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(54) **SMART RAIL AND METHOD FOR DETERMINING AN OCCUPANCY STATE OF A TRACK SECTION**

(57) The present invention concerns a smart rail and a method for determining an occupancy state of a track section, the smart rail (11, 12) comprising an intelligent system (111) configured for providing intelligence to the rail, wherein said intelligent system (111) is configured for communicating with an intelligent system (111) of another smart rail (11, 12) of said track section for exchanging a Guided Vehicle Presence signal (hereafter GVPRE) that is used by the intelligent system (111) for determining an occupancy state of each smart rail (11, 12) of said track section by a guided vehicle (21).

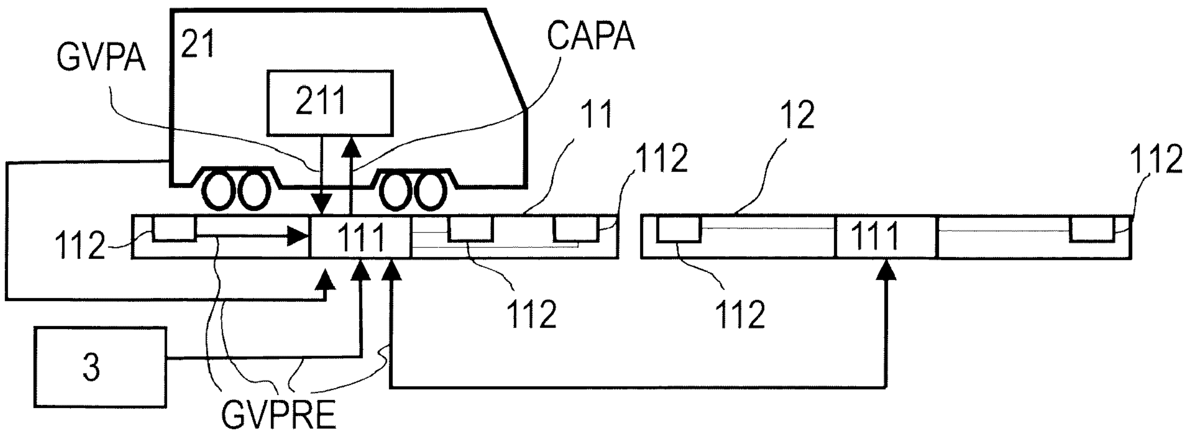

FIG 1

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Description

[0001] The present invention is related to railway traffic management and concerns more specifically railway occupancy detection and communication.

[0002] Railway traffic management comprises the control of the displacement of guided vehicles over a railway network and requires a determination of the occupancy of track sections, i.e. of segments of track, by a guided vehicle. Said determination of the occupancy of track sections by guided vehicles requires notably an appropriate communication between the guided vehicle and ground equipment (e.g. a trackside system and/or control center equipment) in order to enable an exchange of information regarding an occupancy state of a track section, e.g. occupied or vacant. According to the present invention, the expression "guided vehicle" refers to public transport means such as subways, trains or train subunits, etc., as well as load transporting means such as, for example, freight trains, for which safety is a very important factor and which are guided along a route or railway by at least one rail, in particular by two rails.

[0003] The communication of an occupancy state is typically made through different actors: for instance, an interlocking has to detect and determine the occupancy state of the track section. The interlocking connects then with a Radio Block Center (RBC) and depending on the occupancy state, the RBC communicates or not a movement authorization to the guided vehicle. Said communication may involve other devices, like a signal, whose actuation will depend on the occupancy state of the track section (e.g. the signal may inform a driver that he has to stop the guided vehicle). It is therefore clear that the detection and communication of occupancy states between ground devices and guided vehicles involves several actors, and because of this, the probability of having a failure is increased.

[0004] An objective of the present invention is to reduce the complexity of the determination and communication of an occupancy state of a track section, as well as to reduce the infrastructure and costs required for said determination and communication of occupancy state.

[0005] For achieving said objective, the present invention proposes notably a smart rail and a method for determining and communicating an occupancy state of a track section of a railway network as disclosed by the objects of the independent claims. Other advantages of the invention are presented in the dependent claims.

[0006] The present invention discloses in particular a smart rail (or intelligent rail) configured for being installed on a section of a track of a railway network and capable of determining an occupancy state of said track section and of communicating said occupancy state e.g. to a guided vehicle and/or another remote device. The smart rail according to the invention comprises an intelligent system which makes the rail smart, said intelligent system being configured for communicating with an intelligent system of another smart rail of said track section (said another smart rail and said smart rail being notably in line with each other, said another smart rail being preferably of a directly adjacent smart rail) for exchanging data regarding the presence or absence of a guided vehicle, said data being used by the intelligent system for determining the occupancy state of each smart rail of the track section or of a smart rail network.

[0007] The intelligent system comprises notably:

- a processor configured for determining said occupancy state of the track section, i.e. a presence or an absence of a guided vehicle within said track section, wherein said track section comprises at least said smart rail and may comprise one or several other smart rails according to the invention, wherein said determination of the occupancy state is realized by said processor from information received within a Guided Vehicle Presence M.essage or signal (hereafter GVPRE) sent by a first device, wherein said first device might be for instance by

    ◦ a sensor of the smart rail; and/or
    ◦ an on-board device of said guided vehicle or of another guided vehicle; and/or
    ◦ a communication system of another smart rail, preferentially of a directly neighboring smart rail; and/or
    ◦ a trackside system;

  wherein the sensor of the smart rail is preferentially configured for detecting a presence or absence of a guided vehicle within its detection area. Preferentially, the processor is further configured for determining from guided vehicle parameters (hereafter GVPA), which might be received from the guided vehicle or stored within a memory of the intelligent system, at least one of the following calculated parameters (hereafter CAPA):

    ◦ a guided vehicle movement authority, i.e. a distance over which the guided vehicle is authorized to move;
    ◦ a guided vehicle speed, which may indicate a speed increase or a speed decrease or a speed limit (upper or lower limit for instance) or a constant speed (i.e. a speed which has to be maintained by the guided vehicle);

- a communication system for communicating with said first device and optionally with a remote control center, said communication system being in particular configured for sending and/or receiving said GVPRE, wherein the communication system is configured for sending said GPRE to the communication system of another smart rail, preferentially only to the communication system of any directly neighboring smart rail (i.e. each of the adjacent smart rail with respect to the rail length), said communication system being configured for receiving the GVPRE from any of said first device, the communication system being further preferentially configured for receiving from the on-board device of the guided vehicle a GVPA and/or for sending to said on-board device said at least one CAPA. Optionally, the communication system might be configured for automatically sending the determined track section occupancy state to the guided vehicle, i.e. to the on-board device of the guided vehicle;

- optionally, a memory for storing the track section occupancy state, and optionally the GVPRE, and/or the GVPA, and/or the CAPA. Said memory might also be used for storing any data relevant to the management of the railway traffic with respect to said track section.

[0008] Optionally, the smart rail intelligent system comprises a rail wear detection system enabling to determine a wear of the smart rail resulting from the contact of the smart rail surface with wheels of guided vehicles.

[0009] The present invention proposes therefore to provide intelligence to the rail (i.e. a steel bar) by incorporating to the latter said processor, optional memory, and communication system. Advantageously, the present invention enables a continuous and direct detection of guided vehicles moving over a track made of adjacent smart rails, since each smart rail is able to determine a presence or absence of a guided vehicle located over it, the smart rails of a railway network constituting therefore a smart rail network which enables to continuously determine which of said smart rails or which part(s) of said smart rails is/are occupied by a guided vehicle, this information being then preferentially dispatched to other devices, like an on-board device of a guided vehicle moving on this railway network, and wherein the communication of each smart rail with the previous and next smart rail makes each smart rail aware of the presence or absence of other guided vehicles on a predefined set (used for instance for separating the railway network in different regions, each equipped with smart rails according to the invention) or preferentially all smart rails of the railway network. This provides a great advantage compared to current techniques wherein for instance a guided vehicle entering on a railway network, or restarting on the railway network, needs for instance to move until a first balise in order to be located and to start communicating with the RBC. According to the invention, the detection and location are continuous and take place as soon as the guided vehicle contacts a smart rail.

[0010] According to the present invention, the track section comprises one or several smart rails installed one after another, each smart rail being configured for communicating with each of its directly adjacent neighboring smart rails and for determining an occupancy state of the track section comprising said smart rail, and capable therefore of providing occupancy state information to a guided vehicle whose displacement comprises moving over the smart rails of said track section. Preferentially, at least the processor, communication system, and memory form the intelligent system of the smart rail, said intelligent system being at least partially, preferentially completely, embedded in the smart rail, e.g. in its base or directly installed on a surface of the rail, e.g. against its web. Each smart rail is therefore equipped with such an intelligent system which enables notably a communication of the smart rail with each of its smart rail direct neighbors when considering its length. In particular, if a track comprises two parallel rails, each of said rails might be a smart rail according to the invention in order to provide redundancy, the intelligent systems of each of said parallel smart rails are redundant in order to increase reliability, e.g. by enabling a guided vehicle or a neighboring smart rail to compare the messages/data sent by the intelligent system of both parallel smart rails, or in order to provide diversity: for instance, the intelligent system of one of the parallel smart rails provides functionalities which are different from the functionalities provided by the intelligent system of the other parallel smart rail, increasing therefore the quantity of data that might be exchanged with an on-board device of a guided vehicle (e.g. one of the parallel smart rails provides a first set of data and the other of said parallel smart rails provides a second set of data, wherein the data comprised within the first set are different and/or of a different type compared to the data comprised within the second set) and/or the processor of one of said parallel rails is characterized by a first design or architecture, e.g. characterized by a first operating system programmed in C language, and the other of said parallel rails is characterized by a second design or architecture, different from said first design/architecture, e.g. another operating system programmed in ADA language. Advantageously, such a diversity enables to avoid systematic errors when the outputs of both smart rails are compared.

[0011] Due to the finite length of each smart rail and the communication of the smart rail with each of its neighboring smart rails, each intelligent system is able to determine a position of the tail (end) and/or head of a guided vehicle with respect to the position of each smart rail within the railway network, and/or for instance, with respect to the position of each smart rail comprised within a track section. In order to make a guided vehicle position determination even more precise, the smart rail according to the invention might be subdivided into several parts, wherein each part comprises a system for detecting a presence or absence of guided vehicle. In such a case, it is advantageously possible to determine which one(s) of said parts is (are) occupied by a guided vehicle or free of any guided vehicle. Preferentially, adjacent smart rails that form a track are separated from each other with insulated rail joints: a track section is typically composed of one or several smart rails separated from each other by said insulated rail joints, wherein the length of the smart rail (i.e. the distance measured along its length between its tail and is head) or of said parts determines an occupancy state resolution within the smart rail network, or for instance, within a track section.

[0012] The present invention concerns also a method for determining an occupancy state of a track section within a railway network, wherein said track section comprises at least one smart rail, the method comprising the following steps:

- a reception by a communication system of a first smart rail of a GVPRE sent by a first device, wherein the GVPRE comprises information about a presence or absence of a guided vehicle with respect to the first smart rail or with respect to a second smart rail of the track section. For instance, said GVPRE might identify one or several smart rails or parts of smart rails within the track section which are occupied by a guided vehicle or free of a guided vehicle;
- a determination, by the processor of said smart rail, of an occupancy state of each smart rail of said track section from the received GVPRE, in particular from all received GVPRE. For instance, the processor may determine an occupancy state of a section of track comprising said smart rail from the received GVPRE;
- optionally, a communication of the determined occupancy state to another device, like the on-board device of a guided vehicle and/or an automatic determination and communication of an action configured for ensuring a safe displacement of a guided vehicle in function of the track section occupancy state.

[0013] Further aspects of the present invention will be better understood through the following drawings, wherein like numerals are used for like and corresponding parts:

Figure 1 schematic representation of a preferred embodiment of a smart rail according to the invention.

Figure 2 flowchart of a preferred method according to the invention.

Figure 3 schematic representation of a first example of occupancy state determination and communication according to the invention.

Figure 4 schematic representation of a second example of occupancy state determination and communication according to the invention.

Figure 5 schematic illustration of a preferred embodiment of a communication between a smart rail according to the invention and a guided vehicle.

Figure 6 schematic illustration of another preferred embodiment of a communication between a smart rail according to the invention and a guided vehicle.

Figure 7 schematic illustration of a rail wear detection system according to the invention.

Figure 8 schematic illustration of further details of a rail wear detection system according to the invention.

[0014] Figure 1 shows a track section comprising a first smart rail 11 and a second smart rail 12 according to the invention. Each smart rail comprises an intelligent unit 111 which comprises a processor, a communication system, and a memory. Optionally, the smart rail comprises one or several sensors 112 capable of detecting the presence of a guided vehicle 21, e.g. from the contact of a guided vehicle wheel with the rail, or using an RFID technique, etc. The communication system of the intelligent unit 111 is configured for receiving GVPRE from a first device, for instance from an on-board device of the guided vehicle 21, or from the sensor 112, or from the intelligent unit 111 of the second smart rail or from a remote or trackside system 3. The intelligent unit 111 is preferentially at least partially embedded in the rail (i.e. built in the rail), e.g. in a cavity of the web or of the base of the smart rail (steel bar), said cavity being hermetically closed by a maintenance door enabling a maintenance of the components of the intelligent system 111. The processor of the intelligent system is configured for determining an occupancy state of the track section from the received GVPRE. Additionally, the intelligent system may receive from the guided vehicle 21 parameters GVPA, like a wheel diameter, a guided vehicle length, a number of axles, a speed, which might be used by the processor, notably together with the track section occupancy state information, for triggering a calculation of parameters which define an action configured for ensuring the safe displacement of the guided vehicle, wherein the calculated parameters CAPA might be then transmitted by the intelligent system to the on-board device 211 of the guided vehicle, being for instance a movement authority or a braking distance, or to another device, like a signal. Apart from the sensor 112, the smart rail may comprise additional types of sensors, like speed detector, object detector, etc., which are configured for improving the smart rail functionalities for ensuring a safe displacement of the guided vehicle 21.

[0015] Figure 2 illustrates a preferred embodiment of the method according to the invention in the form of a flowchart. It describes the determination and communication of an occupancy state for a track section and is further illustrated by Figures 3 and 4 which show special occupancy state cases of a track section.

[0016] Figures 3 and 4 show guided vehicles 21, 22 running on a track comprising a track section equipped with smart rails 11-15 according to the invention. Said smart rails 11-15 are arranged one after the other and, when necessary, will be distinguished from one another by calling them the first smart rail 11, the second smart rail 12, the third smart rail 13, the fourth smart rail 14 and the fifth smart rail 15. Each smart rail is preferentially coupled to its neighboring smart rails (i.e. the next directly consecutive smart rail) by means of insulated rail joint (e.g. one insulated rail joint between each adjacent smart rail). The track may comprise one or two rails comprising said smart rails 11-15, which form a smart rail network. When it comprises two rails, smart rails having a same position with respect to the track length might be used as redundant system or for providing diversity as already explained before. Each smart rail comprises the intelligent system 111 as disclosed in Fig. 1 and which provides intelligence to the rail. The intelligent system of a smart rail, in particular its communication system, is connected (by wire or wirelessly) to each of the intelligent systems, in particular their communication systems, of its directly neighboring smart rails (i.e. the third smart rail 13 is connected to the previous smart rail (second smart rail 12) and to the next smart rail (fourth smart rail 14) which are the directly neighboring smart rails for third smart rail 13), so that occupation state messages, more specifically said GVPRE, might be exchanged between the intelligent systems of the smart rails within the smart rail network.

[0017] At step 201, a communication system of the intelligent system 111 of one of said smart rails receives a GVPRE. The GVPRE provides information with respect to the presence or absence of a guided vehicle for at least one smart rail or part of a smart rail. The GVPRE may comprise a list of smart rails, each identified by a smart rail identification number, and for each smart rail of said list, an indication whether the whole smart rail or a part of said smart rail is occupied by a guided vehicle. For instance, the communication system of the first smart rail 11 receives a GVPRE from a sensor 112 as shown in Fig. 1, informing the processor of the intelligent system 111 that a guided vehicle 21 has been detected on the first smart rail. Additionally, the communication system of the intelligent system of the first smart rail 11 may receive another GVPRE, the latter being sent by the communication system of the second smart rail 12 and indicating that the fourth smart rail 14 and fifth smart rail 15 are occupied by another guided vehicle 22. The GVPRE received by an intelligent system according to the invention will be called hereafter the "incoming GVPRE". At the opposite, GVPRE that would be sent by the communication system of the intelligent system will be called the "outgoing GVPRE". As illustrated in more details in Fig. 1, the processor of the intelligent system 111 of the first smart rail 11 processes each incoming GVPRE and generates an outgoing GVPRE for each of its directly neighboring smart rails, in the present case, the second smart rail 12. Preferentially, outgoing GVPRE are only generated by processors of intelligent systems according to the invention and sent to another intelligent system of a smart rail, preferably to each of the directly adjacent smart rails. According to the special embodiment of Fig. 3, an outgoing GVPRE is sent by the processor of the first smart rail 11, via its communication system, to the processor of the second smart rail 12, wherein the outgoing GVPRE comprises an indication that the first smart rail 11 is occupied by the guided vehicle 21. According to the present invention, each outgoing GVPRE is created by a smart rail processor by analyzing all incoming GVPRE and determining which information has to be forwarded upstream and downstream, i.e. to each of the directly neighboring smart rails, so that only new information (i.e. relevant information that is not already known by an upstream or downstream smart rail intelligent system) is forwarded, which advantageously enables to avoid sending redundant information. The same happens with the processor of the second smart rail 12: said processor receives an incoming GVPRE from the processor of the third smart rail, wherein said incoming GVPRE is configured for informing the processor of the second smart rail 12 about a presence of said another guided vehicle 22 within the fourth and fifth smart rails. Said processor of the second smart rail also receives an incoming GVPRE from the first smart rail 11, wherein said incoming GVPRE is configured for informing the processor of the second smart rail 12 about the presence of a guided vehicle 21 within the first smart rail 11. Additionally, the processor of the second smart rail 12 generates two outgoing GVPRE, one directed to the first smart rail 11 and one directed to the third smart rail 13, wherein the outgoing GVPRE for the first smart rail 11 comprised said information about the presence of said another guided vehicle 22 on the fourth and fifth smart rails and the outgoing GVPRE for the third smart rail 13 comprises information about the presence of the guided vehicle 21 on the first smart rail 11. Similar exchanges of incoming and outgoing GVPRE take place for the intelligent systems of each smart rail. Table 1 summarizes the information comprised in the incoming - outgoing GVPRE sent/received by the communication system of each of the smart rails according to the exemplary embodiment illustrated in Fig. 3.

	incoming GVPRE received by the processor of				
	first smart rail 11	second smart rail 12	third smart rail 13	fourth smart rail 14	fifth smart ra 15
outgoing GVPRE from the processor of: first smart rail 11		first smart rail 11 occupied by the guided vehicle 21			
second smart rail 12	fourth smart rail 14 and fifth smart rail 15 are occupied by another guided vehicle 22		first smart rail 11 occupied by the guided vehicle 21		
third smart rail 13		fourth smart rail 14 and fifth smart rail 15 are occupied by another guided vehicle 22		first smart rail 11 occupied by the guided vehicle 21	
fourth smart rail 14			fourth smart rail 14 and fifth smart rail 15 are occupied by another guided vehicle 22		first smart ra 11 occupied by the guide vehicle 21
fifth smart rail 15				fifth smart rail 11 occupied by the guided vehicle 22	

TABLE 1

[0018] As it can be shown by Table 1, information about a presence or absence of a guided vehicle is passed upstream and downstream from one smart rail to the next one via said incoming and outgoing GVPRE. At the end, information about the presence or absence of guided vehicles with respect to smart rails or parts of smart rails can be therefore shared between all smart rails of the railway network, or optionally, this sharing can be limited to the smart rails belonging to a same track section.

[0019] The GVPRE may not only comprise an information about the presence or absence of a guided vehicle, but also its moving direction, speed, or other relevant information, which might be determined by the intelligent system of a smart rail either from smart rail detectors or sensors, and/or from the GVPA that might be transmitted by the on-board unit of the guided vehicle to the intelligent system of the smart rail. For instance, the processor of the intelligent system of the first smart rail 11 determines from smart rail speed measurement sensors the speed of the guided vehicle 21, or said guided vehicle 1 sends a GVPA comprising its speed to the intelligent system of the first smart rail 11. The latter communicates then said speed to the processor of the second smart rail 12, which may determine a speed decrease for the first guided vehicle in function of the occupancy state of the downstream smart rails and their distance to the guided vehicle 21 (by downstream, it is referred here to the smart rails which are in front of the guided vehicle with respect to its displacement). Said speed information might be further sent to the processor of the third smart rail 13 via the outgoing GVPRE of the second smart rail 12, the processor of the third smart rail 13 determining a stopping order, i.e. a CAPA configured for ensuring that the guided vehicle 21 stops before reaching the fourth smart rail 14 which is still occupied by said another guided vehicle 22. Said information about the guided vehicle 21 speed might be further forwarded until reaching the fifth smart rail 15, the processor of the latter automatically determining for instance an increasing speed order, i.e. a CAPA configured for ensuring that said another guided vehicle 22 leaves the fourth smart rail 14 before the guided vehicle 21 reaches said fourth smart rail 14 if calculations made by the processor showed that the guided vehicle 21 and said another guided vehicle 22 will occupy a same position at a same time. Each CAPA calculated by a processor might then be sent to a guided vehicle or to another device, like a signal, in order to ensure the safe running of guided vehicles over the railway network. For instance, the stopping order determined by the processor of the third smart rail 13 might be sent by its communication system to an on-board device of the guided vehicle 21, triggering an actuation of the brakes of said guided vehicle 21. Similarly, the increasing speed order determined by the processor of the fifth smart rail 15 might be sent to said another guided vehicle 22, triggering automatically an increase of its speed.

[0020] Figure 4 shows another example of use of GVPRE according to the invention. In this example, the intelligent system 111 of the first smart rail 11 determines from an incoming GVPRE and optionally additional GVPA that the last carriage of the guided vehicle 21 occupies the first smart rail 11. For instance, a detector or sensor of the first smart rail 11 may determine that a carriage is present on the first smart rail 11 and an on-board device located in said carriage may provide via a GVPA sent to the intelligent system data indicating that it is the last carriage of the guided vehicle 21. Preferably, each carriage of the guided vehicle 21 may send to the intelligent system 111 a data enabling the processor of the intelligent system 111 to determine the carriage position with respect to the guided vehicle carriage composition (e.g. first carriage (i.e. head of guided vehicle), second carriage, etc., last carriage (i.e. end of guided vehicle)).

[0021] In addition or according to another embodiment, each carriage, or preferably the first and last carriage, is capable of generating and sending to the intelligent system of a smart rail a GVPRE which is configured for informing the processor of the smart rail intelligent system about its presence and additionally, its position with respect to the guided vehicle carriage composition (e.g. an on-board device located in the first carriage may send to the intelligent system a signal (i.e. an outgoing GVPRE) configured for informing the processor of the smart rail that the "head of guided vehicle is present", and an on-board device of the last carriage might be configured for sending a signal (i.e. an outgoing GVPRE) configured for informing said processor that the end of guided vehicle is present on the smart rail), and optionally a direction of displacement of the carriage. From said GVPRE sent by the respective guided vehicle carriages, the processor is configured for determining whether the whole guided vehicle correctly passed over the first smart rail. Additionally, and preferably, the intelligent system 111 according to the invention might be configured for checking a guided vehicle integrity from said incoming GVPRE sent by guided vehicle carriages. In this case, and as illustrated in the exemplary embodiment of Figure 4, the intelligent system 111 of the first smart rail 11 that determines from the incoming GVPRE that the carriage present over its running surface is the last carriage of the guided vehicle 21 generates an outgoing GVPRE towards the second smart rail 12, wherein said outgoing GVPRE is configured for informing the processor of the second smart rail 12 that the first smart rail 11 is occupied by the end of guided vehicle 21. Said information is then forwarded by the second smart rail 12 to the third smart rail 13 by generating by the processor of the second smart rail 12 an outgoing GVPRE comprising said information. The processor of the third smart rail 13 receives thus an incoming GVPRE from the second smart rail 12 providing the information that the first smart rail 11 is occupied by the end of guided vehicle 21 (last carriage) and may receive another incoming GVPRE enabling the processor to determine (as it was the case for the first smart rail 11) that the third smart rail 13 is currently occupied by the head of guided vehicle. From the knowledge of the occupation states of the smart rails by the guided vehicle carriages, the processor of the third smart rail 13 is in particular configured for checking the integrity of the guided vehicle (i.e. determining whether a carriage is missing) and for sending a CAPA configured for informing an on-board device of the guided vehicle 21 about the result of this integrity determination, e.g. "guided vehicle integrity assured" or "guided vehicle integrity failure".

[0022] At step 202, from the received GVPRE, each processor of each intelligent system 111 determines an occupancy state of the section of track. The size of said section of track, i.e. the number of smart rails arranged consecutively to each other may vary and is not limiting for the present invention. Said number may depend for instance on the railway network topology. In particular, each intelligent system 111 of each smart rail 11-15 is aware of all occupancy states of all smart rails (or parts of smart rails) comprised within the smart rail network or comprised within a track section. In this last case, the track section might be considered as a subnetwork of the smart rail network. Defining said predefined number of consecutive smart rails forming a track section enables to create for the smart rail network sets of smart rails, wherein occupancy states are determined within each set, wherein said sets might be separate sets, or might be sets with at least one smart rail in common. For instance, smart rails 11-13 could define a first track section and smart rails 13-15 a second track section. In any case, the definition of the track section does not limit the present invention.

[0023] The occupancy state is for instance determined by the intelligent system 111 of the first smart rail 11 from all incoming GVPRE received by its communication system. Said determination of the occupancy states of the smart rails of the track section or of all smart rails of the smart rail network is preferentially used within the smart rail network for managing the traffic of guided vehicles over said smart rail network. Preferentially, the determination of the occupancy states takes place in real time, wherein incoming and outgoing GVPRE are received and sent in real time, so that a continuous update of the occupancy states of the smart rail network is realized by each smart rail according to the invention.

[0024] At step 203, the intelligent system 111 of the smart rail, e.g. of the first smart rail 11, may communicate the determined occupancy states of the smart rail of the track section or of the whole smart rail network to another device, like an on-board device of the guided vehicle 21, or to a trackside or remote system 3. Preferentially, the determination of said occupancy state is configured for triggering at least one action configured for ensuring the safe displacement of the guided vehicles over said smart rail network. Such action may comprise sending CAPA to the guided vehicle or another device, wherein said CAPA triggers for instance a change within the current motion dynamic of the guided vehicle, like a decrease or increase of its speed, or triggers an actuation of a signal, etc.

[0025] As previously explained, the intelligent system of the smart rail may comprise detectors or sensors configured for detecting the presence of a guided vehicle and/or of a carriage of said guided vehicle. Such detector or sensor may detect for instance the presence of an axle 51, 61 of the guided vehicle using known techniques, e.g. based on a wheel sensor configured for detecting the presence of the wheel 21A, 21B affixed to the axle 51, 61, such technique being for instance used for axle counters. Additionally, or alternately, and as presented in Figures 5 and 6, the present invention proposes two different embodiments for enabling a communication of the guided vehicle with the smart rail, and enabling for instance the intelligent system to determine a presence or absence of guided vehicle, as well as the exchange of CAPA and GVPA. For instance, the intelligent system 111 may comprise a remote processing unit 52, 62 configured for being installed on-board the guided vehicle and for managing the exchange of data, notably said GVPRE, CAPA and GVPA, between the intelligent system of the smart rail and other on-board devices of the guided vehicle. According to the embodiment shown in Fig. 5, the remote processing unit 52 comprises a transmit/receive connection 53 connected to a first part of the axle 51 to which is affixed a first guided vehicle wheel 21A and a ground connection 54 connected to a second part of the axle 51 to which is affixed a second wheel 21B, wherein the first wheel 21A and the second wheel 21B are configured for mechanically and electrically contacting respectively the first smart rail 11A and the second smart rail 11B (i.e. the respective rail of the pair of parallel smart rails of the track), and wherein the first part and the second part are isolated from each other so that the first part, the first wheel 21A and the first smart rail 11A are electrically connected to each other and isolated from the second part, while said second part, the second wheel 11B and the second smart rail 11B are also electrically connected with each other. Due to this connection of the remote processing unit 52 to the first rail 11A and second rail 11B, a communication, e.g. a serial communication, between the smart rail and the guided vehicle is possible. For instance the first smart rail 11A comprises an intelligent system with a first processor 113 installed for instance within the base of the smart rail 11A and which exchanges data with the remote processing unit via the transmit/receive connection and further receives as input the ground from a connection of the first processor 114 to the base of the second smart rail 11B or to a second processor 114 of the second smart rail 11B. Each smart rail 11A, 11B is configured for electrically connecting the processor of the intelligent system to the wheel of the guided vehicle: the first processor 113 is electrically connected to the first wheel 21A and the second processor 114 is electrically connected to the second wheel 21B. Said second processor 114 receives said ground as input via its electric connection to the second wheel 21B through the second smart rail 11B. Said second processor 114 might also receive as input data from the transmit/receive connection to the remote processing unit 52 via a connection to the first smart rail 11A (e.g. via an electric connection to its base) or via a connection to the first processor 113.

[0026] While Figure 5 presented a wire connection of the remote processing unit to the smart rail, Figure 6 presents a wireless solution, wherein the remote processing unit 62 provides data to be exchanged with the intelligent system of the smart rail via a wireless communication system installed for instance on the axle 61 of the guided vehicle. For instance, each axle of the guided vehicle might be equipped with such a wireless communication system, wherein each wireless communication system is preferably configured for providing a GVPA comprising an identification of the axle on which it is installed. The communication system of the intelligent system uses then also a wireless communication technique for exchanging data, e.g. CAPA, GVPA, GVPRE, with the wireless communication system of the remote processing unit 62. According to Fig. 6, the remote processing unit 62 might be connected to a first wireless communication system 63 and to a second wireless communication system 65 which are respectively configured for communicating with the communication system 64 of the first smart rail 11A and with the communication system 66 of the second smart rail 11B. Redundant data might be exchanged with each smart rail 11A, 11B, or different data might be exchanged with each of said smart rails 11A, 11B of the pair of parallel smart rails. The communication system 64 of the first smart rail 11A, respectively the communication system 66 of the second smart rail 11B parallel to the smart rail 11A, is then connected to the processor 113 of the intelligent system of the first smart rail 11A, and respectively to the processor 114 of the intelligent system of the second smart rail 11B.

[0027] The remote processing unit 52, 62 enables the sending of GVPA from the guided vehicle to the processor of the intelligent system. For instance, due to the connection of the remote processing unit 52 to other on-board devices of the guided vehicle, said remote processing unit 52, 62 may determine or acquire GVPA such as the guided vehicle speed, length, the diameter of the wheel 21A, 21B, etc. Said GVPA are then automatically sent to the smart rail intelligent system processor either using a wire solution such as disclosed in Fig. 5 or a wireless solution such as disclosed in Fig. 6. Of course, other wire or wireless solution might be used for the communication between the remote processing unit 52, 62 and the processor of the smart rail. By this way, a communication between an on-board device of the guided vehicle (e.g. the remote processing unit 52, 62, or another on-board device connected to said remote processing unit 52, 62) and the smart rail is made possible. The intelligent system of the smart rail, depending on the determination of the occupancy states of the track section smart rails or smart rail network, taking into account optionally other railway network information that can be communicated by a remote device or trackside device, is configured for communicating to the remote processing unit 52, 62 installed on-board the guided vehicle CAPA, which comprise for instance a guided vehicle movement authority, and/or a speed limit that it can reach, and/or whether brakes have to be activated, etc. The remote processing unit 52, 62 is then configured for taking appropriate actions in function of the communicated CAPA. The processor of the smart rail may determine other actions in function of the occupancy states of the track section smart rails or smart rail network and/or in function of said other railway network information (like maintenance of a track, failure of a guided vehicle, change of a displacement schedule, etc.): for instance, it can be connected to a railroad switch and determine which switch position will give rise to the best or suitable route for reaching a predefined destination (e.g. the best or suitable route might be the one that provides the shortest displacement time for the guided vehicle, or the one which enables a stop at a specific station, etc.); it can be connected to a trackside system like a signal and control the latter in function of said occupancy states and/or other railway network information. Optionally, the smart rail according to the invention, in particular its communication device, may use routing protocols or a routing algorithm for determining how it will communicate with other communication systems (like the communication system of other smart rails or with the communication system/device on-board a guided vehicle or a communication system/device of a remote system) for distributing or exchanging information, notably by selecting routes within the smart rail network which satisfy requirements of said routing protocol or algorithm.

[0028] Figures 7 and 8 show details of a preferred embodiment of a wear detection system of the smart rail according to the invention. Such a wear detection system enables to automatically measure or detect a wear of the smart rail. As illustrated in Fig. 7 and 8, the smart rail 11 comprises longitudinal electrical wires 71 embedded in the smart rail head 81, wherein said longitudinal electrical wires are embedded within the smart rail head 81 (i.e. not apparent from the outside), arranged horizontally, i.e. parallel to the running surface 811 of the smart rail head, extending according to at least part of its length, and protected (or separated) from the rail head constituting material by an insulating cover, so that contact between the electrical wire 71 and the constituting matter of the rail head is avoided. Said electrical wires 71 are distributed at different places with respect to the running surface 811 of the rail head, for instance within each edge 812 of the rail head and within a central part 813 of the rail head when considering a transversal section of the smart rail as shown in Fig. 7A, wherein Fig. 7B shows an enlargement of the top of the rail head shown in Fig. 7A. Preferentially, the electrical wires 71 are embedded at different depths from the running surface 813. Preferably, said electrical wires 71 are embedded at different depth levels, each depth level comprising one or several electrical wires, said depth levels defining planes parallel to the running surface 811. Preferentially, for a first electrical wire 71A located in the depth level which is the closest to the running surface 811, then the smart rail 11 comprises at least a second electrical wire 71B located in the next depth level that is the closest to the running surface, wherein said second electrical wire 71 is arranged and extends within a same vertical plane as the first electrical wire 71A as shown in Fig. 7B. Otherwise said, the present invention proposes to arrange horizontal electrical wires (i.e. which are arranged longitudinally according to the length of the smart rail in a plane which is parallel to the running surface of the rail head) within a vertical plane (i.e. a plane perpendicular to the running surface) at different depths from the running surface so as to determine the wear of this running surface 811. Indeed, and as shown in Fig. 8, the longitudinal extremities of each electrical wire 71 arranged and extending at different depths within a same vertical plane and which are within or close to a same section of the smart rail are all electrically connected to a same connection wire 72, extending for instance substantially vertically from the smart rail head to its web or base, said connection wire 72 connecting said electrical wires to a resistor and a power supply of the intelligent system so as to create an electrical circuit whose impedance is measured by the processor 113 as shown in Fig. 8. By this way, the intelligent system is able to measure wear of the running surface 811 in function of changes of the impedance of each electrical circuit comprising longitudinal electrical wires 71 embedded in a same vertical plane, but at different depths from the running surface. Indeed, during aging (wear) of the smart rail, the electrical wires that are built inside the rail head will successively break (electrical wire open) due to the wheel wear, starting from the electrical wires which are the closest to the running surface and continuing then with the electrical wires which are deeper and deeper embedded in the rail head at said different depth levels, the breaking of each electrical wire 71 by a guided vehicle wheel changing therefore the impedance of the electrical circuit, wherein the processor 113 is configured for determining a wear level, and optionally location, in function of said change of impedance. In particular, each electrical wire 71 has an impedance which is known by the processor or is connected to a resistor whose impedance is known and predefined for enabling a measurement by the processor of electrical circuit impedance changes.

[0029] For instance, as the running head is worn out, the electrical wires 71 with impedance z1 73 and z2 74 will be successively destroyed so that a voltage measured by the processor 113 will be successively modified, said succession of modifications enabling the processor 113 to determine the level of wear and which part (e.g. one of the edge or central part of the rail head) of the running surface is affected. The present invention further proposes to use different impedances for the electrical wires so that each change of impedance within the electrical circuit might be directly and unambiguously associated to the destruction of a specific electrical wire by the guided vehicle wheel, making it therefore possible to determine which electrical wire was destroyed and therefore which part of the rail was affected.

[0030] Finally and to summarize, the present invention described a new kind of railway rail which differs from known railway rails in that it comprises an intelligent system providing intelligence to the railway rail, this intelligent railway rail, called smart rail, is configured for communicating with an intelligent system of a directly adjacent smart rail for exchanging a Guided Vehicle Presence signal that is used by the intelligent system for determining an occupancy state of each smart rail of a smart rail network or of a track section comprising said smart rails.

Claims

1. Railway rail of a track section, wherein said railway rail is **characterized in that** it comprises an intelligent system (111) configured for providing intelligence to said railway rail - called hereafter smart rail (11, 12) - wherein said intelligent system (111) is configured for communicating with an intelligent system (111) of another smart rail (11, 12) of said track section for exchanging a Guided Vehicle Presence signal (hereafter GVPRE) that is used by the intelligent system (111) for determining an occupancy state of each smart rail (11, 12) of said track section by a guided vehicle (21).

2. Smart rail (11, 12) according to claim 1, wherein said intelligent system (111) comprises:

   - a processor configured for determining said occupancy state of the track section from received GVPRE;
   - a communication system for sending/receiving the GVPRE to said directly adjacent smart rail (11, 12) ;

   wherein the intelligent system (111) is at least partially embedded into the smart rail.

3. Smart rail (11, 12) according to claim 2, wherein the GVPRE is sent to the communication system of the intelligent system (111) by at least one of the following:

   - a sensor (112) of the smart rail (11);
   - an on-board device of the guided vehicle (21);
   - a communication system of the intelligent system of said another smart rail (111);
   - a trackside system.

4. Smart rail (11,12) according to one of the claims 1 to 3, configured for exchanging data with guided vehicle (21), said data comprising guided vehicle parameters - hereafter GVPA - sent by the guided vehicle (21) to the intelligent system (111) and calculated parameters - hereafter CAPA - determined by the intelligent system (111) and sent to the guided vehicle (21).

5. Smart rail (11, 12) according to claim 4, wherein said CAPA comprises a guided vehicle movement authority, and/or a guided vehicle speed.

6. Smart rail (11, 12) according to one of the claims 1 to 5, wherein the intelligent system (111) is configured for automatically determining an action configured for ensuring a safe displacement of the guided vehicle (21) from the determined occupancy state of each smart rail.

7. Smart rail (11, 12) according to one of the claims 1 to 6, comprising a rail wear detection system.

8. Smart rail (11, 12) according to claim 7, wherein the rail wear detection system comprises electrical wires built in the smart rail head and extending longitudinally according to at least a part of the length of the smart rail.

9. Method for determining an occupancy state of a track section comprising one or several smart rails (11, 12), the method comprising:

   - a reception (201) by the intelligent system (111) of a smart rail (11) of a GVPRE, wherein the GVPRE comprises information about a presence or absence of a guided vehicle with respect to the smart rail or with respect to another smart rail of the track section;
   - a determination (202), by the intelligent system (111) of said smart rail, of an occupancy state of each smart rail of said track section from the received GVPRE.

10. Method according to claim 9, comprising a communication (203) of the determined occupancy state to another device.

11. Method according to claim 9 or 10, wherein the GVPRE is sent to a communication system of the intelligent system (111) by at least one of the following systems/devices:

    - a sensor (112) of the smart rail (11);
    - an on-board device of the guided vehicle (21);
    - a communication system of the intelligent system of said another smart rail (111);

- a trackside system.

12. Method according to one of the claims 9-11, comprising automatically measuring a wear of the smart rail (11, 12) .

13. Method according to one of the claims 9-12, comprising an exchange of data between the intelligent system (111) of the smart rail and an on-board device of the guided vehicle (21).

14. Method according to one of the claims 9 to 13, comprising automatically determining, from the determined occupancy state of each smart rail and by means of the intelligent system (111), an action configured for ensuring a safe displacement of the guided vehicle (21).

15. Method according to one of the claims 9 to 14, comprising automatically checking an integrity of a guided vehicle by means of the intelligent system (111) of the smart rail (11, 12).

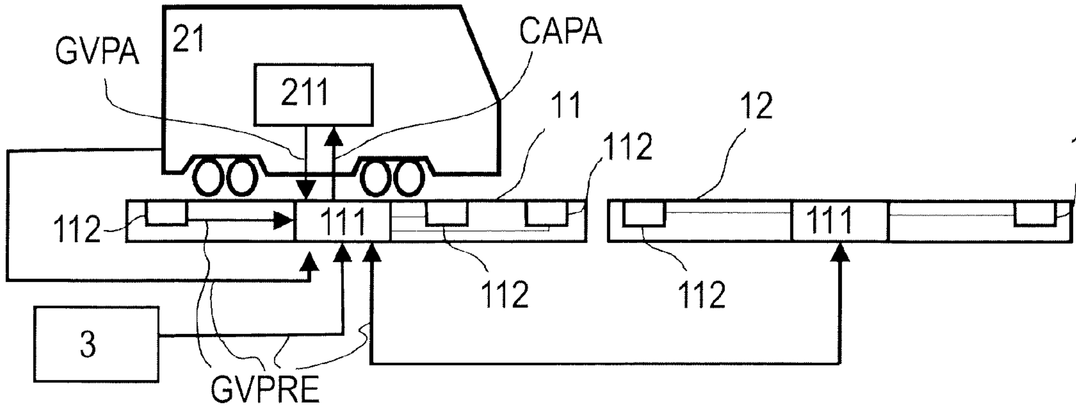


FIG 1

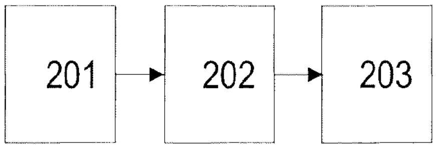


FIG 2

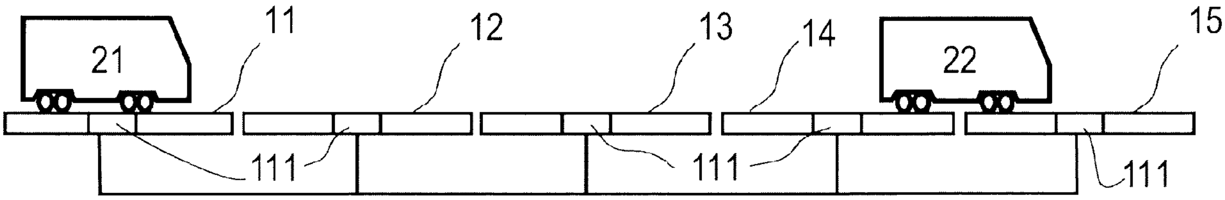


FIG 3

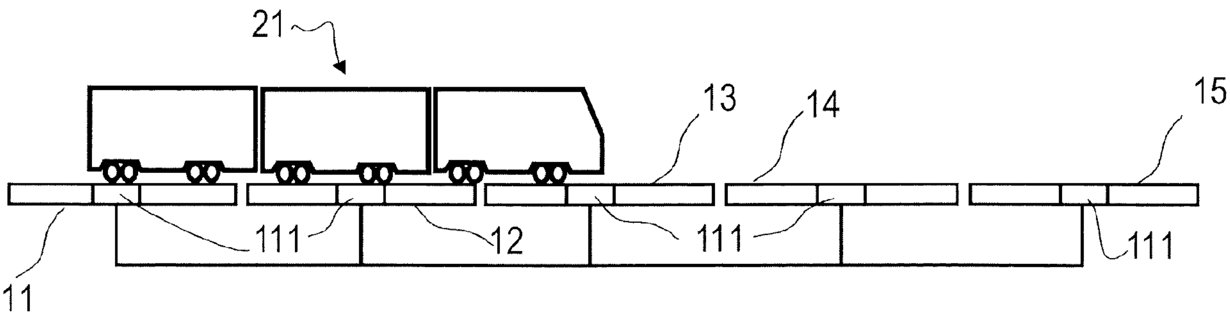


FIG 4

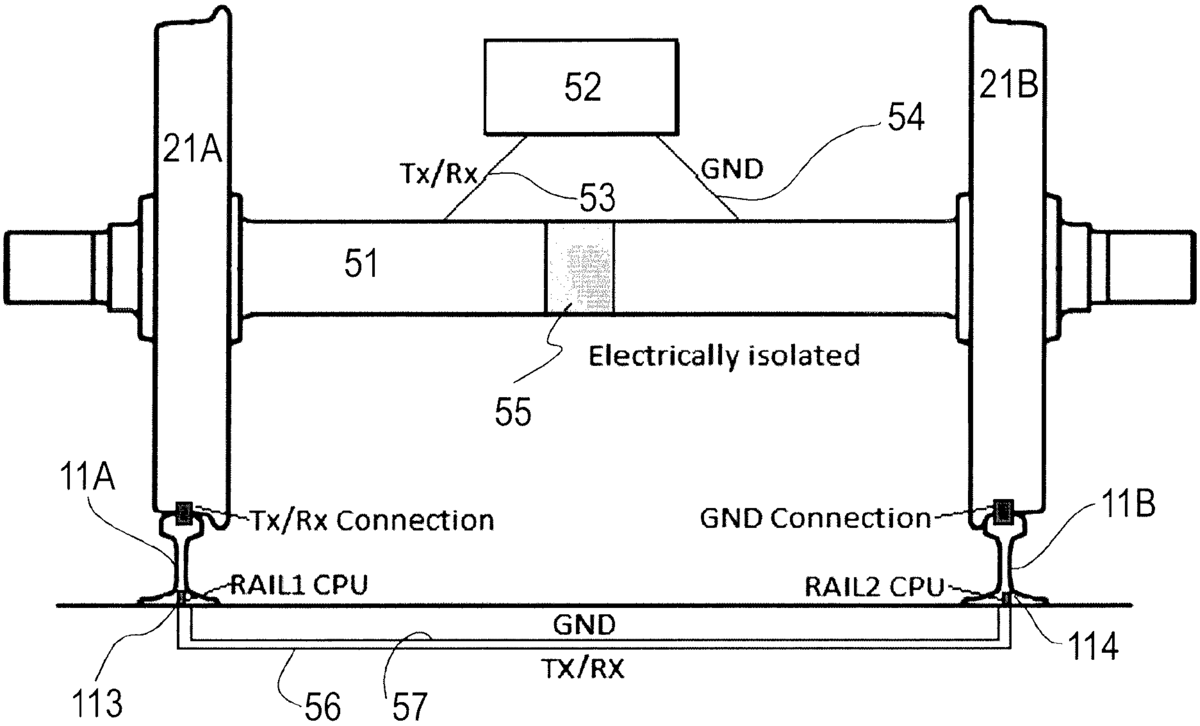

52
Tx/Rx
53
GND
54
21A
21B
51
Electrically isolated
55
11A
Tx/Rx Connection
GND Connection
11B
RAIL1 CPU
RAIL2 CPU
GND
TX/RX
113
56
57
114

FIG 5

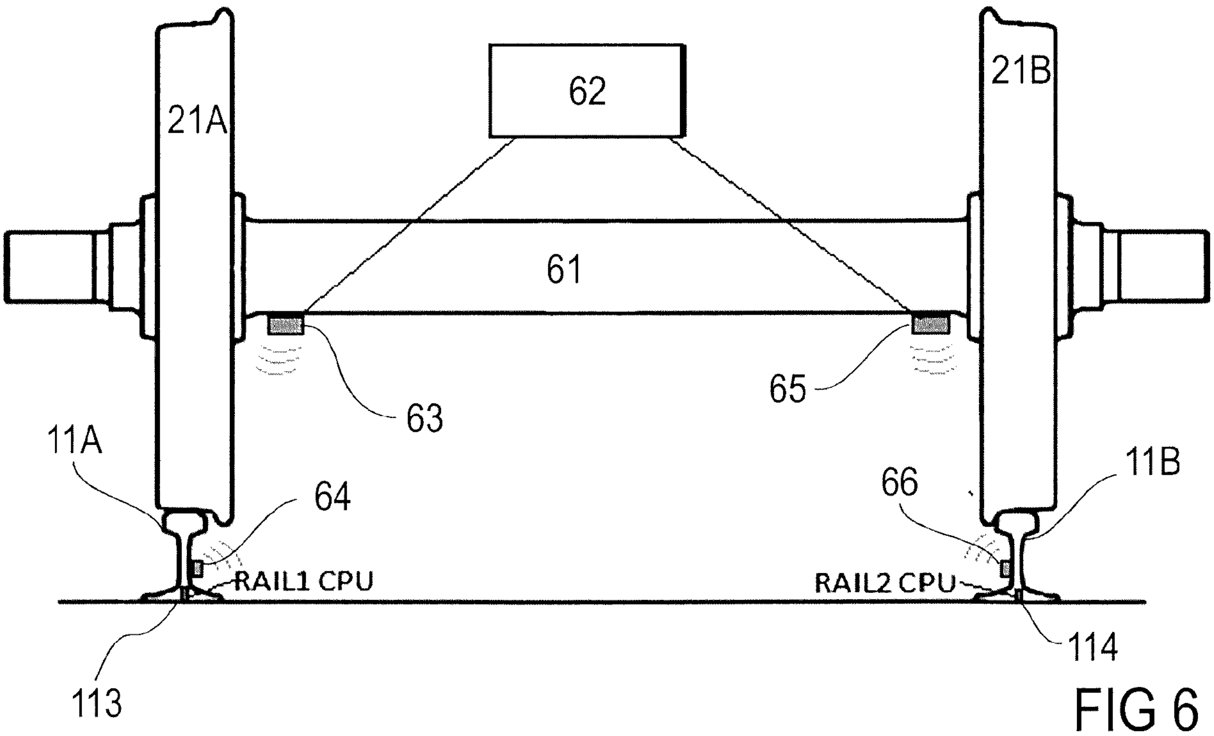
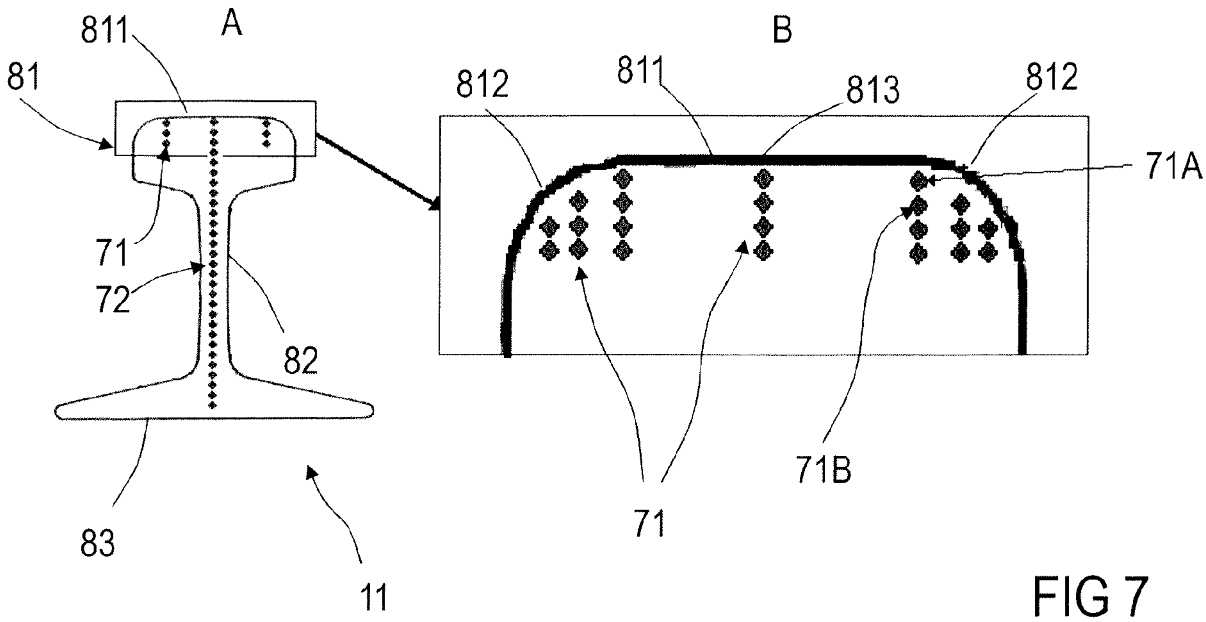

62
21A
21B
61
63
65
11A
64
66
11B
RAIL1 CPU
RAIL2 CPU
113
114

FIG 6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B
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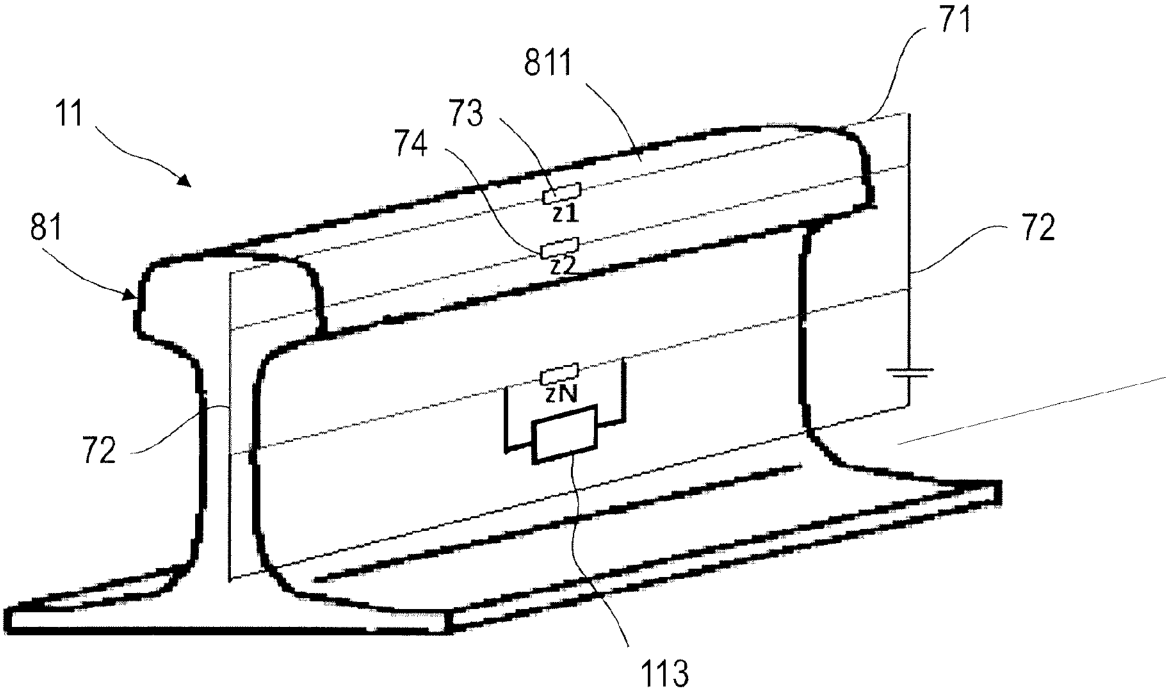
813
812
71A
71
71B

FIG 7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74
11
81
72
z1
z2
zN
72
113

FIG 8

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EUROPEAN SEARCH REPORT

Application Number
EP 20 38 0004

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X Y	EP 3 281 838 A1 (SIEMENS AG [DE]) 14 February 2018 (2018-02-14) * paragraph [0013] - paragraph [0014]; figure 1 * * paragraph [0026] - paragraph [0027] * -----	1-6, 9-11, 13-15 7,12	INV. B61L1/14 B61L1/16 B61L1/02 B61L3/00 B61L3/12 B61L3/22 B61L23/04 B61L25/02 B61L25/04 B61L27/00 B61K9/10 B61L15/00 B61K9/08
X	DE 195 09 696 A1 (SIEMENS AG [DE]) 12 September 1996 (1996-09-12) * column 2, line 18 - line 44; figure 1 * * column 5, line 41 - line 68; figure 3 * -----	1,6, 9-11,13, 14	
A	US 2020/023871 A1 (SNYDER TODD [US] ET AL) 23 January 2020 (2020-01-23) * paragraph [0028] - paragraph [0029]; figure 3 * -----	2	
Y A	CN 109 291 954 A (UNIV EAST CHINA JIAOTONG; CHENG XIAO) 1 February 2019 (2019-02-01) * paragraph [0002] - paragraph [0018]; figures 1,2c * -----	7,12 8	TECHNICAL FIELDS SEARCHED (IPC) B61L B61K
A	WO 2012/131683 A2 (INNOWATTECH LTD [IL]; KLEIN GREGORY [IL] ET AL.) 4 October 2012 (2012-10-04) * abstract; figure 5 * -----	7,8,12	

The present search report has been drawn up for all claims

3

Place of search	Date of completion of the search	Examiner
Munich	17 September 2020	Pita Priegue, Miguel

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

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Application Number
EP 20 38 0004

CLAIMS INCURRING FEES

The present European patent application comprised at the time of filing claims for which payment was due.

☐ Only part of the claims have been paid within the prescribed time limit. The present European search report has been drawn up for those claims for which no payment was due and for those claims for which claims fees have been paid, namely claim(s):

☐ No claims fees have been paid within the prescribed time limit. The present European search report has been drawn up for those claims for which no payment was due.

LACK OF UNITY OF INVENTION

The Search Division considers that the present European patent application does not comply with the requirements of unity of invention and relates to several inventions or groups of inventions, namely:

see sheet B

☒ All further search fees have been paid within the fixed time limit. The present European search report has been drawn up for all claims.

☐ As all searchable claims could be searched without effort justifying an additional fee, the Search Division did not invite payment of any additional fee.

☐ Only part of the further search fees have been paid within the fixed time limit. The present European search report has been drawn up for those parts of the European patent application which relate to the inventions in respect of which search fees have been paid, namely claims:

☐ None of the further search fees have been paid within the fixed time limit. The present European search report has been drawn up for those parts of the European patent application which relate to the invention first mentioned in the claims, namely claims:

☐ The present supplementary European search report has been drawn up for those parts of the European patent application which relate to the invention first mentioned in the claims (Rule 164 (1) EPC).

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LACK OF UNITY OF INVENTION
SHEET B

Application Number
EP 20 38 0004

The Search Division considers that the present European patent application does not comply with the requirements of unity of invention and relates to several inventions or groups of inventions, namely:

1. claims: 1-6, 9-11, 13-15

   Determining train occupancy

   ---

2. claims: 7, 8, 12

   Measuring rail wear

ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 20 38 0004

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on
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17-09-2020

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WO 2012131683 A2	04-10-2012	NONE	

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For more details about this annex : see Official Journal of the European Patent Office, No. 12/82