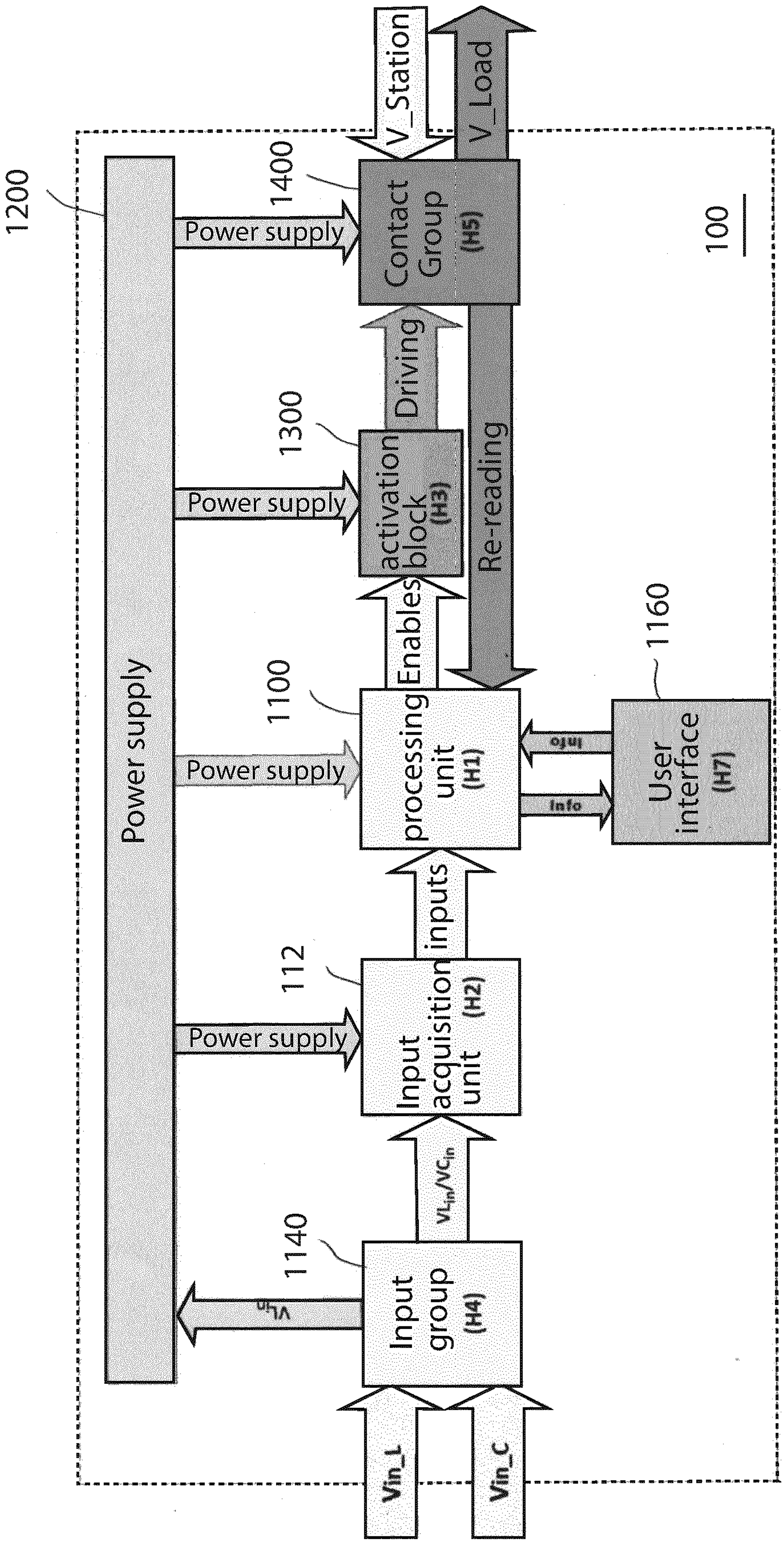
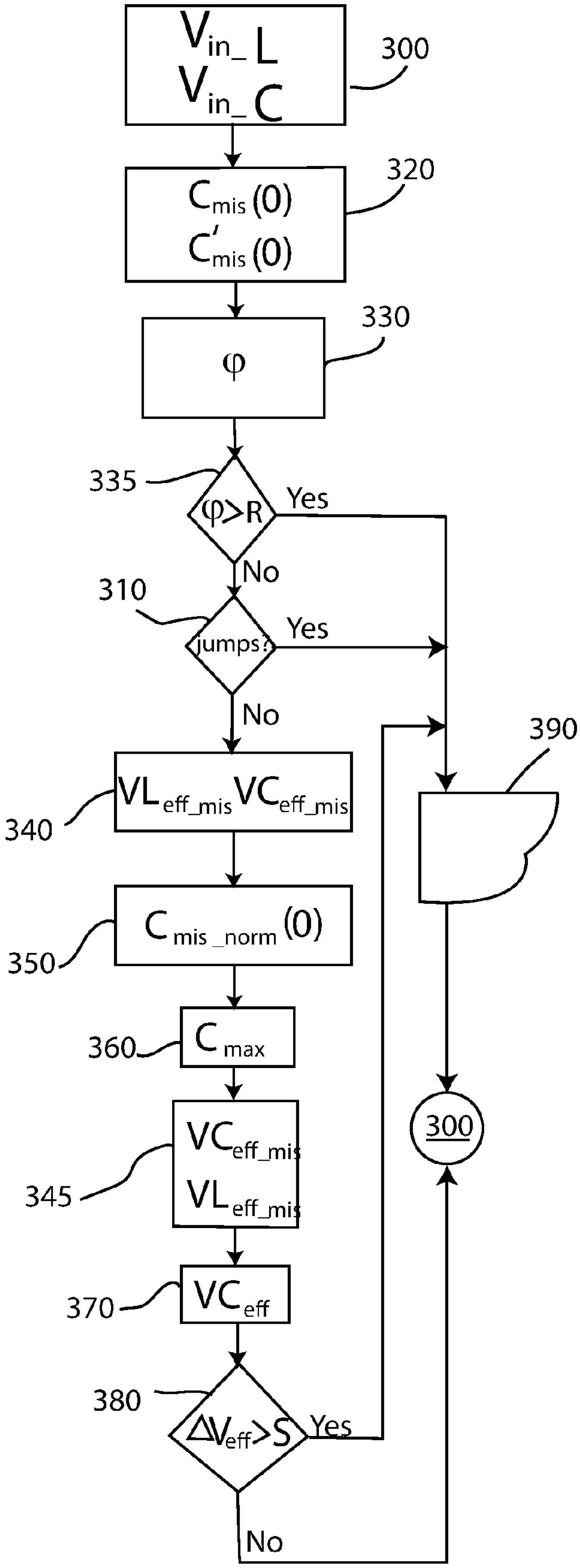

V_Station
V_Load
1400
Contact Group (H5)
1200
Power supply
Power supply
Power supply
Power supply
Power supply
100
1300
activation block (H3)
Driving
Re-reading
Enables
1100
processing unit (H1)
Info
Info
1160
User interface (H7)
112
Input acquisition unit (H2)
inputs
VL_{in}/VC_{in}
1140
Input group (H4)
VL_{in}
Vin_L
Vin_C

Fig. 2



$V_{in\_}L$
$V_{in\_}C$
300
$C_{mis}(0)$
$C'_{mis}(0)$
320
φ
330
335
φ>R
Yes
No
310
jumps?
Yes
No
390
$VL_{eff\_mis}VC_{eff\_mis}$
340
$C_{mis\_norm}(0)$
350
C_{max}
360
VC_{eff_mis}
VL_{eff_mis}
345
300
VC_{eff}
370
380
$\Delta V_{eff}>S$
Yes
No

Fig. 3

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EUROPEAN SEARCH REPORT

Application Number
EP 20 18 8605

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Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
A	EP 2 100 792 A1 (BOMBARDIER TRANSP GMBH [DE]) 16 September 2009 (2009-09-16) * paragraph [0023] - paragraph [0045]; figures 1-7 * -----	1-15	INV. B61L25/02 B61L1/10 B61L1/18
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A	JP 2016 015603 A (NIPPON SIGNAL CO LTD; UNIV SAITAMA) 28 January 2016 (2016-01-28) * abstract; figures 5-9 * -----	1-15	

TECHNICAL FIELDS SEARCHED (IPC)

B61L

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	14 December 2020	Kassner, Holger

CATEGORY OF CITED DOCUMENTS

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14-12-2020

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