METHOD AND APPARATUS FOR DETECTING GUIDEWAY BREAKS AND OCCUPATION

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ABSTRACT
The present invention provides a method and system for detecting guideway anomalies. In particular, the present invention generates and couples a wave pulse into a guide- way. The wave pulse travels down the guideway until it reaches an anomaly. The anomaly causes a return wave pulse. The time difference between the generated wave and the return wave allows calculation of the deference to the anomaly.
200

- GENERATE WAVE PULSE
- TRANSMIT WAVE PULSE TO GUIDEWAY
- WAIT FOR A RETURN SIGNAL
- RECEIVE THE RETURN SIGNAL
- CONVERT INTO A SIGNAL USEABLE BY A PROCESSOR
- TRANSMIT TO PROCESSOR
- PROCESS

FIG. 2
METHOD AND APPARATUS FOR DETECTING GUIDEWAY BREAKS AND OCCUPATION


FIELD OF THE INVENTION

[0002] The present invention relates to track detection systems and, more particularly, to a detection system that detects local and distant rail breaks and track occupation.

BACKGROUND OF THE INVENTION

[0003] Trains and other rail or guideway moving vehicles and/or objects travel along common tracks at various speeds. The stopping distance of some trains can be many miles, but driver visibility is often less than this distance because of fixed conditions such as curves, embankments, trees, tunnels through hilly or mountainous terrain, and the like, or variable conditions such as poor weather. To maintain the desired operating speeds, train drivers need to know that the track ahead is free of breaks and not occupied by other vehicles. Thus, an automated warning system is frequently employed with the primary goal of detecting other trains on the track ahead and signaling the driver to slow or stop as necessary to avoid a collision.

[0004] Currently, track occupation detection involves a signaling system that is substantially external to the trains. The present signaling system regulates traffic flow and ensures train separation by dividing the entire length of track into a multitude of relatively short fixed blocks of various lengths, typically each no longer than some one to two miles. At the approach to each block, a visual indicator instructs the train crew to proceed according to the status of the track ahead, typically by providing a general speed range (go, may-have-to-stop, stop-immediately) that is based on whether or not other trains exist in the next few blocks of track. In particular, the indicator device provides a “go” or “proceed at normal speed” indication (meaning no train exists in the next few blocks), a “may have to stop” or “proceed with caution” indication (meaning a train is not in the next block of track but ahead in a subsequent block), or a “stop immediately” indication (meaning a train exists in the next block).

[0005] In order to detect the presence of a train in a signaling block, an electrical circuit method is usually employed. An electrical signal generator applies a continuous signal (generally a DC, audio frequency AC, or pulse coded voltage) between the two rails at one end of the block, and a relay or similar detection device measures the signal voltage between the two rails at the other end of the block. The rails of each block are electrically isolated from the rails of the adjoining blocks using special rail joints known as Insulated Joints (IJs). If no trains exist in the block, the rails act as an electric circuit with the signal generator at one end of the block energizing the relay at the other end of the block through the two conducting rails. A train at some location in a block is determined in a manner similar to a short circuit detection. Any locomotive or railcar axles, or any other conductive member, within the block act as a circuit shunt between the two rails to greatly diminish the signal voltage so that the relay becomes de-energized, thus closing a set of contacts connected to the signal indicators. The signal indicators will then warn any approaching vehicle to stop before entering the block because the track is already occupied.

[0006] The present system also has the added benefit that a fault or break in either rail within the track block can be determined in a manner similar to open circuit detection. A mechanical failure of a rail often leads to a small separation gap at the break because the rail is typically in tension at low to average temperatures. This interrupts the signal current path and also de-energizes the signaling relay. Based on the detection of an open circuit in a block, an approaching vehicle will be apprized to stop before entering the block because the track has a fault indication in it.

[0007] Generally, the electronic equipment and visual indicators exist as wayside equipment. The actual indicator may be, for example, a set of lights (a.k.a. “signals”) on the side of the track. The “go” indication is typically a green light that means no known breaks and no other trains in the next two or more blocks of track. The “may-have-to-stop” indication is typically a yellow light that means no known break or other train in the next block of track, but a break or train may exist in a subsequent track block. The “stop immediately” indication is typically a red light that means the next block of track has a break or is occupied. Thus the train operator should proceed at normal speed upon seeing a green light, stop upon seeing a red light, or slow on seeing a yellow light in anticipation of a possible red light at the next set of signals.

[0008] As can be imagined, the existing external detection system requires significant wayside infrastructure for every relatively short block of track. The signal generation circuitry, detection circuitry and the indicator lights require electrical power and are often located in remote and sometimes difficult to reach locations. The cost per mile of new track installation is burdened by the capital outlay for signaling equipment and interconnecting cabling, additional construction and installation expense, and costs associated with providing electrical power at regular intervals along the track. In operation, the wayside infrastructure has high maintenance and upkeep costs per mile of track. Signaling equipment is subjected to extreme temperatures and poor weather conditions, and is susceptible to equipment failures that sometimes lead to expensive traffic delays.

[0009] Many railroad companies are investigating Communication Based Train Control (“CBTC”) as an alternative means of regulating the speed and separation of track vehicles. It is proposed that GPS location and speed information from each vehicle would be sent via data communication, such as radio frequency broadcast, to a central coordinating facility, somewhat akin to an air traffic control center. The optimum desired speed would then be sent back to each vehicle via the same communication system. CBTC would allow for more flexible train spacing and more graduated speed control to optimize traffic flow, improve safety, and maximize rail utilization efficiency. CBTC would also provide improved fuel efficiency by avoiding cycles of breaking and acceleration that the present system sometimes produces.

[0010] The implementation of CBTC is intended to replace the primary signaling system function of traffic
regulation and could potentially provide additional significant cost savings by allowing the removal of the present signaling system and associated wayside infrastructure, except that this system serves an important secondary function. The signaling system current passing through the rails provides for the detection of any rail break that interrupts the current flow. This feature has averted many potential train derailments, and therefore an alternative method to detect rail breaks is required. A viable alternative must be more cost effective than maintaining the present signaling system for the sole remaining purpose of detecting broken rails; should provide at least equivalent protection in terms of range (monitored distance ahead of the train) and sensitivity to various break types; and should be as compatible as possible with present track designs, structures, and track maintenance practices.

[0011] It should be noted that CBTC would only protect against collisions with other vehicles that are being accurately tracked in the database of the central coordinating facility, i.e., only those vehicles equipped with CBTC, GPS, and data communication systems, and where all systems were operating correctly. For example, CBTC would not protect against collisions involving non-CBTC track occupation such as an unexpected detached railcar.

[0012] Thus, it would be desirable to develop an alternative apparatus and method for the detection of rail breaks and unexpected track occupation.

SUMMARY OF THE INVENTION

[0013] The foregoing and other features, utilities and advantages of the invention will be apparent from the following more particular description of a preferred embodiment of the invention as illustrated in the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWING

[0014] The accompanying drawings, which are incorporated in and constitute a part of this specification, illustrate embodiments of the present invention, and together with the description, serve to explain the principles thereof. Like items in the drawings are referred to using the same numerical reference.

[0015] FIG. 1 is a functional block diagram illustrative of one example of an embodiment of the present invention;

[0016] FIG. 2 is illustrative of a flowchart showing one method of implementing an embodiment of the present invention;

[0017] FIG. 3 is a side elevation view of a locomotive containing an embodiment of the present invention; and

[0018] FIG. 4 is a bottom elevation view of a potential track coupler shown in FIG. 1.

DETAILED DESCRIPTION

[0019] The present invention will now be described with particular reference to the figure(s). While the present invention is described with particular reference to railroads, locomotives, and the associated tracks, one of ordinary skill in the art will now recognize that the present invention could be used with any system that has a "guideway" where a signal can be transmitted along the guideway. Such guideways include, for example, rail tracks, conveyor belt systems, assembly lines, and other systems where the longitudinal members of the guideways are conductive and at least partially isolated from each other. Alternatively, non-conductive guideways can be made conductive by adding conductors, such as wires or conductive rods.

[0020] The present invention describes an improved rail break detection system operating independently from the existing wayside signaling system. The invention may be used in conjunction with present signaling systems to provide specific advantages such as determining the exact break location, but the invention is particularly suitable to be used in conjunction with CBTC as a replacement for the present signaling system. The combination of CBTC and the present invention will supersede all of the functions of the present signaling system by providing advanced traffic management as well as improved broken rail detection. As an adjunct to the CBTC system, the present invention can also indicate track occupation as a failsafe to avoid vehicle collisions.

Method Selection

[0021] Several methods of broken rail detection and track occupation are possible. However, it has been determined that any viable replacement system should avoid replacing the existing wayside electrical equipment with an alternative wayside system. Replacing one wayside infrastructure system with another would likely not significantly reduce maintenance expenses, which are a major component of ongoing railroad costs, or solve the reliability problems associated with a widely distributed infrastructure operating in harsh field conditions. Thus it was established that the ideal system would be one that mounted on the lead locomotive of each train. On average, the number of locomotives employed by a railroad is far less than the number of existing signaling blocks, so far fewer systems would be required. It would then become feasible to increase reliability by providing redundant systems on each locomotive. Key components would be housed in the better-controlled environment of the locomotive cab, further improving reliability. Maintenance of a locomotive-based system could be centralized to existing locomotive workshops and coincide with regular locomotive maintenance, rather than requiring a large number of distributed support and maintenance personnel in the field.

[0022] It was also established that the replacement system should perform real time rail break detection ahead of the train with a sufficient range and warning time to allow stopping or at least significantly slowing the train. The ability for fast, real time rail break detection is made more important because the CBTC potentially decreases separation between sequential trains, and rail breaks can be precipitated by the preceding train.

[0023] With these constraints in mind, it was determined an ideal method to detect rail breaks would be for the lead locomotive of the train to transmit a wave signal that would propagate along the rail. If the propagating wave signal encountered a break, a reflection would be sent back towards the lead locomotive that would be received by a receiving unit in the lead locomotive. Instead of a separate transmitter and receiver, the present invention could use a transceiver.

[0024] Types of wave signals that could be sent from a transmitter mounted on a train, propagated along the rails,
reflected by a rail break, and detected by a receiver mounted on the train include, for example, acoustic waves and electromagnetic waves. Acoustic waves might have the capability to detect some rail integrity failures (and partial or imminent failures) that electromagnetic waves would not. For example, acoustic waves might detect large internal defects or internal fractures in the rail indicative of a pending break, allowing repair prior to an actual break occurring. Furthermore, it is also possible for a rail to be broken (i.e., mechanically separate) and yet maintain electrical continuity. One example is an “S” shaped rail break originating as a horizontal web defect in which the non-vertical faces of the two rail parts rest against each other. Other possibilities include a break resting on a conductive metal tie plate, or a break occurring with the rail at an elevated temperature and therefore under compression due to thermal expansion. Acoustic waves might detect these failures because the acoustic wave travel may be impeded by the defect or break. Whereas an electromagnetic wave would not see the failure because a complete electrical connection still exists, allowing transmission of the electromagnetic signal.

[0025] One major disadvantage with acoustic waves, however, is that they would be attenuated over relatively long distances by the regular firm mechanical anchoring of the rail to the track structure using wooden, concrete, or steel cross ties. Acoustic waves would also be greatly attenuated by common track components, such as bolted rail joints and track turnouts. Thus, acoustic waves would have a limited range and would be “blinded” beyond existing joints, turnouts and other common track structures unless major changes were made to existing track components, construction methods, and maintenance procedures. Also, many other common track features such as normal bolt holes would probably cause false-positive indications because the acoustic wave would be partially reflected, even though the bolt holes are deliberate and do not represent structural defects. Although a well designed system might map and track these numerous reflectors in a database, new acoustic reflectors such as added bolt holes and rail ends (e.g., plated defects and temporary plug rail repairs) would have to be continuously updated in the database to avoid unnecessary traffic delays.

[0026] For these reasons, electromagnetic waves may provide better detecting than acoustic waves. While potentially not as efficient at detecting partial rail breaks or breaks with maintained electrical continuity, electromagnetic waves are very compatible with existing detection sensitivity and rail maintenance procedures, because the basic detection principle is the same; that is, the detection of a local dramatic variation in rail conductivity due to a rail break. Therefore, all breaks that are detectable by the existing signaling system are likely to be detectable by the present invention. The major difference is that detection will be based on the reflection of an electrical pulse that is both generated and received at the moving locomotive, rather than the interruption of a continuous electrical current between two separate fixed locations using wayside equipment.

[0027] Another system may combine both acoustic and electrical signals for detection. The acoustic wave, it is believed, may provide superior short distance detection, while the electromagnetic wave, it is believe, may provide superior long distance detection. Thus, combining both wave forms into a single detector system may provide a system that overcomes the drawbacks of either wave form used alone.

[0028] FIG. 1 shows a simple functional block diagram of a sample rail break detection system 100. The rail break detection system includes a waveform generator 102, a wave transmitter 104, a track coupler 106, a wave receiver 108, and a processor 110. Processor 110 is connected to a data link 112. Data link 112 may connect the present invention to the CBTC system. Data link 112 could be a cable connection, a wireless connection, an antenna, a bus connection, a network connection (LAN, WAN, Ethernet, or Internet), or the like. The device is mounted in a locomotive (not specifically shown) in this example, but could be installed on other rail vehicles, at fixed locations, or on any device traveling over a guideway as described above. An appropriate processor controls the entire system with software modules configured to instruct the various components and process the results. Waveform generator 102 may be caused to operate with particular unique operating characteristics to allow for easy of identification of generators. For example, one or more generators could be identified according to the entire code or a subset of the code used to modulate the initial transmitted pulses. Data link 112 could be connected to a memory or storage unit 114 or a global positioning system 116. Finally, while the components of system 100 are shown discretely, the various components may be combined into less components or separated into still other components.

[0029] Referring to FIG. 2, a flowchart 200 showing the operation of system 100 is provided. First, processor 110 causes wave generator 102 to generate a wave pulse over a predetermined length of time, step 202. The generated wave pulse is coupled or transmitted to the guideway by track coupler 106, step 204. Next processor 110 causes system 100 to wait for a return signal, step 206. The wait period is provided to allow system 100 to receive a return or echo pulse from the guideway anomaly, if any exist. System 100 receives the return or echo pulse at track coupler 106, step 208, which is sent to processor 110 for processing, step 210. The processing may include filtering, amplification, verification that the received signal is the return or echo and not noise, or the like. Receiver 108 converts the signal into a format usable by processor 110, step 210, and transmits the signal to processor 110, step 212. Processor 110 processes the signal, step 214. Processor 110 may calculate or process the information to determine features such as whether an anomaly exists, type of anomaly indicated (break or obstruction), distance to anomaly, alternative routes to avoid the anomaly, rate of approach, or the like. Processor 110 may transmit information using data link 112 to a central coordination system to update information. Anomalies may include, for example, actual breaks, guideway occupation, pending breaks, or the like.

[0030] Waveform generator 102 is shown as a single generator, but waveform generator 102 may actually comprise one or more generators. Also, a single generator may produce a plurality of waveforms. A plurality of waveforms may be generated substantially simultaneously, simultaneously, or discretely to provide different information. For example, a high frequency signal may be provided with a lower frequency signal to provide wave pulses capable of measuring both short distance anomalies and long distance
anomalies without significant interference, as the high and lower frequency signals are distinguishable. Instead of frequency changes, waveform generator may comprise alternative differentiation characteristics, such as, for example, different phases, different modulations, different type of waveforms, different wait periods, or the like.

[0031] In operation, processor 110 would trigger wave generator 102 to generate an electronic signal that the wave transmitter 104 converts into an electromagnetic, acoustic, electric, magnetic, radio frequency pulse or the like that can travel along the rails. Track coupler 106, which could be, for example, the locomotive wheels or an inductive wire loop 402 (shown in FIG. 4) disposed adjacent to the two rails, couples the electromagnetic wave into the rail. Other potential devices to couple a signal into the rails are disclosed by U.S. Pat. No. 1,517,549, issued Nov. 19, 1919, titled Rail Signaling System, incorporated herein by reference. While the '549 Patent discloses direct, inductive, and capacitive coupling techniques to direct a wave in a rail, it should be understood that the '549 Patent discloses coupling a continuous wave into the track with signal generation and analysis occurring concurrently. Track conditions are determined by measuring modifications of rail input impedance caused by the standing waves that result from the interaction of outgoing and reflected waves. However, the '549 Patent does not work at any useful detection range, and is not presently implemented. The changes in rail characteristic impedance caused by distant rail breaks or track occupation are not statistically significant due to the large signal attenuation between the original and reflected wave components of the standing wave. Conversely, instead of using a continuous wave, the present invention uses a pulse-echo method so that the transmit time period is not concurrent with the receive time period. The large difference in signal level between the original transmitted pulse and the reflected, potentially highly attenuated pulse is irrelevant since the received signal can be amplified to a suitable level by receiver 108 at a time when transmitter 104 is inactive. Further, the pulse-echo timing indicates the exact distance to the reflector rather than relying on the interpretation of small variations in signal levels, which are also subject to many extraneous variables, to detect small track impedance changes caused by reflected waves (as required by the '549 Patent).

[0032] Time Domain Reflectometry (TDR) is often employed to identify and locate electrical faults in transmission line cables. Every transmission line has an associated characteristic impedance determined by the physical cross section and the electrical properties of the conducting and insulating materials used in construction. An electrical fault in the cable will cause a local deviation from the characteristic impedance, with a complete short circuit or a complete open circuit representing the most extreme cases. A TDR-based cable tester operates by injecting an electrical pulse at a test location to propagate outward along the cable. If a change in impedance is encountered, some amount of the pulse is reflected back to the test location where it is measured and analyzed. The amount of reflection is determined by the degree of impedance mismatch (100% reflection in the case of an open or short circuit), the phase of the reflected signal indicates whether the fault is a higher or lower impedance than the characteristic value, and the time delay between transmitting and receiving the pulse is used to calculate the distance to the fault for a given propagation velocity. The use of TDR pulse-echo testing to locate and identify transmission line faults is well known in the art and will not be further explained herein.

[0033] In the present invention the electromagnetic signal is coupled into the track with the two rails acting as a two-wire differential transmission line, as disclosed in the '549 Patent. Methods of coupling radio pulses into and from a two-wire differential transmission line are well known in the art and will not be further explained herein. For broken rail detection, a change in transmission line impedance will be caused by the rail break, i.e., an open circuit. For occupied rail detection, the axles and wheels of the preceding train acts as a short or short circuit between the two rails that will also cause a reflection. When either of these conditions is encountered, a reflection is returned towards the locomotive. Track coupler 106 transfers the reflected pulse from the track to wave receiver 108. Wave receiver 108 supplies the received information to processor 110. Processor 110 uses the information to determine whether a break or occupation of the track exists. Processor 110 can measure the time between the outgoing wave pulse being generated and the reception of the reflection pulse to calculate the distance to the break. Also, if additional information, such as train speed, is input to processor 110, additional processing can be performed and additional useful data can be calculated. Such additional data could include time to break, rate of approach, or the like. An automated emergency braking function could also be provided according to a predefined set of rules and safety requirements.

[0034] Apart from replacing the broken rail detection function of the present signaling system and eliminating the need for wayside equipment, the proposed method has many additional advantages. For example, the exact location of the break or occupying train can be indicated rather than just the signal block, so a driver response can be more appropriate and rail breaks can be more quickly found and repaired. A further advantage is that the maximum detection range will be determined by a broader set of parameters, rather than just the accumulated shunt loss of signal between the rails due to track bed conductance (a.k.a. “ballast leakage current”) that sets the usual upper range limit (maximum block length) for present signaling systems. Although the range of the present invention is also affected negatively by the shunt conductance acting to attenuate the differential pulse signal, methods are available for increasing the transmitted energy (longer pulse, higher power) and recovering weak received signals from noise (coherent signal averaging and signal processing) to compensate for higher attenuation of the signal at greater distances. This provides an opportunity to overcome the usual range (block length) limitation of present systems, typically given as 1, 2 or 5 miles.

[0035] The lead locomotive would have a signal coupling mechanism 106 that would allow a radio frequency (RF) pulse to be differentially coupled into the rail pair to travel forward, ahead of the train. The two rails act as a differential pair transmission line to propagate the electrical pulse to the rail break. At the break, the interruption of current flow would cause a partial reflection of the RF pulse back toward the train. The same or similar coupling mechanism (used in reverse) would then convert the arriving pulse into an electrical signal to be amplified and then processed by correlating the received signal to the original transmitted signal. The exact time delay between the transmitted and any
received signal would be calculated by processor 110, and, based on the known or measured electromagnetic propagation speed, the distance to the reflector would be determined and displayed.

**[0036]** It is contemplated that the RF pulse would be a high power pulse to provide greater distance of travel. Each train could use a specific modulation code and/or pulse repetition timing sequence so multiple trains in a specific area could each identify their own signals. This coding could optionally be used in conjunction with “matched filtering” of the received signals to provide “pulse compression” and “processing gain”. These signal correlation techniques improve timing accuracy and allow very small signals to be recovered, even from below the level of ambient electrical noise and interference. Correlation of signals received in different pulse-echo test cycles would require appropriate compensation for the change in locomotive location between transmitted pulses. Methods of small signal recovery, signal correlation, movement compensation, reflector classification and reflector range determination are well known in the art, particularly in the fields of electromagnetic pulse-echo RADAR, acoustic pulse-echo ultrasonic testing and acoustic pulse-echo SONAR, and will not be further explained herein.

**[0037]** A further benefit of this method of detecting broken rails is that it would provide an auxiliary safety mechanism to avoid train collisions and maintain appropriate traffic separation. Transmission line theory indicates that any impedance change will cause a reflection (relative to the degree of impedance mismatch), and the voltage phase of the reflected signal will be inverted for a lower impedance (e.g., short circuit) or non-inverted for a higher impedance (e.g., open circuit). Any rail shunt, such as the last axle of the preceding train, would cause a signal reflection, and the phase of the return signal would distinguish the rail shunt from a broken rail. Thus while CBTC is expected to provide the primary means of ensuring safe separation of traffic, each train will also be able to independently measure the distance to the train ahead (within the achievable detection range) to help maintain a safe stopping distance in case of an emergency situation. It should be noted that a rail failure can be triggered by the passage of the preceding train. If such a broken rail occurs under the preceding train, and the distance to that train is being continuously monitored by the following train using the present invention, the signal phase of the reflected signal will invert as soon as the last axle of the preceding train has passed beyond the break. In this way, the presence and location of the broken rail can be indicated to the driver of the following train at the earliest possible moment so that appropriate action can be taken. The ability to detect and locate any rail shunt in the track ahead is also highly desirable since CBTC will not provide protection against any track shunting equipment or individual railcars that are not registered in the CBTC system.

**[0038]** Present signaling systems detect a break or track occupation based on the electrical properties of the track. Each rail is normally highly conductive while conduction between the rails of unoccupied track is normally reasonably low. A break will usually lead to poor rail conductance while track occupation results in high rail to rail conductance. Although the detection method is very different, the present invention relies on the same fundamental electrical properties of tracks, breaks and occupation, so converting to the new method will be straightforward, i.e., no major changes in track construction or maintenance procedures will be required. For example, a temporary bolted track repair that was compatible with the existing signaling system (i.e., with suitable intrinsic or added electrical conduction to allow normal signal operation) would also be suitable for the proposed system and would not introduce a new “false” signal reflector. No changes in the installation, replacement or repair of Continuous Welded Rail (CWR) track would be required; although new installations or major re-railing projects would benefit from not needing to add signaling IJs at regular intervals. The usual practice would continue of using bond wires to electrically bypass any poorly or intermittently conducting ordinary joints in jointed track, or where occasional joints were necessary in CWR.

**[0039]** Many existing signaling systems use IJs to electrically isolate the signal blocks. These IJs would simply be electrically bypassed and the signaling system turned off. Over time, these IJs could be replaced with welded plug rails and signaling equipment could be removed. If desired, it would be possible to operate the new and old systems in parallel during a gradual changeover period. By using suitably tuned filter circuits to bypass the signal IJs at the RF pulse frequency, the new system could provide protection beyond IJs while the operation of the signaling system at DC or low frequency AC would not be affected.

**[0040]** It would be beneficial to continue protection beyond track turnouts and crossing diamonds. This could be achieved by providing electrical circuit switching to operate in parallel with the mechanical track switching. The electrical continuity of the rail pairs would correspond to the track selection through the turnout, so that breaks or occupation in the track that the train was about to enter (after the turnout) would be properly detected while the status of the other track (e.g., a siding occupied by a waiting train) would be properly ignored. IJs would be required in the immediate vicinity of the turnout to electrically isolate the separate tracks so that only the selected pair of rails was electrically connected around the turnout. An additional benefit of this approach is that in case the train was approaching a turnout that was set against it (i.e., traveling toward the turnout along the unselected track) the track would indicate appropriately as an unconnected or “broken” rail. Crossing diamonds (used at the intersection of two tracks) would also require IJs, with permanent crossing cables providing the proper electrical continuity of each pair of rails. In this case, a fixed wayside system may be justified to interlink the two tracks via relays so that a train approaching or across the intersection on either track would register as an occupation of both tracks.

**[0041]** In order to determine reflector location and to properly compensate for train movement when correlating signal reflections measured in different test cycles, processor 110 requires input from some form of sensor indicating the speed and/or location of the train. This information could be provided, for example, by an independent GPS receiver on the locomotive. Preferably, processor 110 could have a data link to the CBTC system. This link could provide access to the locomotive GPS data utilized by the CBTC system, and also provide new and useful information back to the CBTC system, such as, rail failure location or rail pending failure location, unidentiffied track occupation, or the like. Further, the location of other track vehicles known to the CBTC system could be compared to track occupations determined
by the present invention to verify the correct operation of both systems, and to indicate any unexpected track occupation not identified within the CBTC system (e.g., an uncoupled freight railcar). Also, a centralized database of known partial reflectors could be maintained within the CBTC system so that the location of any detected reflector might first be checked against the known reflector locations before raising an alarm. Such partial reflectors would include, for example, road crossings where the application of salt for winter ice control may lead to a slight, local track impedance variation due to higher conductance between the rails. It may also be useful to combine information from the present invention with information from the CBTC system onto a common display for the locomotive crew, depicting all useful information on the status and conditions of the track ahead.

[0042] While the present system is described as forward-looking with respect to the locomotive, a similar system could be installed at the rear end of the train to send a backwards-traveling pulse as well. This backwards-traveling pulse could tell a locomotive of an approaching locomotive, which would be especially useful if the front train was slow moving (or reversing) and the approaching train was not equipped with detection equipment. Also, the backwards-traveling pulse could indicate rail failures caused by the passage of the train. This would be useful in conjunction with the data CBTC uplink because the failure location could be relayed to the following train, and a repair crew immediately dispatched. Further, the CBTC system could reroute following trains based on track failure information.

[0043] The present invention has been largely described as operating from a moving vehicle, such as a locomotive, to detect rail breaks or occupation. FIGS. 3 and 4 show possible placement of, for example, system 100 in a locomotive 302. Referring specifically to FIG. 3, an elevation/ cut-away view of locomotive 302 is shown. As with conventional locomotives, locomotive 302 has a driver or conductor control stand 304. An interface unit 306 located about the stand contains conventional controls as well as an interface 308, such as a display, monitor, light, bell, whistle, buzzer, or other indicator connected to processor 110. Information determined by processor 110 can be provided to interface 308 such that the driver can act. Processor 110, and other components of system 100, may be mounted in various locations, but typically processor 110 would be mounted in electronics cabinet 310. Track coupler 106 could be located in the locomotive axle 400 or somewhere on the locomotive. FIG. 4 shows a particular track coupler 402. Coupler 402 comprises a wire trace or coil that provides inductive signal coupling to tracks 404.

[0044] However, instead of mounting system 100 on a locomotive, such as shown in FIGS. 3 and 4, the present invention would also be useful at a fixed location to detect breaks or determine the exact speed and distance for an approaching track vehicle. One example would be to automatically adjust the timing of road crossing warning signals and gates so that road drivers would have adequate warning to stop even for the fastest trains, but not become impatient (and perhaps attempt to circumvent the barrier) waiting for the slowest trains. A further example would be to indicate train proximity for pedestrians or passengers waiting at a station. Rail workers operating on or near a track could also use a portable system to warn of approaching trains.

[0045] The present invention has been largely described to detect unexpected rail breaks or occupation. However, it would also be possible to locate reflectors placed deliberately in the railroad system at predetermined locations to provide calibration signals, location markers, track status signals or the like. Typically, the deliberate reflectors would be partial reflectors to allow the present invention to distinguish between actual breaks and/or occupation and a calibration signal, or the like. Further, partial reflectors allow some of the pulse energy to travel beyond the partial reflector to provide continuing detection of any subsequent unexpected reflectors. Also, rail workers could place deliberate reflectors (such as a track shunt) to signal their location to approaching locomotives.

[0046] Instead of using passive reflectors, the track status indicators, calibration devices and/or worker locations could be active transponders. Rather than passively reflecting an arriving signal, a transponder would actively transmit a response that could include additional identification or status information. These signals would typically be received by the receiver on the locomotive as a specially modified signal that would be readily distinguishable from a normal rail break or occupation signal. Alternatively, one leg of the normal pulse-echo path through the track could be substituted with another path such as a direct atmospheric radio link, similar in principle to the operation of aircraft RADAR transponders.

[0047] The placement of predefined markers for calibration is helpful because changes in environmental conditions can also change the transmission line properties of the rails (whether using acoustic or electromagnetic waves). Thus, having preset calibration points would allow for real time calibration of processor 110 for range, transmit signal level, break location accuracy and the like.

[0048] Each locomotive could also provide several different pulses at various frequencies. For example, high frequency pulses generally allow shorter pulse lengths which would be useful for avoiding overlapping timing of the transmit pulse and reflected signal from nearby reflectors. Also, higher frequencies have shorter wavelengths and would generally provide better resolution of the reflector location. However, because of the nature of the rail transmission line parameters, signal attenuation increases rapidly at higher frequencies indicating that lower frequencies are probably more appropriate for detecting reflectors at greater distances. Thus, a locomotive may send two or more pulses at various frequencies to cover the required detection range for the encountered track conditions. These various frequencies could be generated simultaneously, substantially simultaneously, or sequentially as a matter of design choice.

[0049] Railroad authorities and companies are extremely concerned with the safety of employees. In order to help insure the safety of the locomotive crew, the present invention could include a signal monitoring means to ensure sufficiently low levels of radiated RF energy in and around the locomotive to meet RF exposure safety guidelines. Further, such monitoring means would be useful to indicate the general proper operation of the system and would detect, for example, excessive signal radiation caused by a failure or incorrect adjustment of the track coupler 106.

[0050] Using the present invention in conjunction with the CBTC GPS-based system or with an independent GPS
receiver would provide access to the standardized, highly precise reference clock incorporated into each GPS satellite. Using the GPS timing reference would allow for a high degree of coordination between multiple units utilizing the present invention on various locomotives and fixed locations. This timing reference could be used to avoid overlapping pulse-echo test cycles between multiple units, or to calculate the distance to various other units by observing the arrival time of the transmitted pulses from those other units.

[0051] While the above invention has been described to provide a RF pulse into a track, system 100 would operate very similarly if an acoustic pulse was utilized. For example, wave transmitter 104 could produce an ultrasonic pulse that would be coupled into the track and directed forward of the locomotive. Additionally, combinations of pulses could be provided. For example, a RF pulse could be used in combination with an acoustic pulse. The RF pulse would provide detection for actual breaks and occupation that can be characterized by an electrical impedance change, but the acoustic pulse would provide detection of some breaks and pending failures that may only be evident as an acoustic impedance change.

1 claim:

1. A method of determining a distance to an anomaly in a guideway, the method preformed on a processor comprising the steps of:
   generating a wave pulse;
   coupling the wave pulse into the guideway;
   waiting a predetermined wait time to receive a return pulse from the guideway;
   if the return pulse is received within the predetermined wait time, determining whether an anomaly exists on the guideway; and
   after the predetermined wait time, repeating the generating, coupling, and waiting step.

2. The method of claim 1, wherein the wave pulse comprises at least one of an electrical wave pulse, an acoustic wave pulse, a magnetic wave pulse, an electromagnetic wave pulse, or a radio frequency wave pulse.

3. The method of claim 1, wherein the guideway comprises at least a pair of conductive members.

4. The method of claim 3, wherein the pair of conductive members are at least partially isolated.

5. The method of claim 1, wherein the determining whether an anomaly exists step comprises detecting impedance variations.

6. The method of claim 3, where the step of detecting impedance variations comprises detecting impedance variations in both conductive members of the pair of conductive members.

7. The method of claim 5, wherein an increase in impedance provides an indication of an anomaly consistent with a break in the guideway and a decrease in impedance provides an indication of an obstruction in the guideway.

8. The method of claim 1, wherein the step of generating a wave pulse generates the pulse over a predetermined pulse timeframe.

9. The method of claim 8, wherein the step of generating a wave pulse generates a plurality of relatively short wave pulses over the predetermined pulse timeframe.

10. The method of claim 9, wherein the plurality of short wave pulses comprise at least a first short wave pulse at a first frequency and a second short wave pulse at a second frequency, different from the first frequency.

11. The method of claim 2, wherein the wave pulse is modulated.

12. The method of claim 8, wherein the predetermined pulse timeframe and the predetermined wait timeframe are based on a minimum distance and maximum distance for which the anomaly is to be detected over the guideway.

13. The method of claim 12, wherein the wave pulse is a short duration high frequency tone burst.

14. The method of claim 1, wherein the predetermined wait time comprises a plurality of predetermined wait timeframes.

15. The method of claim 14, wherein each particular wait timeframe is selected from the plurality of predetermined wait timeframes according to a preselected code basis.

16. The method of claim 14, wherein each particular wait timeframe is selected from the plurality of predetermined wait timeframes on at least one of a random or a pseudo-random basis.

17. The method of claim 1, wherein the step of generating a wave pulse comprises generating a plurality of wave pulses having at least one different characteristic.

18. The method of claim 17, wherein the at least one different characteristic comprises at least one characteristic selected from the group of characteristics consisting of: frequency, modulation code, phase, and amplitude.

19. A system for detecting anomalies in a guideway, the system comprising:
   at least one signal generator;
   at least one coupler connected to the at least one signal generator, the at least one coupler to transmit the signal generated by the at least one signal generator into the guideway;
   at least one signal receiver, the at least one signal receiver connected to the at least one coupler such that a return signal is transmitted from the guideway to the at least one signal receiver; and
   a processor, the processor coupled to the signal generator and the at least one signal receiver, such that the processor can determine whether the return signal is indicative of an anomaly based on the signal generated by the at least one signal generator.

20. The system of claim 19, wherein the at least one signal generator and at least one signal receiver form a transceiver.

21. The system of claim 19, wherein the processor causes the at least one signal generator to periodically generate a signal to be transmitted to the guideway.

22. The system of claim 19, wherein the at least one signal processor generates a plurality of signals, at least one of the plurality of signals has at least one different characteristic.

23. The system of claim 19, wherein the at least one signal generator has a uniquely identifiable operating characteristic.

24. The system of claim 19 further comprising at least one waveform transformer, the waveform transformer coupled between the at least one signal generator and the at least one coupler to convert the at least one signal generated by the at least one signal generated into a form transmittable to the guideway by the at least one coupler.
25. The system of claim 19, wherein the at least one signal receiver receives a plurality of return signals and the processor correlates the plurality of return signals to compensate for relative movement of the system between transmission and return.

26. The system of claim 19 further comprising at least one data link and at least one memory, the at least one data link and the at least one memory coupled to the processor such that the processor can store information regarding detected anomalies.

27. The system of claim 26, wherein the stored information comprises at least one type of information selected from the group of information consisting of: location of the anomaly, impedance variation, rate of movement of anomaly, expected impedance, signal propagation information, guideway imperfections, environmental conditions, or guideway conditions.

28. The system of claim 27, wherein the stored information is provided to the processor to assist in detecting anomalies.

29. The system of claim 19, wherein the at least one signal generator and the at least one signal receiver are located remote from each other such that anomalies are detected by variations in expected signals received at the at least one signal receiver.

30. The system of claim 19 wherein the processor detects anomalies using time domain reflectometry based on the return signal being a reflection of the wave pulse.

31. The system of claim 19 wherein the system is mounted on an object traveling along the guideway.

32. The system of claim 31, wherein the object is a rail vehicle.

33. The system of claim 32, wherein the rail vehicle is at least one of a locomotive engine and a railcar.

34. The system of claim 31 further comprising:

- a remote signal generator; and
- a remote coupler to transmit the signal from the remote signal generator to the guideway such that the processor can detect anomalies using through-transmission between the remote signal generator and the at least one signal receiver and time domain reflectometry between the at least one signal generator and the at least one signal receiver.

35. The system of claim 19 further comprising a data link and a communication link to a broadcast or distributed timing reference such as a global positioning system such that a plurality of systems can be coordinated.

36. The system of claim 19, further comprising at least one indicator, the at least one indicator providing at least one indication selected from a group of indications consisting of: a warning indication, a stop indication, a go indication, distance to anomaly indication, and a rate of approach of anomaly indication.

37. The system of claim 36, wherein the at least one indicator comprises at least one of a light, a display, a whistle, a bell, and a barrier.

38. A system for detecting breaks, potential breaks, or obstruction in railroad tracks, the system comprising:

- at least one rail vehicle; and
- a pair of conductive rail tracks at least partially isolated from each other;
- the at least one rail vehicle comprising:
  - a processor;
  - at least one signal generator, the at least one signal generator coupled to the processor such that the processor causes the at least one signal generator to generate electrical waveform information at a selected time;
  - at least one waveform generator connected to the at least one signal generator to covert the waveform information into a transmittable waveform capable of traveling along at least one track of the pair of conductive rail tracks;
  - at least one track coupler to transfer the transmittable waveform from the at least one waveform generator to the at least one track and to transfer a return waveform from the at least one track;
  - at least one signal receiver coupled to the at least one track coupler to receive the return waveform from the at least one track and convert the return waveform into a return signal useable by the processor; the at least one signal receiver coupled to the processor to transfer the return signal to the processor, wherein the processor can detect anomalies.

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