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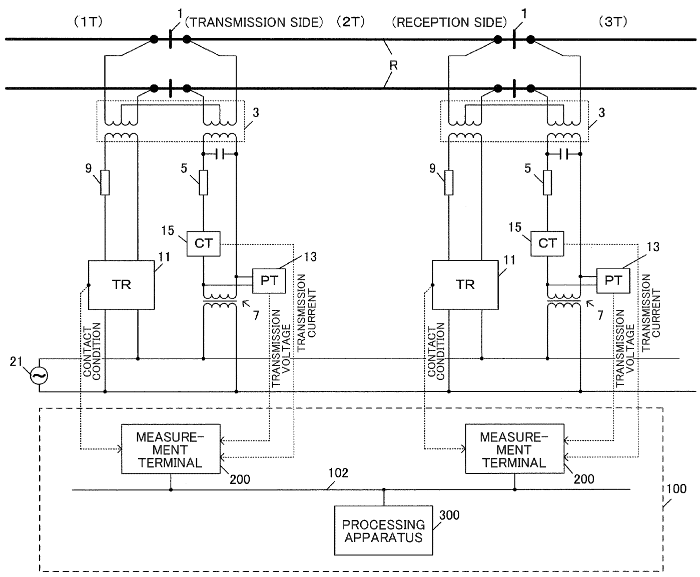
(54) **RAILWAY-TRACK CIRCUIT STATE DETERMINATION APPARATUS**

(57) A track circuit state determination apparatus (100) includes measurement terminals (200) provided at section boundaries between track circuits and a processing apparatus (300). The processing apparatus (300) calculates a current vector of transmission current to transmission voltage in each track circuit, and divides the calculated current vector into a segment of a period in the presence of an on-rail train and a segment of a period in the absence of an on-rail train. The processing apparatus (300) compares the current vector locus in each period with a reference vector locus based on past current vector loci of the corresponding track circuit to determine the state of the track circuit including at least one of a normal state and an abnormal state.

FIG. 1



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Description

[TECHNICAL FIELD]

[0001] The present disclosure relates to a track circuit state determination apparatus that determines the state of an AC track circuit.

[BACKGROUND ART]

[0002] Track circuits in railway traffic are apparatuses that detect the presence or absence of an on-rail train by the use of rails as part of an electric circuit. The track circuits are configured to transmit a signal from one end side of the rails and detect the presence or absence of a received signal resulting from a short-circuit between the rails on the axle of the on-rail train by a track relay provided on the other end side of the rails. Since the track circuits are installed outdoors, there may occur a problem that the track relay abnormally drops under the influence of a natural environment such as rainfall and snow coverage. Thus, there are known various techniques for detecting abnormal state of AC track circuits (for example, refer to Patent Documents 1 and 2).

[RELATED-ART DOCUMENTS]

[PATENT DOCUMENTS]

[0003]

[Patent Document 1] Japanese Unexamined Patent Application Publication No. 1992-113941

[Patent Document 2] Japanese Unexamined Patent Application Publication No. 1999-278269

[SUMMARY OF THE INVENTION]

[TECHNICAL PROBLEM]

[0004] The conventional state monitoring of track circuits is performed by comparing the transitions of signals (for example, voltage value, current value, phase difference, and the like) on the transmission side or the reception side with a predetermined threshold to determine whether the track circuits are in the normal or abnormal state. However, the track circuits differ in the circuit length (rail length), the distance between the transmitter/receiver and the rails (cable length), and the parameters of circuit elements including rails and ballast. This requires maintenance personnel (user) to set a threshold appropriate for each track circuit depending on their experience and knowledge. Thus, there has been demand for a new technique by which to mechanically perform the state determination of track circuits without depending on the knowledge the maintenance personnel (user) has.

[0005] An issue resolved by the present disclosure is to provide a new technique for determining the state of AC track circuits.

[SOLUTION TO PROBLEM]

[0006] A first aspect to achieve the foregoing object is a track circuit state determination apparatus that determines the state of an AC track circuit, comprising:

a storage that stores a reference vector locus of a current vector to a voltage transmitted to the AC track circuit;
a calculation section that, based on measurement values of a transmission voltage and a transmission current of a transmitter in the AC track circuit measured by a transmission-side measurer, calculates a current vector of the transmission current to the transmission voltage; and
a determination section that determines the state of the AC track circuit by calculating a vector locus from a locus of the current vector calculated by the calculation section for a predetermined period of time and comparing the vector locus with the reference vector locus.

[0007] As a result, in the first aspect, it is possible to determine the state of the AC track circuit including at least a normal state or an abnormal state by a new method by which to compare the current vector locus to the transmission voltage with the reference vector locus.

[0008] A second aspect is the track circuit state determination apparatus in the first aspect, in which
the storage stores an on-rail train-present reference vector locus that is the reference vector locus in the presence of an on-rail train in the AC track circuit, and
the determination section calculates the vector locus from the current vector calculated by the calculation section in the presence of an on-rail train in the AC track circuit and compares the vector locus with the on-rail train-present reference vector locus.

[0009] As a result, in the second aspect, it is possible to determine the state of the track circuit, targeting at the current vector locus in the presence of an on-rail train.

[0010] A third aspect is the track circuit state determination apparatus in the first or second aspect, in which
the storage stores an on-rail train-absent reference vector locus that is the reference vector locus in the absence of an on-rail train in the AC track circuit, and
the determination section calculates the vector locus from the current vector calculated by the calculation section in the absence of an on-rail train in the AC track circuit and compares the vector locus with the on-rail train-absent reference vector locus.

[0011] As a result, in the third aspect, it is possible to determine the state of the track circuit, targeting at the current vector locus in the absence of an on-rail train.

[0012] A fourth aspect is the track circuit state determination apparatus in the second or third aspect, further comprising a segmentation section that, when the current vector calculated by the calculation section satisfies a predetermined steep-change condition, divides the current vector into a segment of the current vector in the presence of an on-rail train from the satisfaction of the steep-change condition to return to the current vector before the satisfaction and the other segment of the current vector in the absence of an on-rail train.

[0013] The current vector hardly changes in the absence of an on-rail train. However, once a train passes, the current vector steeply changes and then recovers to the original current vector or its proximity. Thus, as in the fourth aspect, the current vector can be divided into the segment in the presence of an on-rail train and the segment in the absence of an on-rail train according to changes in the current vector at each passage of a train through the track circuit.

[0014] A fifth aspect is the track circuit state determination apparatus in any of the first to fourth aspects, in which

the storage stores a plurality of the reference vector loci in association with accompanying information indicating at least a situation including one of season, time zone, and weather condition in which the AC track circuit was operating, and

the determination section selects the reference vector locus satisfying a predetermined condition in proximity with the situation in which the measurement was performed as a comparative target and conducts the comparison.

[0015] Since the track circuit is installed outdoors, the transmission current varies depending on an external environment involved in rain and temperature, which causes a change in the current vector locus. Thus, as in the fifth aspect, selecting and using the reference vector locus that is in proximity in the measurement situation of the transmission voltage and the transmission current including season, time zone, and weather condition for comparison with the current vector locus, allows higher-accuracy state determination of the track circuit.

[0016] A sixth aspect is the track circuit state determination apparatus in any of the first to fifth aspects, in which the reference vector locus is data generated as an appearance probability distribution at each locus position based on vector loci of past current vectors calculated by the calculation section, and

the determination section calculates an evaluation value of a vector locus to be determined based on an appearance probability on the appearance probability distribution traced by the vector locus to be determined and determines the state of the AC track circuit based on the evaluation value.

[0017] As a result, in the sixth aspect, the reference vector locus is the appearance probability distribution at each locus position based on the past current vector loci. Thus, the evaluation value of the current vector locus to be determined can be determined as the appearance probability that is the degree of agreement with the past current vector loci.

[BRIEF DESCRIPTION OF DRAWINGS]

[0018]

FIG. 1 is a diagram showing an application example of a track circuit state determination apparatus.

FIG. 2 is a diagram describing a current vector.

FIG. 3A is a diagram describing a current vector locus.

FIG. 3B is a diagram describing a current vector locus.

FIG. 4 is a diagram describing segments of the current vector.

FIG. 5A is a diagram describing generation of an appearance probability distribution.

FIG. 5B is a diagram describing generation of an appearance probability distribution.

FIG. 6 is a diagram describing calculation of a degree of abnormality.

FIG. 7 is a functional configuration diagram of the track circuit state determination apparatus.

FIG. 8 is a diagram showing an example of current vector locus data.

FIG. 9 is a diagram showing an example of determination result data.

FIG. 10 is a diagram showing an example of reference vector locus data.

FIG. 11 is a flowchart of a track circuit state determination process.

[DESCRIPTION OF EMBODIMENTS]

[0019] Preferred embodiments of the present disclosure are described below with reference to the drawings. The present disclosure is not limited by the embodiments described below, and embodiments to which the present disclosure is applicable are not limited to the following embodiments. In the drawings, identical elements are denoted with identical reference numerals.

[System configuration]

[0020] FIG. 1 shows an application example of a track circuit state determination apparatus 100 in the present embodiment. As shown in FIG. 1, there is a track provided with track circuits 1T, 2T, 3T, ... in sections of left and right rails R with a predetermined length. The track circuits are apparatuses that detect the presence of an on-rail train, taking advantage of the fact that the left and right rails R are electrically short-circuited by a wheelset of the train. In the present embodiment, double-rail track circuits are provided with rail joint insulation 1 on the left and right rails R at the section boundary between the track circuits. Provided at the boundary between the track circuits are two sets of impedance bonds 3 with the rail joint insulation 1 therebetween.

[0021] A transmission transformer 7 as a transmitter is connected across the rails R on one end side (transmission side) of each track circuit via the impedance bonds 3 and a current decreasing resistor 5. A track relay 11 is connected across the rails on the other end side (reception side) via the impedance bonds 3 and a phase adjustor 9. The current decreasing resistor 5 is provided to limit current and prevent burning of the devices.

[0022] The transmission transformer 7 transforms AC power supplied from a power source 21 such as a commercial power source to generate a track signal (train detection signal), and transmits the signal across the rails R on the transmission side of each track circuit. That is, the track circuits in the present embodiment are AC track circuits.

[0023] The track relay 11 is a binary track relay that has two coils, a track coil and a local coil, and drives a contact by the voltages applied to the coils and a phase difference between them. The track coil is connected across the rails R on the reception side of the track circuit and to which the voltage of the track signal flowing through the track circuit is applied. An AC voltage supplied from the power source 21 is applied to the local coil. The voltage applied to the local coil (hereinafter called "local voltage") is stable in phase (also referred to period). Thus, the phase of the local voltage is used as a reference.

[0024] At entry of a train into the track circuit, the rails R are short-circuited by the axle of the train so that the voltage applied to the track coil in the track relay 11 (hereinafter called "reception voltage") and also referred to "incoming voltage") decreases and the phase difference between the reception voltage and the local voltage becomes smaller. Thus, the track relay 11 changes from a raised state to a dropped state, whereby the entry of the train into the track circuit is detected. The phase adjustor 9 is provided to adjust the phase of the reception voltage such that the phase difference between the reception voltage and the local voltage in the absence of an on-rail train becomes a value optimally suited for keeping the raised state of the track relay 11.

[0025] The track circuit state determination apparatus 100 is configured such that a plurality of measurement terminals 200 and a processing apparatus 300 are communicably connected by a transmission line 102 to determine states of individual track circuits to be determined.

[0026] Each measurement terminal 200 is provided at the section boundary between the track circuits and into which a voltage of the track signal generated by the transmission transformer 7 (transmission voltage) and current (transmission current) are input as measurement values relating to one of the track circuits adjacent to each other at the boundary, and into which a contact condition of the track relay 11 is input as a measurement value relating to the other of the track circuits adjacent to each other at the boundary. The measurement terminal 200 calculates a phase difference of the transmission current from the transmission voltage (transmission current phase difference), and outputs the calculated phase difference together with the input measurement values to the processing apparatus 300 via the transmission line 102.

[0027] The transmission voltage is measured by a potential transformer (PT) 13 that is a transmission-side measurer connected to a secondary side of the transmission transformer 7. The transmission current is measured by a current transformer (CT) 15 that is a transmission-side measurer inserted into between the secondary side of the transmission transformer 7 and the rail R. The transmission current may be calculated by detecting a voltage across the current decreasing resistor 5.

[0028] The processing apparatus 300 is a kind of computer that includes an electronic circuit performing arithmetic control. The processing apparatus 300 determines the state of each track circuit including at least a normal state or an abnormal state based on the measurement values input from the corresponding measurement terminal 200.

[Determination principle]

[0029] A principle of state determination on the track circuit by the processing apparatus 300 will be described. The processing apparatus 300 determines the state of the track circuit to be determined by calculating a current vector of the track circuit from the measurement values input from the measurement terminal 200 relating to the track circuit to be determined and comparing a locus of the current vector with a reference vector locus.

[0030] FIG. 2 is a diagram describing a current vector. As shown in FIG. 2, the current vector is a vector (x, y) that has an origin O as the starting point in an XY orthogonal coordinate system in which the voltage vector is oriented in an X-axis positive direction, and has a phase difference θ from the X axis as transmission current phase difference and has a magnitude as transmission current value. The measurement values including the transmission current and the transmission current phase difference input from the measurement terminal 200 are associated with measurement time. Thus, the current vector at each measurement time can be calculated from the transmission current and the transmission current phase difference at the measurement time. Time-series variations in the current vector (x, y) at the continuous measurement times constitute the locus of the current vector.

[0031] The shape of the locus of the current vector varies depending on whether a train has entered in the corresponding track circuit (in the presence of an on-rail train) or not (in the absence of an on-rail train). FIGS. 3A and 3B are diagrams schematically showing examples of current vector loci. FIG. 3A shows a current vector locus in the absence of an on-rail train for a certain period of time, and FIG. 3B shows a current vector locus in the presence of an on-rail train for one cycle of the train from the entry into to exit from the corresponding track circuit.

[0032] As shown in FIG. 3A, in the absence of an on-rail train, the transmission current and the transmission voltage are almost constant, and thus the current vector hardly changes and the current vector locus almost concentrates on one point.

[0033] On the other hand, in the presence of an on-rail train, as shown in FIG. 3B, the transmission voltage is almost constant but the transmission current greatly changes because the impedance varies depending on the short-circuit position of the rails caused by the axle of the running train. That is, as the transmission current value and the transmission current phase difference greatly change, the current vector greatly changes and has a current vector locus that fluctuates more widely than that in the absence of an on-rail train. In addition, the changes in the current vector are steeper than those in the absence of an on-rail train. Specifically, the current vector locus takes a crescent-like shape that makes a closed path at each passage of a train through the corresponding track circuit. FIG. 3B shows a current vector locus at each passage of a train from the entry into to exit from the corresponding track circuit. In the current vector locus, the current vector in the absence of an on-rail train changes due to the entry of the train such that the current phase difference becomes smaller, and then changes again such that the current phase difference becomes larger, thereby recovering to near the current vector before the entry (that is, the current vector in the absence of an on-rail train). The current vector loci vary by the track circuit, but form almost the same shape from track circuits of the same kind in the same state.

[0034] As described above, the current vector locus greatly differs depending on the presence or absence of an on-rail train. Thus, the current vector locus is divided into segments based on the difference to perform the state determination of the track circuit. FIG. 4 is a diagram schematically describing segments of the current vector locus. FIG. 4 outlines three-dimensionally time-series changes of a current vector of a certain track circuit on an XY plane that is a vector plane along a depth direction and a vertical direction and at time along a rightward direction. The XY axes are the same as those shown in FIGS. 3A and 3B, and the X-axis positive direction is the direction of the voltage vector.

[0035] As trains intermittently pass through the track circuit, an on-rail train-present period and an on-rail train-absent period alternate repeatedly. Thus, the on-rail train-present period and the on-rail train-absent period are each segmented as one determination period. The segmentation boundary between the determination periods can be determined depending on whether the current vector satisfies a predetermined steep-change condition. The steep-change condition is a condition under which the current vector can be regarded as having steeply changed, and for example, the steep-change condition is set to one of the following: for a predetermined unit time, 1) the magnitude of the current vector has changed by a first change amount or more and the orientation of the current vector has changed by a first change angle or more; 2) the magnitude of the current vector has changed by a second change amount or more; and 3) the orientation of the current vector has changed by a second change angle or more.

[0036] That is, in the absence of an on-rail train, the current vector hardly changes (see FIG. 3A) and thus does not satisfy the steep-change condition. When a train has entered the track circuit, the current vector greatly changes within the unit time and thus satisfies the steep-change condition. During the running of the train in the track circuit, the current vector continues to satisfy the steep-change condition. Then, when the train has exited the track circuit and the current vector has recovered to near the state before the entry, the current vector no longer satisfies the steep-change condition (see FIG. 3B). Therefore, assuming that a time point at which the current vector has changed from the state not satisfying the steep-change condition to the state satisfying the steep-change condition is a time point of the train's entry into the track circuit, the on-rail train-present period is defined as a period from the foregoing time point to a time point at which the current vector has recovered to near the state immediately before the satisfaction of the steep-change condition. The on-rail train-absent period is defined as the other period. The current vector's "recover to near" the previous state means that the current vector has reached a coordinate value that is almost equivalent to a coordinate value of the previous current vector. The range of almost equivalent values can be set as appropriate. In short, the current vector's "recover to near" the previous state can be said to the current vector's "return" to the previous state, and thus the term "return" will be used as appropriate in the present embodiment.

[0037] As described above, the state of the corresponding track circuit is determined by dividing the current vector locus into the determination periods that are the on-rail train-present period and the on-rail train-absent period and comparing each determination period with the reference vector locus based on the past current vector loci. That is, the current vector locus in the on-rail train-present period is compared with the reference vector locus based on the current vector loci in the past on-rain train-present periods, and the current vector locus in the on-rail train-absent period is compared with the reference vector locus based on the current vector loci in the past on-rain train-absent periods. In the present embodiment, comparison operations with the reference vector locus are implemented in such a manner that the reference vector locus is used as an appearance probability distribution that represents appearance probabilities at locus positions.

[0038] FIGS. 5A and 5B are each diagrams describing a method for generating an appearance probability distribution. FIG. 5A shows an appearance probability distribution relating to the reference vector locus in the absence of an on-rail train, and FIG. 5B shows an appearance probability distribution relating to the reference vector locus in the presence of an on-rail train. The appearance probability distribution relating to the reference vector locus is generated based on a plurality of past current vector loci, where a vector locus in one determination period is treated as one vector locus. The X and Y axes shown in FIGS. 5A and 5B are the same as the X and Y axes shown in FIGS. 3A, 3B, and 4.

[0039] A current vector locus is actually a set of time-series data, that is, a set of current vectors (values) as discrete data. FIGS. 5A and 5B each show the current vector locus in a small number of plots for ease of understanding. In actuality, however, the current vector loci are represented in a larger number of plots than shown in the drawings. Plotting the current vectors constituting the plurality of current vector loci produces a high-density plot group at the positions that are likely to be taken as locus positions, and produces no or few plots at the positions that are unlikely to be taken as locus positions. Consequently, superimposing the plots of the plurality of current vector loci makes it possible to obtain a frequency distribution of the locus positions that can be taken as vector locus. In the present embodiment, for each of regions of the XY plane that is divided in a predetermined size, the ratio of the number of the current vectors plotted in the region to the total number of the plotted current vectors is defined as appearance probability p in the region.

[0040] However, the appearance probability p may be defined as described below without reference to the number of plots. Specifically, the plots relating to one current vector locus are binarized depending on whether they exist in the regions of the XY plane divided in a predetermined size. If one or more plots exist in the region, the number of plots in the region is set to one. Accordingly, the appearance probability distribution obtained by superimposing the past current vector loci is based on the number of the current vector loci that have passed through each region, and the appearance probability in each region represents the rate at which the current vector loci pass through the region.

[0041] In the present embodiment, the past current vector loci used for generation of the reference vector locus are a predetermined number of current vector loci starting from a time point to be determined (or a time point of measurement of measurement data to be determined). Alternatively, the appearance probability p may be defined as described below. Since the track circuits are installed outdoors, the transmission current phase difference may differ from time to time under the influence of natural environments such as rainfall, snow covering, and temperature. Thus, for example, the current vector loci in the determination periods are classified by the measurement situation including season, time zone, and weather conditions such as rain or clear sky. Thus, the past current vector loci of which the measurement situation is in agreement with or in proximity to that of the current vector locus to be determined may be used to generate the appearance probability distribution relating to the reference vector locus.

[0042] By comparison with the thus generated appearance probability distribution relating to the reference vector locus, a degree of abnormality a is calculated as an evaluation value of one current vector locus. FIG. 6 is a diagram describing calculation of the degree of abnormality a. The X and Y axes are the same as those shown in the other drawings. FIG. 6 shows an example of a current vector locus in the presence of an on-rail train. The degree of abnormality a in the one current vector locus is calculated by the following equation (1):

$$\text{Degree of normality } N = \Sigma p(i)/n$$

$$\text{Degree of abnormality } a = 1 - N \quad \ldots (1)$$

[0043] The term "p(i)" refers to the appearance probability in a region that contains a current vector i representing the individual locus positions of the current vector locus, and "n" refers to the number of the current vectors representing the individual locus positions of the current vector locus.

[0044] That is, the degree of normality N is an average of the appearance probabilities p(i) that correspond to the current vectors i constituting the current vector locus, which indicates the degree of agreement with the reference vector locus. The degree of normality N is an average of the appearance probabilities and thus takes a value within a range of $0.0 \leq N \leq 1.0$. The degree of abnormality a also takes a value within a range of $0.0 \leq a \leq 1.0$.

[0045] The calculated degree of abnormality a is compared with a predetermined threshold to determine the state of the corresponding track circuit. For example, when the degree of abnormality a is greater than the threshold, it is determined that the track circuit is abnormal, and otherwise it is determined that the track circuit is normal. Stepwise thresholds may be preset so that the abnormality levels can be determined stepwise. In that case, when the abnormality level is low, it can be determined that there is a sign of abnormality.

[Functional configuration]

[0046] FIG. 7 is a functional configuration diagram of the track circuit state determination apparatus 100. The track circuit state determination apparatus 100 is configured such that the plurality of measurement terminals 200 provided at the individual section boundaries between the AC track circuits are communicably connected to the processing apparatus 300.

[0047] Each of the measurement terminals 200 receives inputs of the transmission voltage and the transmission current from the track circuit on the transmission side and an input of a contact condition of the track relay 11 from the track circuit on the reception side, at the section boundary between the track circuits where the measurement terminal 200 is provided. The measurement terminal 200 has a phase difference calculation section 202 and a transmission control section 204.

[0048] The phase difference calculation section 202 calculates the phase difference of the transmission current from the transmission voltage, based on the measurement values of the transmission voltage and the transmission current of the transmitter in the track circuit obtained by the transmission-side measurer. That is, the phase difference calculation section 202 calculates the phase difference of the input transmission current from the input transmission voltage.

[0049] The transmission control section 204 associates the input transmission voltage and transmission current as the measurement values relating to the track circuit on the transmission side, the values of the phase difference calculated by the phase difference calculation section 202, and the value of the input contact condition as the measurement value relating to the reception-side track circuit with measurement date and time and identification information of the track circuit, and transmits the same as measurement data to the processing apparatus 300.

[0050] The processing apparatus 300 includes an input section 302, a display 304, a communication section 306, a processing section 310, and a storage 330, and can be configured as a sort of computer.

[0051] The input section 302 is implemented by input devices such as button switches, touch panel, and keyboard, to output an operation signal according to a performed operation to the processing section 310. The display 304 is implemented by a display device such as a liquid crystal display (LCD) or touch panel, to provide various indications according to a display signal from the processing section 310. The communication section 306 is implemented by a wired or wireless communication device, for example, to communicate with the measurement terminals 200 via a transmission line.

[0052] The processing section 310 is implemented by an arithmetic device such as a central processing unit (CPU), for example, to transmit instructions or data to the components of the processing apparatus 300 based on programs and data stored in the storage 330, thereby to perform overall control of the processing apparatus 300. The processing section 310 also executes a track circuit state determination program 332 stored in the storage 330 to serve as functional blocks such as a current vector calculation section 312, a current vector segmentation section 314, a state determination section 316, a notification section 318, and a reference vector locus generation section 320. However, these functional blocks can be each configured as independent arithmetic circuits by application specific integrated circuits (ASICs) or field programmable gate arrays (FPGAs).

[0053] The current vector calculation section 312 calculates a current vector of the transmission current to the transmission voltage based on the measurement values input from the measurement terminal 200. Specifically, the current vector calculation section 312 calculates a current vector (x, y) in the XY orthogonal coordinate system in which the phase difference θ from an X axis with the voltage vector along the X-axis positive direction is a transmission current phase difference and the magnitude of the current vector is a transmission current value. Since the measurement values including the transmission current and the transmission current phase difference input from the measurement terminal 200 are associated with the measurement times, the current vector at each measurement time can be calculated from the transmission current and the transmission current phase difference at the corresponding measurement time (see FIG. 2). The current vectors at the individual measurement times can be set in time-series manner to obtain a current vector locus.

[0054] The current vector segmentation section 314 divides the current vector calculated by the current vector calculation section 312 into the segments in the presence of an on-rail train and the segments in the absence of an on-rail train. Specifically, assuming that a time point at which the time-series current vector according to the measurement time satisfies the steep-change condition is a time point of a train's entry of into the corresponding track circuit, the on-rail train-present period for the train to pass through the track circuit one time is defined as a period from the foregoing time point to a time point at which the current vector has recovered to near the state immediately before the satisfaction of the steep-change condition. Then, the on-rail train-absent period is defined as the period other than the on-rail train-present period (see FIGS. 3A and 3B).

[0055] The state determination section 316 sets each of the on-rail train-present period and the on-rail train-absent period divided by the current vector segmentation section 314 as one determination period, and determines the state of the corresponding track circuit including the normal state and the abnormal state, in each determination period from the current vector locus. Specifically, the state determination section 316 calculates the degree of abnormality a by comparing the current vector locus in each determination period with the reference vector locus, and compares the degree of abnormality a with a predetermined threshold to determine the state of the corresponding track circuit. When the corresponding determination period is the on-rail train-present period, the state determination section 316 compares the current vector locus with the reference vector locus in the presence of an on-rail train, and when the corresponding determination period is the on-rail train-absent period, the state determination section 316 compares the current vector locus with the reference vector locus in the absence of an on-rail train. In the present embodiment, the reference vector locus is the distribution data of the appearance probabilities p at the individual positions. Thus, the average of the appearance probabilities p at the positions corresponding to the current vectors constituting the current vector locus is calculated as the degree of normality N, and the degree of normality N is subtracted from "1.0" to calculate the degree of abnormality a (see FIG. 6).

[0056] The notification section 318 performs a predetermined notification according to the result of determination by the state determination section 316. For example, when the state determination section 316 determines that a track circuit is in the abnormal state, the notification section 318 may perform a notification such as displaying on the display 304 a message indicating the abnormality in the corresponding track circuit, outputting the message from a sound output section, or turning on a lamp associated with the corresponding track circuit. Further, if a plurality of stepwise thresholds are set for the state determination, the notification section 318 may notify the abnormality level depending on any of the thresholds has been exceeded, or may notify the occurrence of a sign of abnormality when the threshold condition for a sign of abnormality has been satisfied.

[0057] The reference vector locus generation section 320 generates the reference vector locus to be compared with the current vector locus. Specifically, in the present embodiment, since the reference vector is represented as an appearance probability distribution, the reference vector locus generation section 320 generates the appearance probability distribution relating to the reference vector. The reference vector locus generation section 320 classifies the past current vector loci into the current vector loci in the presence of an on-rail train and the current vector loci in the absence of an on-rail train, and uses the current vector loci in the presence of an on-rail train to generate the appearance probability distribution relating to the reference vector locus in the presence of an on-rail train (see FIG. 5B). The reference vector locus generation section 320 also uses the current vector loci in the absence of an on-rail train to generate the appearance probability distribution relating to the reference vector locus in the absence of an on-rail train (see FIG. 5A).

[0058] At this time, the reference vector locus generation section 320 uses a predetermined number of past current vector loci regarded as latest from the measurement dates and times to generate the appearance probability distribution relating to the reference vector locus. A plurality of classification conditions may be set from combinations of measurement situations including season, time zone, and weather. Thus, the reference vector locus generation section 320 uses the past current vector loci satisfying each of the classification conditions to generate the appearance probability distribution relating to the reference vector locus. The current vector loci may vary between before and after the maintenance work of the track circuit. Thus, the reference vector locus generation section 320 may use the past current vector loci of which the measurement dates and times are the same as or later than the latest date and time of the maintenance work to generate the appearance probability distribution relating to the reference vector locus.

[0059] The storage 330 is implemented by a storage device such as a hard disk, read only memory (ROM), or random access memory (RAM) to store programs, data, and the like for the processing section 310 to comprehensively control the processing apparatus 300. The storage 330 also serves as a work area for the processing section 310 to temporarily store results of arithmetic operations executed by the processing section 310 according to the programs, data input via the input section 302 and the communication section 306, and the like. In the present embodiment, the storage 330 stores the track circuit state determination program 332 and track circuit data 340.

[0060] The track circuit data 340 is generated for each track circuit and contains measurement data 344, current vector locus data 346, determination result data 348, reference vector locus data 350, threshold data 352, and maintenance history data 354, in association with a track circuit ID 342 for identifying the corresponding track circuit.

[0061] The measurement data 344 is data of measurement values input from the corresponding measurement terminal 200. Specifically, the measurement data 344 is data of measurement values of transmission voltage, transmission current, the contact condition of the track relay 11, the phase difference between the transmission voltage and the transmission current (transmission current phase difference), which are associated with the measurement times.

[0062] The current vector locus data 346 is data of the current vector locus in the determination period that is the on-rail train-present period or the on-rail train-absent period. As in an example shown in FIG. 8, the current vector locus data 346 includes on-rail train-present data 346a relating to the current vector locus in the on-rail train-present period and on-rail train-absent data 346b relating to the current vector locus in the on-rail train-absent period. Either of the data contains the measurement date and time, measurement time zone equivalent to the determination period, weather, and the current vector locus, as accompanying information indicating the measurement situation, in association with locus No. for identifying the current vector locus. The current vector locus is time-series data of the current vectors at the measurement times in the measurement time zone.

[0063] The determination result data 348 is data relating to results of state determination on the current vector locus in each determination period. As in an example shown in FIG. 9, the determination result data 348 contains on-rail train-present data 348a relating to the current vector locus in the on-rail train-present period and on-rail train-absent data 348b relating to the current vector locus in the on-rail train-absent period. Either of the data contains reference No. of the reference vector locus used for the state determination, the degree of abnormality, and the determination result such as the normal state or the abnormal state, in association with locus No. of the corresponding current vector locus.

[0064] The reference vector locus data 350 is data of the reference vector loci used for state determination. As in an example shown in FIG. 10, the reference vector locus data 350 contains on-rail train-present data 350a relating to the on-rail train-present current vector locus and on-rail train-absent data 350b relating to the on-rail train-absent current vector locus. Either of the data contains classification conditions, an applied current vector locus list, and appearance probability distribution data, in association with reference No. for identifying the corresponding reference vector locus. The classification conditions are conditions for the current vector loci used for generation of the corresponding reference vector locus, which constitute a combination of measurement situations including season such as spring, summer, fall, or winter, time zone such as daytime or nighttime, weather conditions such as clear sky, rain, or snow. The applied current vector locus list is a list of locus Nos. of the past current vector loci used for generation of the corresponding reference vector locus, which are selected from among the past current vector loci satisfying the classification conditions described above. The appearance probability distribution data is data indicating the corresponding reference vector locus, which contains distribution data of appearance probabilities p ($0.0 \leq p \leq 1.0$) at the individual positions (the individual regions in the present embodiment) on the XY plane.

[0065] The threshold data 352 is data of thresholds used for the state determination on the corresponding track circuit.

[0066] The maintenance history data 354 is a history of maintenance work performed on the corresponding track circuit. For example, the maintenance history data 354 contains the dates and times of the maintenance work, the track circuit ID of the track circuit having undergone the maintenance work, and the contents of the maintenance work performed, in association with one another.

[Process flow]

[0067] FIG. 11 is a flowchart of a track circuit state determination process. This process is executed by the processing section 310 on each track circuit as a target.

[0068] First, the current vector calculation section 312 calculates the current vector whenever necessary based on the measurement values input from the measurement terminal 200 (step S1). The current vector segmentation section 314 determines the boundary between the segments in the presence of an on-rail train and in the absence of an on-rail train, depending on whether changes in the current vector satisfy the steep-change condition. When the boundary between the segments is determined (YES in step S3), the state determination section 316 sets one determination period from the previous segment to the current segment, and calculates the current vector locus from the current vectors in the determination period (step S5). The state determination section 316 also specifies whether the determination period is in the presence of an on-rail train or in the absence of an on-rail train (step S7). The state determination section 316 stores the calculated current vector locus in association with the measurement situations including the measurement date and time, time zone, and weather (step S9). The reference vector locus generation section 320 specifies the classification conditions of the current vector locus from the measurement situation, and generates the reference vector locus by the use of the past current vector loci satisfying the classification conditions (step S11).

[0069] The state determination section 316 compares the current vector locus with the generated reference vector locus to calculate the degree of abnormality a (step S13). The state determination section 316 compares the calculated degree of abnormality a with a threshold to determine the state of the track circuit (step S15). Then, the notification section 318 performs a predetermined notification such as displaying and outputting the track circuit and the determination results (step S17). Upon completion of the foregoing series of steps, the process returns to step S1 to repeat the same processing.

[Advantageous effects]

[0070] As described above, according to the present embodiment, it is possible to determine the state of the AC track circuit including at least the normal state or the abnormal state by the new method by which the current vector locus relative to the transmission voltage is compared with the reference vector locus. The current vector locus changes differently between in the presence of an on-rail train and in the absence of an on-rail train, and thus discriminating these changes allows high-accuracy determination. The current vector locus differs among the track circuits, and thus generating the reference vector locus by the use of the past current vector loci of the corresponding track circuit makes it possible to generate data indicating features specific to the corresponding track circuit.

[0071] Since the track circuits are installed outdoors, the measurement values of the transmission current and others are vulnerable to external environments. Thus, classifying the past current vector loci depending on the measurement situation, generating the reference vector loci under the classifications, and comparing the current vector locus to be determined with the reference vector locus belonging in the classification according to the measurement situation allows higher-accuracy determination.

[0072] Note that applicable embodiments of the present disclosure are not limited to the embodiment described above, and that the foregoing embodiments can be modified as appropriate without deviating from the scope of the present disclosure.

(A) Setting of the thresholds

[0073] For the state determination of the track circuit, the thresholds to be compared with the degree of abnormality a based on the current vector loci may be set according to time-series transition of the past degrees of abnormality a, for example. In this case, the thresholds are set separately for the on-rail train-present section and the on-rail train-absent section of the past current vector loci. The setting of the thresholds may be performed in such a manner that the transition of the past degrees of abnormality a are presented to the user by displaying on the display 304 or the like so that the user provides an operation instruction for setting the thresholds by the input section 302. Alternatively, the past current vector loci may be classified by the classification conditions such as season, time zone, and weather condition so that the thresholds are set from the transition of the degree of abnormality a in the corresponding current vector locus.

(B) Reference vector locus

[0074] Instead of generating the reference vector locus for each determination, the reference vector loci are generated in advance in correspondence with the plurality of classification conditions. The current vector locus to be determined may be compared with the reference vector locus selected from among the reference vector loci under the classification conditions satisfying the measurement situation.

[REFERENCE SIGNS LIST]

[0075]

100 track circuit state determination apparatus
200 measurement terminal
202 phase difference calculation section, 204 transmission control section
300 processing apparatus
310 processing section
312 current vector calculation section, 314 current vector segmentation section
316 state determination section, 318 notification section
320 reference vector locus generation section
330 storage
332 track circuit state determination program
340 track circuit data
342 track circuit ID, 344 measurement data
346 current vector locus data, 348 determination result data
350 reference vector locus data, 352 threshold data
354 maintenance history data

Claims

1. A track circuit state determination apparatus that determines the state of an AC track circuit, comprising:

   a storage that stores a reference vector locus of a current vector to a voltage transmitted to the AC track circuit;
   a calculation section that, based on measurement values of a transmission voltage and a transmission current of a transmitter in the AC track circuit measured by a transmission-side measurer, calculates a current vector of the transmission current to the transmission voltage; and
   a determination section that determines the state of the AC track circuit by calculating a vector locus from a locus of the current vector calculated by the calculation section for a predetermined period of time and comparing the vector locus with the reference vector locus.

2. The track circuit state determination apparatus as defined in claim 1, wherein
   the storage stores an on-rail train-present reference vector locus that is the reference vector locus in the presence of an on-rail train in the AC track circuit, and the determination section calculates the vector locus from the current vector calculated by the calculation section in the presence of an on-rail train in the AC track circuit and compares the vector locus with the on-rail train-present reference vector locus.

3. The track circuit state determination apparatus as defined in claim 1 or 2, wherein
   the storage stores an on-rail train-absent reference vector locus that is the reference vector locus in the absence of an on-rail train in the AC track circuit, and the determination section calculates the vector locus from the current vector calculated by the calculation section in the absence of an on-rail train in the AC track circuit and compares the vector locus with the on-rail train-absent reference vector locus.

4. The track circuit state determination apparatus as defined in claim 2 or 3, further comprising a segmentation section that, when the current vector calculated by the calculation section satisfies a predetermined steep-change condition, divides the current vector into a segment of the current vector in the presence of an on-rail train from the satisfaction of the steep-change condition to return to the current vector before the satisfaction and the other segment of the current vector in the absence of an on-rail train.

5. The track circuit state determination apparatus as defined in any one of claims 1 to 4, wherein
   the storage stores a plurality of the reference vector loci in association with accompanying information indicating at least a situation including one of season, time zone, and weather condition in which the AC track circuit was operating, and
   the determination section selects the reference vec-

tor locus satisfying a predetermined condition in proximity with the situation in which the measurement was performed as a comparative target and conducts the comparison.

6. The track circuit state determination apparatus as defined in any one of claims 1 to 5, wherein
the reference vector locus is data generated as an appearance probability distribution at each locus position based on vector loci of past current vectors calculated by the calculation section, and
the determination section calculates an evaluation value of a vector locus to be determined based on an appearance probability on the appearance probability distribution traced by the vector locus to be determined and determines the state of the AC track circuit based on the evaluation value.

FIG. 1

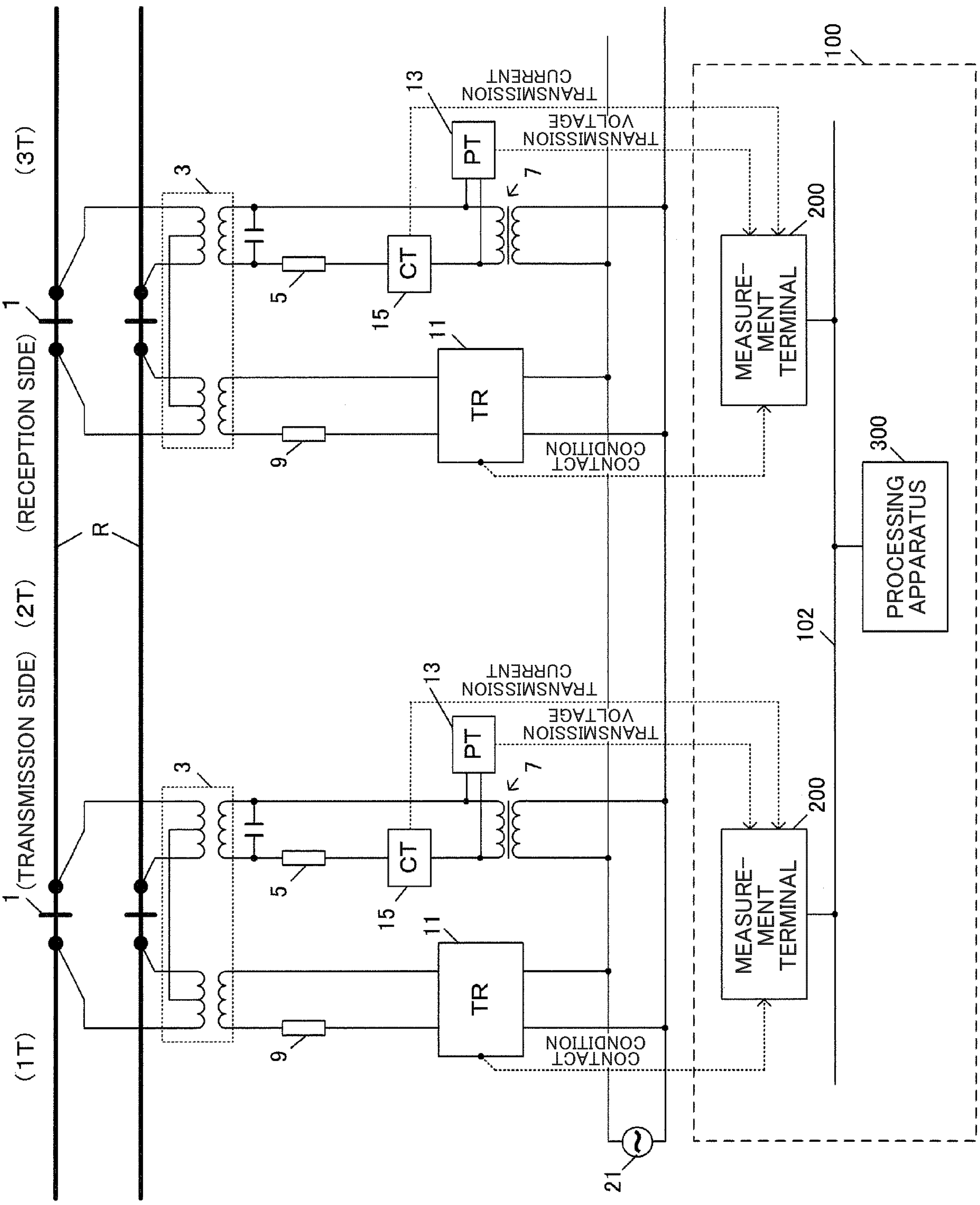

(1T)
(TRANSMISSION SIDE)
(2T)
R
(RECEPTION SIDE)
(3T)
1
3
5
7
9
11
13
15
21
PT
CT
TR
TRANSMISSION CURRENT
TRANSMISSION VOLTAGE
CONTACT CONDITION
MEASURE-MENT TERMINAL
200
PROCESSING APPARATUS
300
102
100

FIG. 2

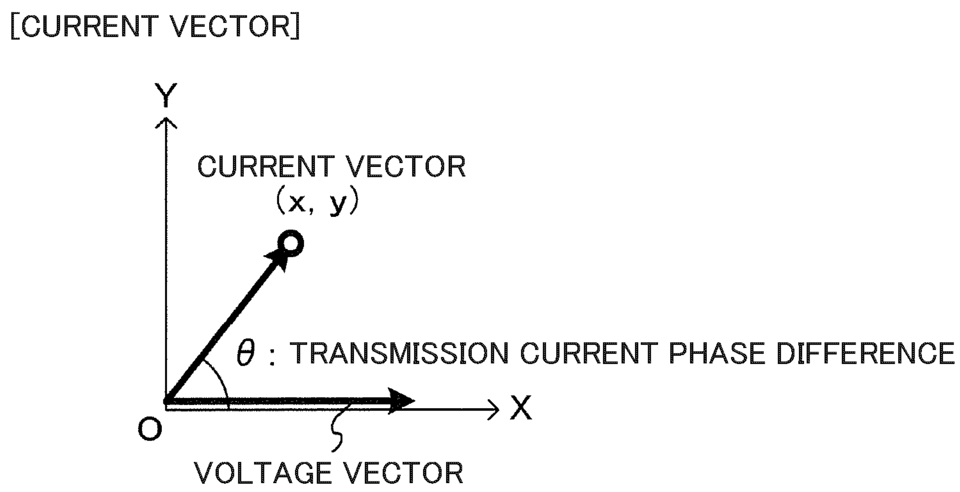

[CURRENT VECTOR]
Y
CURRENT VECTOR
(x, y)
θ : TRANSMISSION CURRENT PHASE DIFFERENCE
O
X
VOLTAGE VECTOR

FIG. 3A

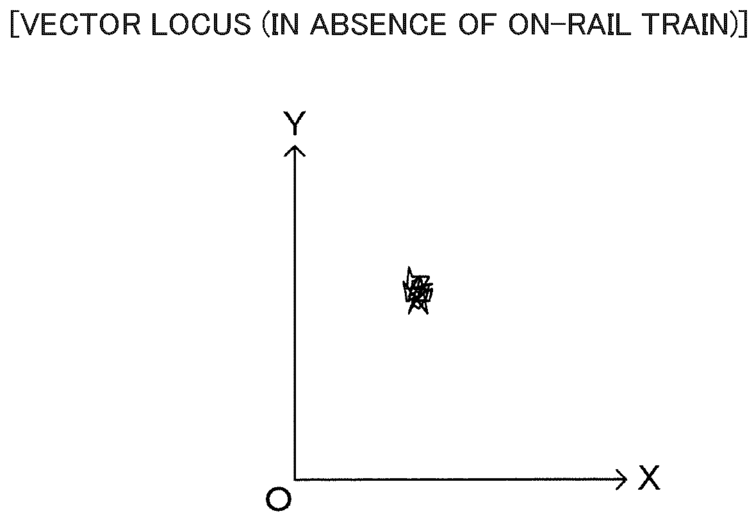

[VECTOR LOCUS (IN ABSENCE OF ON-RAIL TRAIN)]
Y
O
X

FIG. 3B

[VECTOR LOCUS (IN PRESENCE OF ON-RAIL TRAIN)]

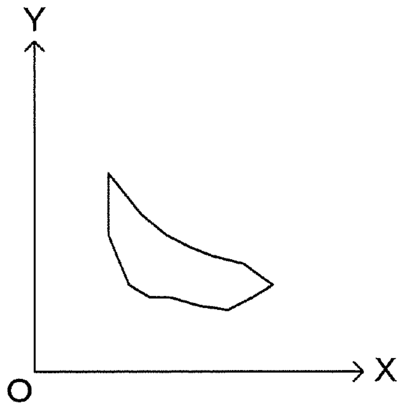


FIG. 4

[CURRENT VECTOR SEGMENTATION]

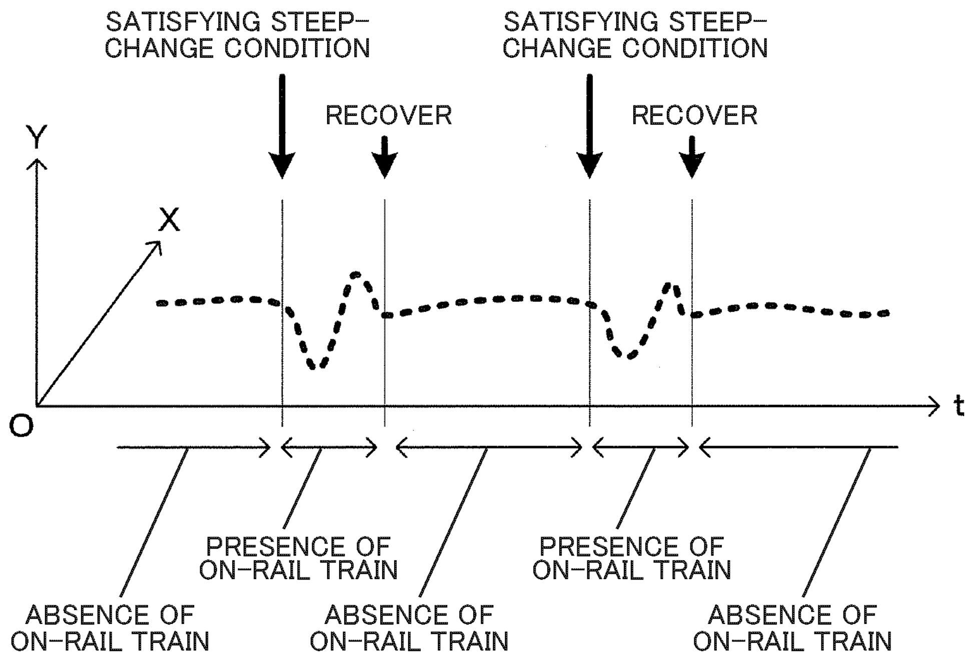


FIG. 5A

[REFERENCE VECTOR LOCUS (IN ABSENCE OF ON-RAIL TRAIN)]

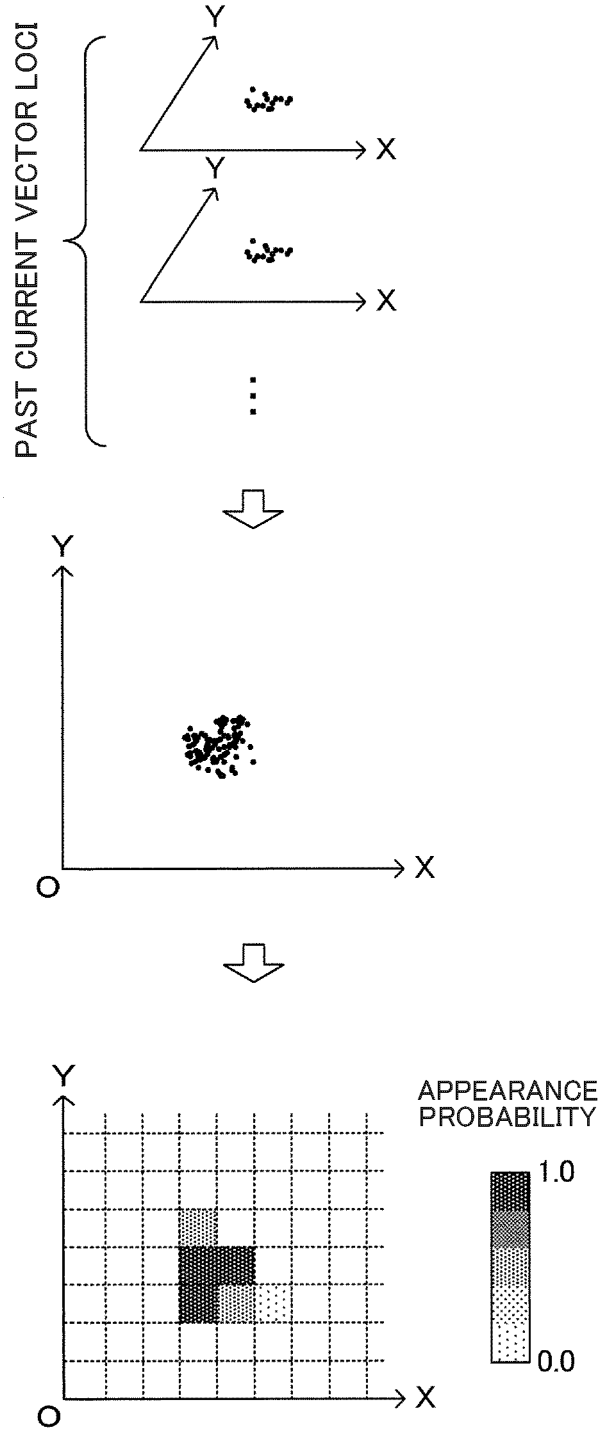


FIG. 5B

[REFERENCE VECTOR LOCUS (IN PRESENCE OF ON-RAIL TRAIN)]

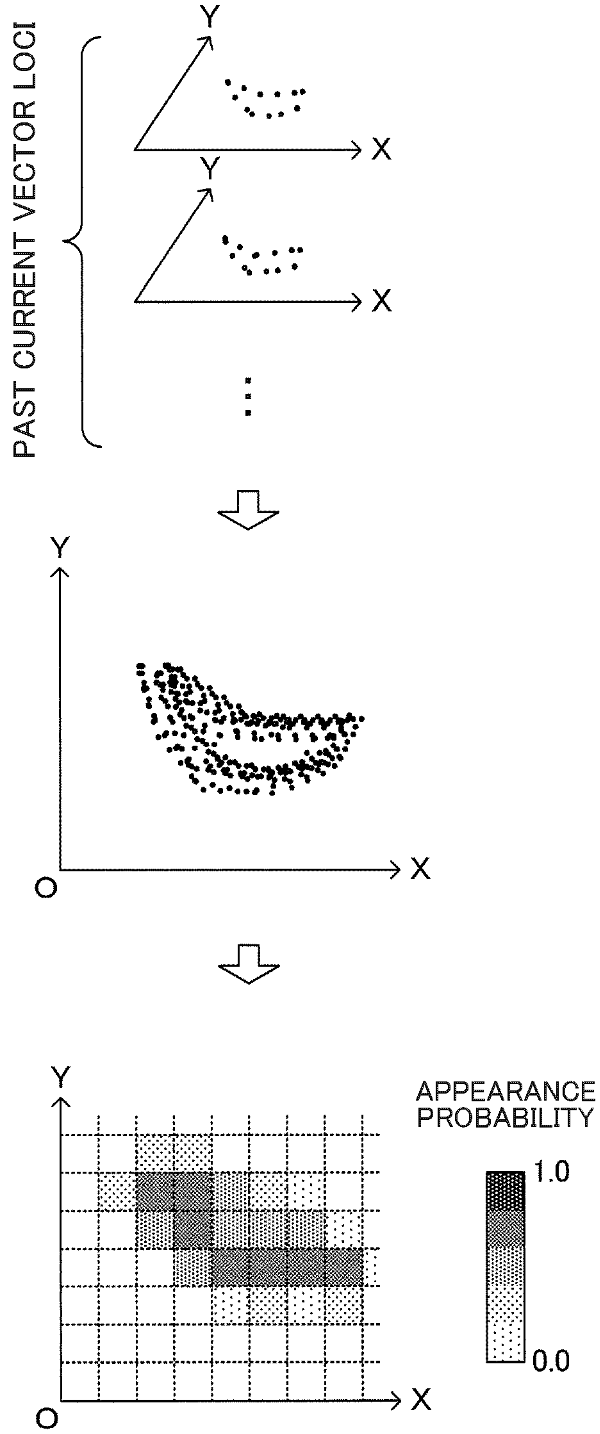
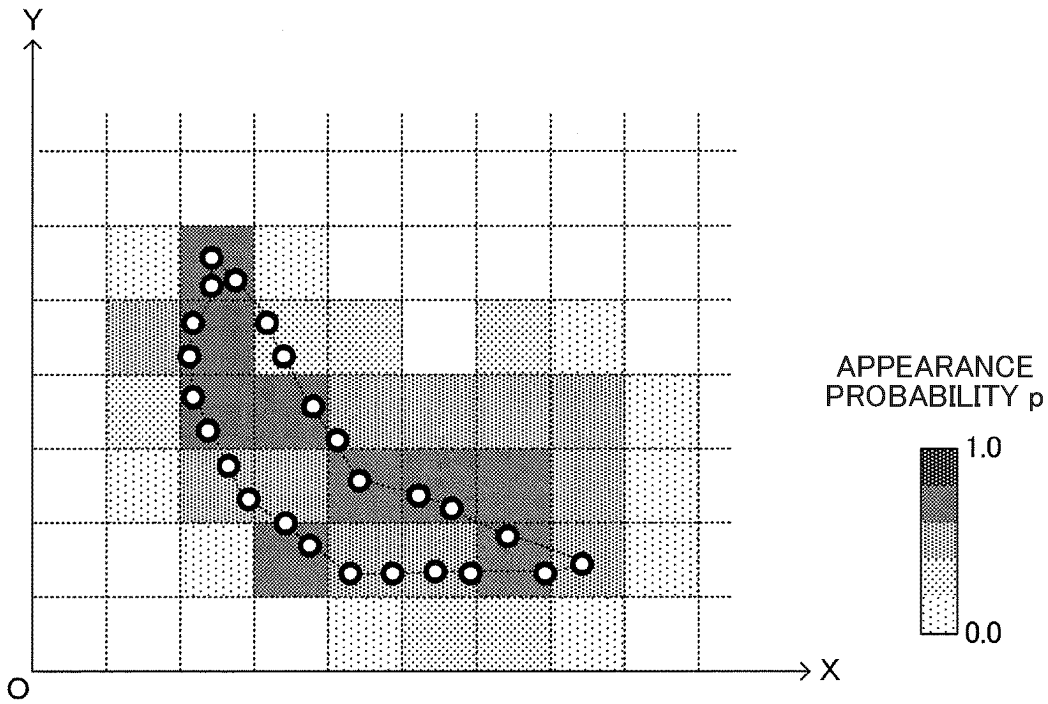


FIG. 6

[CALCULATION OF DEGREE OF ABNORMALITY]



○ : LOCUS POSITION OF CURRENT VECTOR LOCUS

FIG. 7

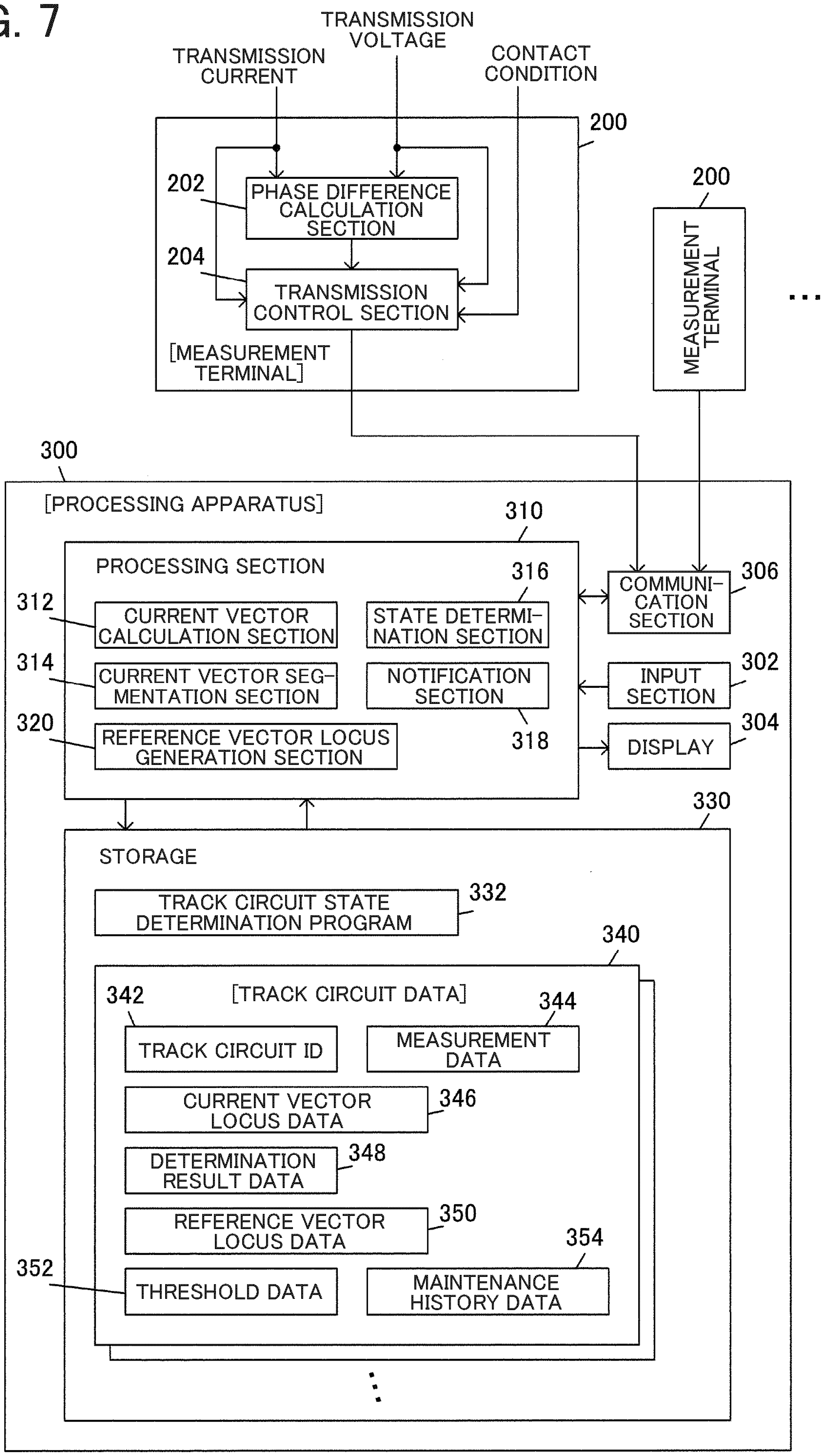

TRANSMISSION CURRENT
TRANSMISSION VOLTAGE
CONTACT CONDITION
200
202
PHASE DIFFERENCE CALCULATION SECTION
204
TRANSMISSION CONTROL SECTION
[MEASUREMENT TERMINAL]
200
MEASUREMENT TERMINAL
...
300
[PROCESSING APPARATUS]
310
PROCESSING SECTION
316
312
CURRENT VECTOR CALCULATION SECTION
STATE DETERMI-NATION SECTION
314
CURRENT VECTOR SEG-MENTATION SECTION
NOTIFICATION SECTION
320
REFERENCE VECTOR LOCUS GENERATION SECTION
318
306
COMMUNI-CATION SECTION
302
INPUT SECTION
304
DISPLAY
330
STORAGE
TRACK CIRCUIT STATE DETERMINATION PROGRAM
332
340
342
[TRACK CIRCUIT DATA]
344
TRACK CIRCUIT ID
MEASUREMENT DATA
CURRENT VECTOR LOCUS DATA
346
DETERMINATION RESULT DATA
348
REFERENCE VECTOR LOCUS DATA
350
354
352
THRESHOLD DATA
MAINTENANCE HISTORY DATA

FIG. 8

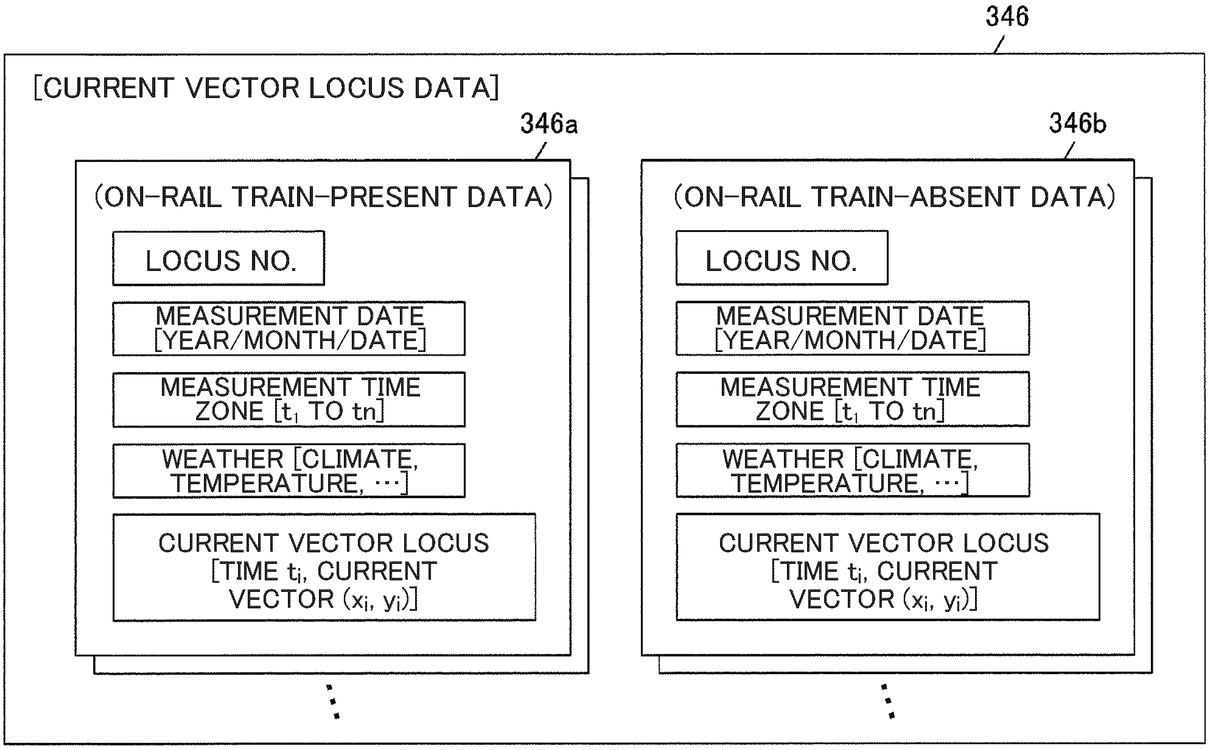

346
[CURRENT VECTOR LOCUS DATA]
346a
346b
(ON-RAIL TRAIN-PRESENT DATA)
LOCUS NO.
MEASUREMENT DATE [YEAR/MONTH/DATE]
MEASUREMENT TIME ZONE [t1 TO tn]
WEATHER [CLIMATE, TEMPERATURE, ···]
CURRENT VECTOR LOCUS [TIME ti, CURRENT VECTOR (xi, yi)]
(ON-RAIL TRAIN-ABSENT DATA)
LOCUS NO.
MEASUREMENT DATE [YEAR/MONTH/DATE]
MEASUREMENT TIME ZONE [t1 TO tn]
WEATHER [CLIMATE, TEMPERATURE, ···]
CURRENT VECTOR LOCUS [TIME ti, CURRENT VECTOR (xi, yi)]

FIG. 9

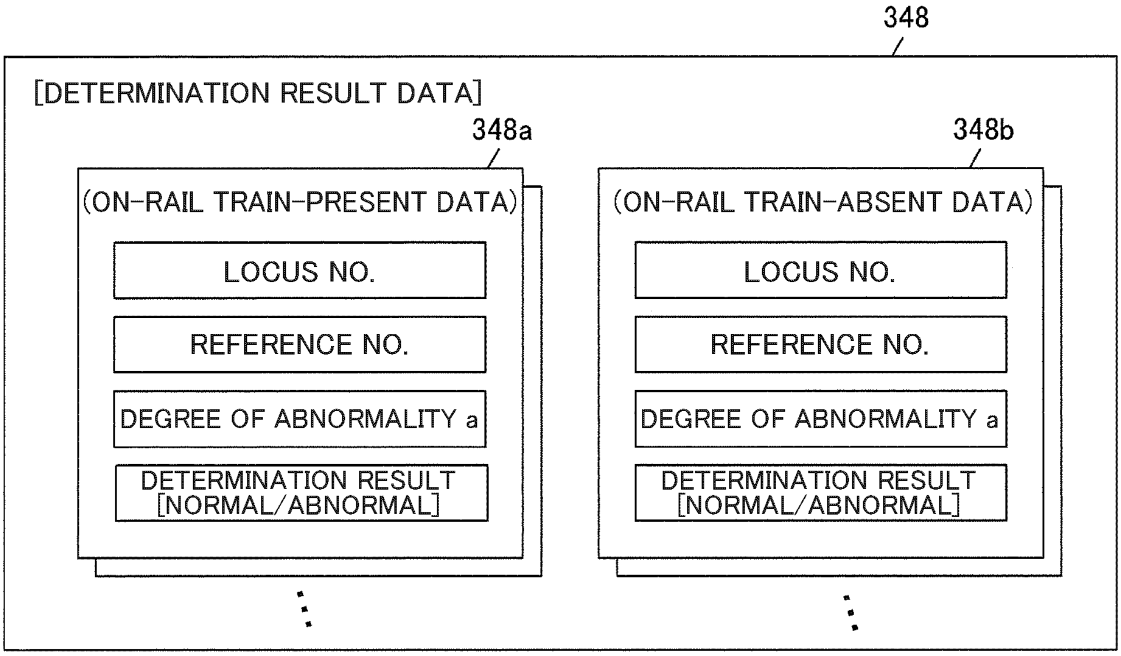

348
[DETERMINATION RESULT DATA]
348a
348b
(ON-RAIL TRAIN-PRESENT DATA)
LOCUS NO.
REFERENCE NO.
DEGREE OF ABNORMALITY a
DETERMINATION RESULT [NORMAL/ABNORMAL]
(ON-RAIL TRAIN-ABSENT DATA)
LOCUS NO.
REFERENCE NO.
DEGREE OF ABNORMALITY a
DETERMINATION RESULT [NORMAL/ABNORMAL]

FIG. 10

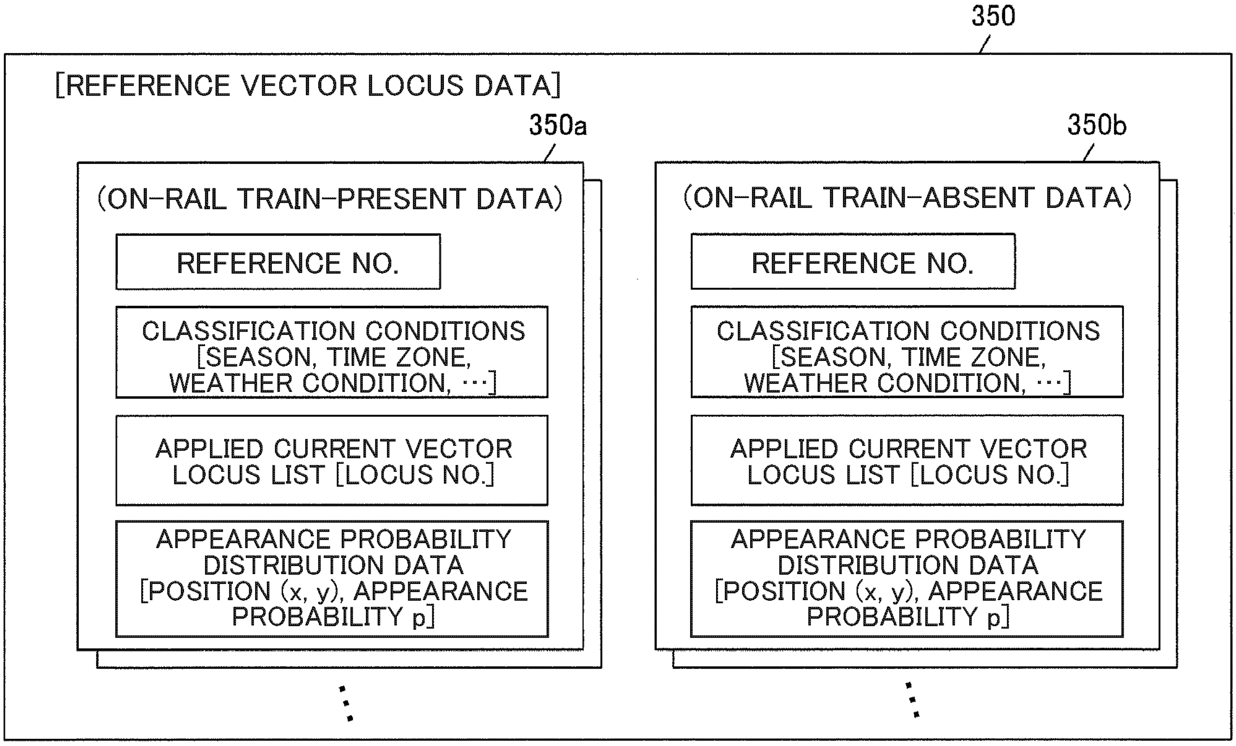
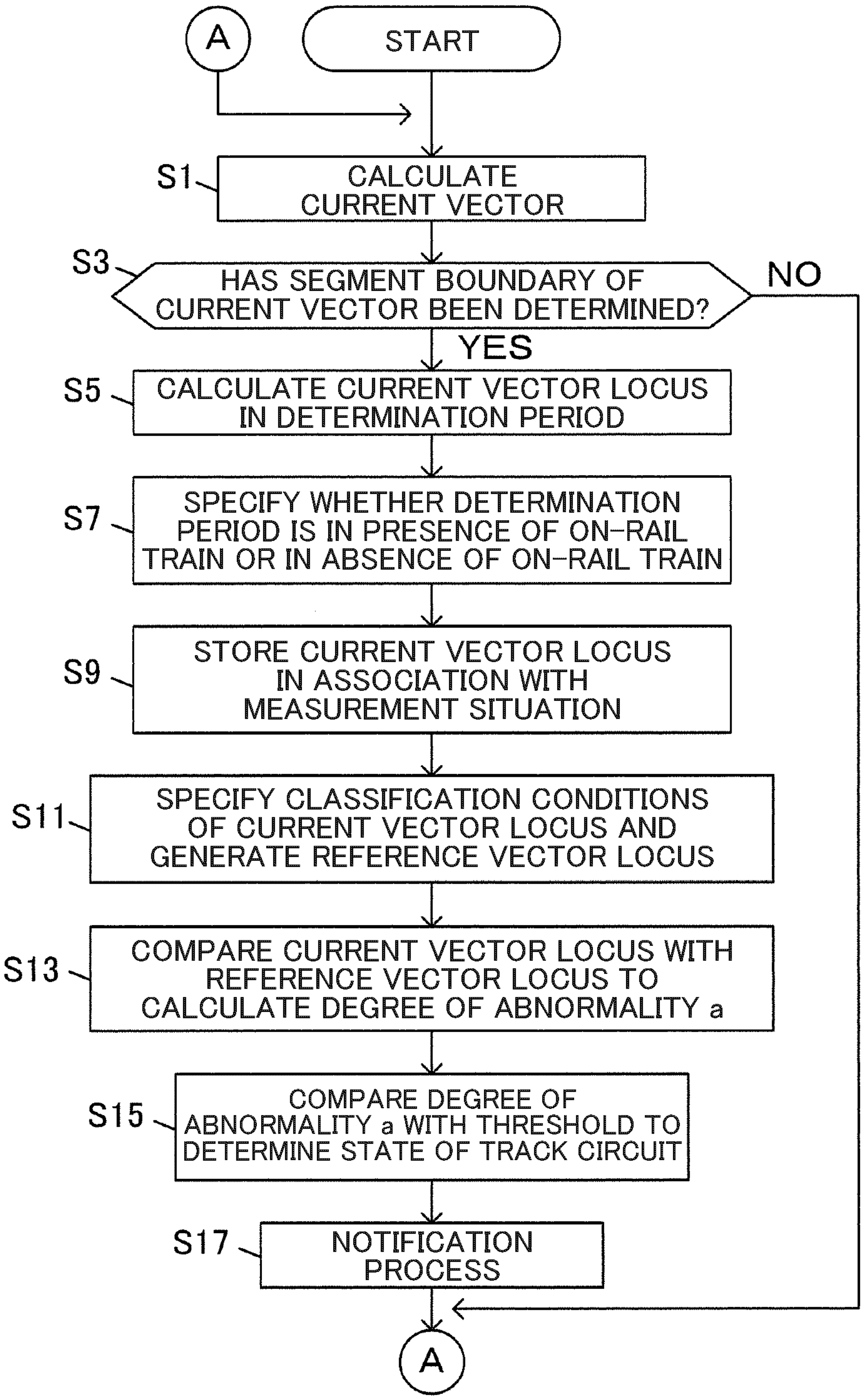

350
[REFERENCE VECTOR LOCUS DATA]
350a
(ON-RAIL TRAIN-PRESENT DATA)
REFERENCE NO.
CLASSIFICATION CONDITIONS [SEASON, TIME ZONE, WEATHER CONDITION, ···]
APPLIED CURRENT VECTOR LOCUS LIST [LOCUS NO.]
APPEARANCE PROBABILITY DISTRIBUTION DATA [POSITION (x, y), APPEARANCE PROBABILITY p]
350b
(ON-RAIL TRAIN-ABSENT DATA)
REFERENCE NO.
CLASSIFICATION CONDITIONS [SEASON, TIME ZONE, WEATHER CONDITION, ···]
APPLIED CURRENT VECTOR LOCUS LIST [LOCUS NO.]
APPEARANCE PROBABILITY DISTRIBUTION DATA [POSITION (x, y), APPEARANCE PROBABILITY p]

FIG. 11


A
START
S1
CALCULATE CURRENT VECTOR
S3
HAS SEGMENT BOUNDARY OF CURRENT VECTOR BEEN DETERMINED?
NO
YES
S5
CALCULATE CURRENT VECTOR LOCUS IN DETERMINATION PERIOD
S7
SPECIFY WHETHER DETERMINATION PERIOD IS IN PRESENCE OF ON-RAIL TRAIN OR IN ABSENCE OF ON-RAIL TRAIN
S9
STORE CURRENT VECTOR LOCUS IN ASSOCIATION WITH MEASUREMENT SITUATION
S11
SPECIFY CLASSIFICATION CONDITIONS OF CURRENT VECTOR LOCUS AND GENERATE REFERENCE VECTOR LOCUS
S13
COMPARE CURRENT VECTOR LOCUS WITH REFERENCE VECTOR LOCUS TO CALCULATE DEGREE OF ABNORMALITY a
S15
COMPARE DEGREE OF ABNORMALITY a WITH THRESHOLD TO DETERMINE STATE OF TRACK CIRCUIT
S17
NOTIFICATION PROCESS
A

INTERNATIONAL SEARCH REPORT

International application No. PCT/JP2019/006545

A. CLASSIFICATION OF SUBJECT MATTER
Int.Cl. B61L1/18(2006.01)i, G01R19/00(2006.01)i

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
Int.Cl. B61L1/18, G01R19/00

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

Published examined utility model applications of Japan	1922-1996
Published unexamined utility model applications of Japan	1971-2019
Registered utility model specifications of Japan	1996-2019
Published registered utility model applications of Japan	1994-2019

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X A	JP 11-278269 A (MITSUBISHI ELECTRIC CORP.) 12 October 1999, paragraphs [0019]-[0058], fig. 4, 7, 9 (Family: none)	1-3 4-6
A	JP 9-226580 A (THE NIPPON SIGNAL CO., LTD.) 02 September 1997, paragraphs [0032]-[0034], fig. 2 (Family: none)	1-6
A	JP 2003-11816 A (HITACHI, LTD.) 15 January 2003, fig. 2 (Family: none)	1-6
A	JP 2009-67114 A (NIHON UNIVERSITY) 02 April 2009, entire text, all drawings (Family: none)	1-6
A	JP 5-8727 A (EAST JAPAN RAILWAY COMPANY) 19 January 1993, entire text, all drawings (Family: none)	1-6

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

* Special categories of cited documents:
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"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
20 May 2019 (20.05.2019)	28 May 2019 (28.05.2019)

Name and mailing address of the ISA/	Authorized officer
Japan Patent Office 3-4-3, Kasumigaseki, Chiyoda-ku, Tokyo 100-8915, Japan	Telephone No.

Form PCT/ISA/210 (second sheet) (January 2015)

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Patent documents cited in the description

- JP 4113941 A **[0003]**
- JP 11278269 A **[0003]**