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(54) ON-BOARD APPARATUS AND METHOD FOR DETERMINING TRAIN INTEGRITY BY LENGTH

(57) The length and integrity of a train (1) may be determined based on the frequency difference Δf obtained at a transmitting and receiving unit (10) between a transmitted sonic FMCW signal St and a corresponding sonic return signal Sr sent along the length L of a pipe (5) between opposite ends of the train.

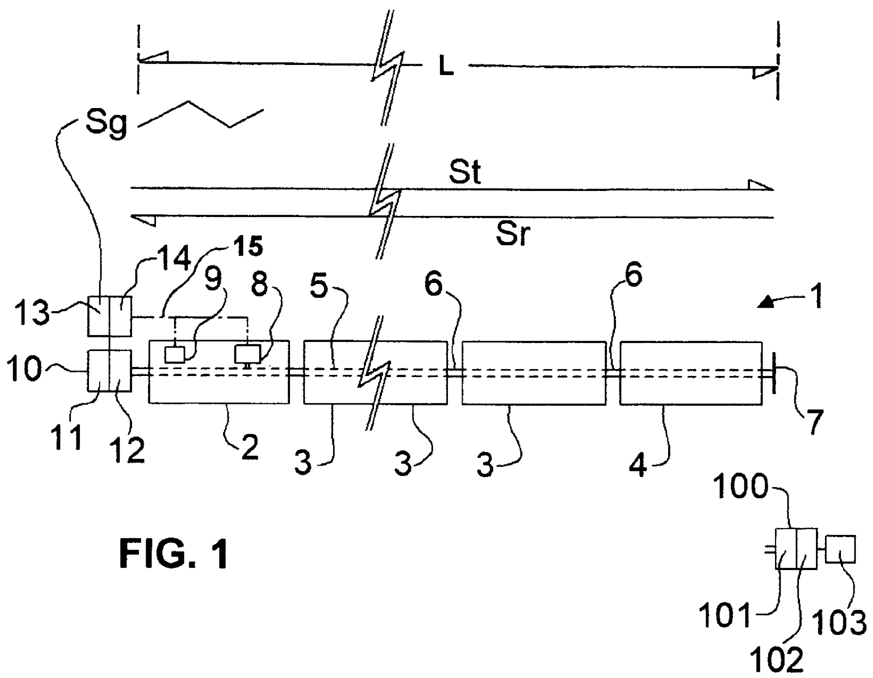

FIG. 1

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Description

Technical Field

[0001] This disclosure relates to on-board systems for determining the integrity of a train, which is to say, for determining whether any part of the train has become decoupled in use. In particular, the disclosure relates to systems for determining the integrity of a train by measuring the length of the train.

Background

[0002] It is known to determine train integrity by sending sonic signals through the brake pipe which extends over the length of the train and supplies compressed air to the braking system of the train. This is convenient because the brake pipe is a standard feature.

[0003] The sonic signal may be reflected from the distant end of the pipe; however, it can be difficult to distinguish the reflected signal from reflections generated by intermediate couplings along the length of the pipe.

[0004] High frequency sound becomes more attenuated with distance and so is more difficult to detect over a long train. However, sonic noise may be generated by moving parts of the train at relatively lower frequencies, and so it may be difficult to separate a relatively low frequency signal from noise emitted at the same frequency.

[0005] In order to help distinguish the sonic signal over noise, the signal may be coded; however, this makes the signal processing system more complex.

[0006] Alternatively, the length of the train may be determined by means of electromagnetic signals, which are not affected by sonic noise. However, unless a special electrical conductor is provided, it is more difficult to guide an electromagnetic signal along the length of the train so as to obtain a constant indication of the length of the train when it travels around a bend.

[0007] For example, AU 2015224435 A1 teaches transmitting coded signals between units at opposite ends of the train. The codes are validated to separate the signal from noise, thus confirming the integrity of the carrier medium and hence the train. The carrier medium may be an electrical cable carrying electrical signals, or a brake pipe carrying sonic signals.

[0008] WO 201815478 A2 teaches an ultrasonic speaker and detector arranged at the head of a train. Ultrasonic signals with an identifiable signature are emitted into the brake pipe, and the length of the train determined from the time delay of the signal reflected from the opposite end of the pipe. The signals may comprise a sequence of tonebursts or a non-periodic pulse train.

[0009] DE 3124884 A1 teaches sending and returning signals between units at opposite ends of a train. The signals may be processed to determine relative movement by the Doppler effect, or to measure train length by the frequency modulated continuous wave radar technique. Ultrasonic signals may be used instead of electromagnetic signals. Electromagnetic signals may be waveguided beneath the train.

[0010] DE 19946168 A1 teaches measuring train length by frequency modulated continuous wave radar signals between units at opposite ends of the train, wherein a time delay and optionally also a frequency shift is introduced by the transponder unit. The transceiver antenna is mounted preferably on the roof of the locomotive.

Summary of the Disclosure

[0011] In accordance with the present disclosure there is provided a method for determining integrity of a train based on a length L of a pipe, the pipe extending from a first end of the train to a second end of the train.

[0012] The method includes arranging a first unit including a first sonic transmitter and receiver at the first end of the train to transmit and receive sonic signals through the pipe; generating a signal Sg and transmitting the signal Sg as a sonic signal St through the pipe, from the first unit, to produce a corresponding sonic return signal Sr in the pipe at the second end of the train; and receiving the return signal Sr through the pipe at the first unit after a delay time interval Td from said transmitting. The delay time interval Td corresponds to a combined time of flight of the transmitted and return signals St, Sr through the pipe over the length L of the pipe.

[0013] The signals Sg, St, and Sr are frequency modulated continuous wave signals, and the method further includes combining the return signal Sr received at the first unit with the generated signal Sg to determine a frequency difference Δf indicative of the time of flight, and making a determination of train integrity based on the frequency difference Δf.

[0014] The determination includes confirming train integrity if the frequency difference Δf corresponds to an expected value Δfe, wherein the expected value Δfe corresponds to an expected value Le of the length L of the pipe; and, if train integrity is not confirmed, generating an indication that train integrity is compromised.

[0015] In another aspect, the disclosure provides an apparatus including at least the first unit, which is configured to be arranged in use at the first end of the train to transmit and receive sonic signals through the pipe. The apparatus is operable in accordance with the method to generate and transmit the signals Sg, St to produce the sonic return signal Sr in the pipe at the second end of the train; and, after receiving the return signal Sr at the first unit, to combine the signals Sr, Sg to determine the frequency difference Δf, and to make the determination of train integrity.

Brief Description of the Drawings

[0016] Further features and advantages will be appreciated from the various illustrative embodiments which will now be described, purely by way of example and without limitation to the scope of the claims, and with reference to the accompanying drawings, in which:

Fig. 1 shows an apparatus installed in a train;

Fig. 2 shows a carrier wave modulated to obtain the signal Sg;

Fig. 3 shows a pulse as taught in the prior art, by way of comparison;

Fig. 4 shows how the return and generated signals Sr, Sg plotted against frequency f and time t are combined to obtain the frequency difference Δf, wherein the return signal Sr is returned at the same frequency as the generated signal Sg;

Fig. 5 shows how the frequency difference Δf may be determined over the overlap time period To, wherein the return signal Sr is returned at the same frequency as the transmitted signal St; and

Fig. 6 shows how the frequency difference Δf may be determined over the overlap time period To, wherein the return signal Sr is generated at a different frequency to the transmitted signal St.

[0017] Reference numerals and characters that appear in more than one of the figures indicate the same or corresponding elements in each of them.

Detailed Description

[0018] Referring to Fig. 1, a train 1 is assembled from a series of units or vehicles 2, 3, 4, wherein the leading unit 2 defines a respective one of opposite, first and second ends of the train, and the trailing unit 4 defines the other respective one of the first and second ends of the train. Typically, as shown, the leading unit 2 may be a locomotive, while the trailing unit 4 may be another locomotive or a carriage or wagon.

[0019] A pipe 5 extends between the first and second ends of the train. Typically the pipe will supply pressure, e.g. compressed air, to the braking system of the train. A brake control unit 8 in the leading unit 2 of the train may control the brakes of the train by varying the pressure in the pipe 5.

[0020] The pipe 5 includes flexible coupling portions 6 which join together the portions of the pipe in each unit 2, 3, 4 of the train in series relation. Each coupling portion 6 may include valve and coupling elements fixed to each of the respective units of the train. The valve and coupling elements may be connected to join sealingly together in fluid communication the respective parts of the pipe 5 belonging to the adjacent units of the train. The respective valve belonging to the leading or trailing unit 2, 4 of the train, which is not located in-between two units of the train, may be closed to retain pressure in the pipe 5. This closed valve may form a passive reflector 7 as further discussed below.

[0021] A first unit 10 including a first sonic transmitter 11 and a first sonic receiver 12 is arranged at a first end of the train 1 to transmit and receive sonic signals through the pipe 5.

[0022] In this specification, the expression: "at the first end of the train" or "at the second end of the train" means: at a respective one of the leading and trailing units of the train.

[0023] Purely for ease of illustration, the first unit 10 is shown in Fig. 1 at an extremity of the pipe 5. However, it should be understood that the first unit 10 may be arranged in any convenient location in or on the leading unit 2 or trailing unit 4 of the train to transmit and receive signals through the pipe. Most conveniently, the first unit 10 may be arranged at the leading unit 2 of the train, as shown.

[0024] The apparatus may further include a signal generating and processing unit 13 and a controller 14. The controller 14 may include a non-transitory memory and a processor configured to execute instructions stored in the memory to control the transmitter 11, receiver 12, and signal unit 13 to perform the steps of the method. The apparatus, e.g. controller 14, may be in operable communication with a control unit 9 of the train through which a warning signal may be displayed or sounded to alert a driver of the train 1 and/or sent to a remote receiver (not shown), and/or with the brake control unit 8 to control emergency braking of the train 1.

[0025] In use, the apparatus (e.g. signal unit 13) generates a frequency modulated continuous wave (FMCW) signal Sg which is transmitted through the pipe 5 by the transmitter 11 of the first unit 10 as a FMCW sonic signal St.

[0026] By way of example, Fig. 2 shows a carrier wave plotted by amplitude A and time t, and frequency modulated to obtain a frequency modulated continuous wave (FMCW) signal Sg based on a standard formula as known in the art:

$$s(t) = a * \sin(2\Pi ft) \quad \text{where } f = fo + kt$$

[0027] By way of comparison, Fig. 3 shows a pulse generated in accordance with a known function:

$$f_{(x)} = e^{-at} * \sin(t)$$

[0028] An ultrasonic pulse of this latter waveform may be reflected along the length of a brake pipe to determine its time of flight, as taught for example by WO 201815478 A2.

[0029] Returning to the disclosure, as shown in Fig. 4, the frequency of the generated FMCW signal Sg may either increase or decrease continuously and progressively to define a continuously rising or falling tone over each modulation time period Tm (which is indicated in the figure for the transmitted signal St). The tone may both rise and fall in turn during successive modulation time periods Tm, as shown. The tone may have a constant rate of change over each modulation time period Tm. Alternatively, the rate of change could vary progressively over each modulation time period Tm.

[0030] The signal Sg, St is generated and transmitted repeatedly during successive modulation time periods Tm. Each modulation time period Tm may last for several or many seconds, depending on the length of the train. The signal St may be transmitted continuously so that each modulation time period Tm begins at the moment the previous modulation time period Tm ends, e.g. with a constant rate of change defining a triangular or sawtooth waveform as shown. Alternatively the signal St may be transmitted repeatedly but discontinuously so that successive modulation time periods Tm are spaced apart in time.

[0031] It is also possible for multiple FMCW signals to be transmitted and received simultaneously at different frequencies.

[0032] The signal St transmitted from the first unit 10 produces a corresponding FMCW sonic return signal Sr in the pipe 5 at the second end of the train.

[0033] The return signal Sr may be produced by reflecting the transmitted signal St from a passive reflector 7 at the second end of the train 1; which is to say, the return signal Sr may be simply a reflection of the transmitted signal St. The reflector 7 may be the closed valve at the last coupling element of the pipe 5 at the trailing end of the trailing unit 4 of the train.

[0034] Alternatively, the return signal Sr may be generated by a second unit 100, including a second sonic transmitter 101 and sonic receiver 102 and located at the second end of the train 1, responsive to receiving the transmitted signal St at the second unit 100. The second unit 100 may be located anywhere at the respective one of the leading and trailing units 2, 4 of the train remote from the first unit 10, but conveniently may be located at the trailing unit 4. Conveniently but optionally, the second unit 100 may be located at the final coupling element of the pipe 5 at the trailing end of the trailing unit 4. The second unit 100 may be powered by any convenient power source of the train 1.

[0035] The second unit 100 may be configured to generate the return signal Sr at the same frequency as the frequency of the transmitted signal St at the moment that the transmitted signal St is received at the second unit 100.

[0036] Alternatively, the second unit 100 may be configured to generate the return signal Sr at a different frequency to the frequency of the transmitted signal St at the moment that the transmitted signal St is received at the second unit 100.

[0037] The second sonic transmitter and receiver 101, 102, may be an analogue transmitter and receiver.

[0038] The second unit 100 may include an analogue transverter 103 configured to generate the return signal Sr based on the transmitted signal St as received by the receiver 102. The transverter 103 may be configured to generate the return signal Sr at the same frequency, or at a different frequency (with a predefined frequency offset), relative to that of the transmitted signal St.

[0039] In each case, the second unit 100 may transmit the return signal Sr at greater amplitude than the transmitted signal St as received at the second unit 100.

[0040] It will be understood that the return signal Sr is generated based on the transmitted signal St at the moment it is received at the second unit 100, and thus replicates its waveform. The second unit 100 may generate the return signal Sr without any time delay, or alternatively may introduce a time delay, in which case the first unit 10 may be configured to compensate for that time delay when processing the signals and making the determination of train integrity, as will now be discussed.

[0041] The sonic signals St, Sr may be transmitted and returned in a frequency range below 500Hz. In particular, the frequency range may lie between 10Hz and 400Hz.

[0042] Referring again to Fig. 4, the return signal Sr is received through the pipe 5 at the receiver 12 of the first unit 10 after a delay time interval Td from the transmission of the transmitted signal St from the first unit 10. That is to say, any given instantaneous value of the return signal Sr at the first unit 10 follows the moment of transmission of the corresponding instantaneous value of the transmitted signal St by the delay time interval Td. The delay time interval Td corresponds to a combined time of flight of the transmitted and return signals St, Sr through the pipe 5 over the length L of the pipe, which is defined between the first unit 10 and the reflector 7 or second unit 100.

[0043] The principle of distance measurement or ranging by FMCW radar (which is to say, using electromagnetic radio waves) is well known in the art.

[0044] In accordance with the disclosure, this principle is applied to the sonic signals travelling along the pipe 5 to determine, iteratively, the length L of the pipe while the train 1 is in motion.

[0045] The integrity of the train 1 may then be determined based on the measured frequency difference Δf or by calculating the length L of the train from the measured frequency difference Δf.

[0046] Each measured or calculated value L or Δf may be compared with an expected value Le of the length L, or an expected value Δfe of the frequency difference Δf, to determine whether the length L has changed from the expected value Le. A reduction in length L or frequency difference Δf, or a failure to obtain a measured value, may indicate that the integrity of the train 1 is compromised - which is to say, a part of the train 1 may have become decoupled.

[0047] The return signal Sr received at the first unit 10 is combined (e.g. by signal unit 13) with the generated signal Sg to determine a frequency difference Δf between the two signals Sr, Sg which is indicative of the time of flight. That is to say, at the moment of reception of any given instantaneous value of the return signal Sr at the first unit 10, that value is combined with the value of the generated signal Sg at the same moment.

[0048] By combining the return and generated signals Sr, Sg is meant mixing or beating together or otherwise comparing the signals as known in the art. Conveniently the signals may be mixed in electrical form to generate an electrical signal representing the frequency difference Δf, but they could be mixed in sonic form to generate a sonic signal representing the frequency difference Δf which may then be converted into electrical form.

[0049] Referring again to Fig. 4, the modulation time period Tm exceeds the delay time interval Td by an overlap time period To during which the return signal Sr and the generated signal Sg are both present at the first unit 10. As shown, the generated signal Sg may be transmitted as the transmitted signal St during the delay time interval Td and the overlap time period To, in which case the return signal Sr may be combined with the generated signal Sg in the form of the transmitted signal St, or may be converted into an electrical signal and combined in that form with the generated signal Sg. Alternatively the generated signal Sg may be transmitted from the first unit 10 as the transmitted signal St during the delay time interval Td but the transmission may cease before or at the end of the delay time interval Td, in which case the return signal Sr may be converted into an electrical signal which is combined with the generated signal Sg, which is not transmitted during the overlap time period To.

[0050] Those skilled in the art of FMCW radar ranging will appreciate that the frequency difference Δf depends on the delay time Td and the rate of change of the frequency f of the signals St, Sr over time.

[0051] By way of example, referring again to Fig. 4, for a signal modulation waveform with a constant rate of change (e.g. a triangular or sawtooth waveform) over a time T (corresponding to the modulation time period Tm), the distance d over which the signals travel, which is equal to the length L of the train, may be calculated by the standard formula

$$\Delta f = 2 * (d/c) * BW / T \quad \rightarrow \quad d = 0.5 * \Delta f * c * T / BW$$

where:

Δf = frequency difference between the return signal Sr and the generated signal Sg at the moment of arrival of the return signal Sr at the first unit;

T = sweep time, not less than (Td + To);

BW = sweep bandwidth, i.e. change in frequency over time T;

d = distance = length of train L; and

c = speed of sound (~300m/s through air).

[0052] The apparatus (e.g. the controller 14) is further configured to make a determination of train integrity based on the frequency difference Δf.

[0053] In accordance with the determination, the apparatus confirms the integrity of the train 1 if the frequency difference Δf corresponds to an expected value Δfe, wherein the expected value Δfe corresponds to an expected value Le of the length L of the pipe 5.

[0054] The determination may be based directly on the measured frequency difference Δf or on any other value calculated or otherwise derived therefrom, for example, the calculated value L of the length of the train as discussed above.

[0055] If as a result of the determination the train integrity is not confirmed, then the apparatus (e.g. controller 14) generates an indication that train integrity is compromised - which is to say, an indication that a part of the train may have become decoupled.

[0056] In particular, the indication that train integrity is compromised may be generated responsive to a determination that the length L is smaller than the expected length Le, or smaller than the expected length Le by at least a threshold amount.

[0057] An indication that train integrity is compromised may include a warning signal 15. The warning signal 15 may be directed to a control unit 9 of the train which, responsive to the warning signal 15, may display a visual warning or sound an audible warning to alert the train driver. Alternatively or additionally, the warning signal may be directed to a receiver (on the train or elsewhere) to alert other personnel or another system. Alternatively or additionally, the warning signal 15 may be directed to a brake control unit 8 which may apply emergency braking to arrest the train 1 responsive to the warning signal 15. The brake control unit 8 may apply the brakes by altering the pressure in the pipe 5.

[0058] The expected value Le or Δfe may be obtained in an initial configuration step by an initial measurement of the frequency difference Δf when the apparatus is initialised, e.g. when the train is made up or when the train 1 is stationary or has just begun to move. A user confirmation may be provided (e.g. via a user interface to controller 14) to cause the measured value Δf or the value L calculated therefrom to be stored in memory, respectively as the expected value Δfe or Le. Alternatively, the expected value Le or Δfe may be input into the apparatus (e.g. via a user interface to controller 14) as a reference value based on the known length of the intact train 1. If the expected value Le is input as a reference value then the apparatus may be configured to calculate the expected value Δfe based thereon.

[0059] Referring now to Fig. 5, the apparatus may be configured to increase or decrease the frequency of the generated signal Sg, continuously and progressively over a modulation time period Tm, wherein the modulation time period Tm exceeds the delay time interval Td by at least a minimum overlap time period To, and to combine the return signal Sr with the generated signal Sg to determine the frequency difference Δf over at least the minimum overlap time period To.

[0060] The minimum overlap time period To may extend to the end of the modulation time period Tm, as shown in Fig. 5, or may be defined as a part of the overlap time period which ends before the end of the modulation time period Tm, whichever is more convenient.

[0061] Any component of the measured frequency difference Δf which does not have a rate of change, over said at least the minimum overlap time period To, corresponding to a rate of change of the frequency of the generated signal Sg may then be excluded from the determination of train integrity as representing noise. For example, the noise component could be filtered out or simply not included in the signal analysis.

[0062] It should be understood that by "rate of change" is meant either a zero or non-zero rate of change.

[0063] As shown in Fig. 5, where the rate of change of the frequency of the generated signal Sg is constant (hence, a straight slope angle against time, as shown by the transmitted signal St in Fig. 5), that rate of change will correspond to a zero rate of change of the frequency difference Δf (which is represented in Fig. 5 by a flat line over the overlap time period To).

[0064] In this specification, the term: "over" means: "continuously during the entire duration of'.

[0065] Referring now to Fig. 6, as mentioned above, the return signal Sr may be generated at a frequency which is offset from the frequency of the transmitted signal St. The two signals St, Sr may be generated in different frequency bands BW1, BW2, defined respectively by minimum and maximum frequencies fla, f1b of the transmitted signal St and by minimum and maximum frequencies f2a, f2b of the return signal Sr. (In the examples of Figs. 4 and 5 both signals St, Sr lie in the same bandwidth BW defined between maximum and minimum frequencies f1a, f1b.)

[0066] In the illustrated example, the frequency difference Δf is obtained as the function (f1 - f2) wherein f1 is the transmitted signal St and f2 is the return signal Sr.

[0067] As shown in Fig. 6, where the transmitted and return signals St, Sr are generated at different frequencies, the apparatus may be configured to determine the frequency difference Δf as an average of a first frequency difference $\Delta f1$ and a second frequency difference $\Delta f2$.

[0068] The first frequency difference $\Delta f1$ is determined during a first time period T1 over which the generated and return signals Sg, Sr progressively increase in frequency, while the second frequency difference $\Delta f2$ is determined during a second time period T2 over which the generated and return signals Sg, Sr progressively reduce in frequency.

Industrial Applicability

[0069] Advantageously, in use, reflections of the transmitted signal St from intermediate points along the length of the brake pipe will, when received at the first unit and beaten together with the generated signal Sg, due to their relatively shorter time of flight, result in a frequency difference component which does not correspond to the expected value Δfe, and so will not generate a positive confirmation of train integrity.

[0070] By transmitting and returning the signals St, Sr in a frequency range below 500Hz, preferably between 10Hz and 400Hz, the system can be used in longer trains without losing the signals due to attenuation.

[0071] Further advantageously, by beating together the generated and return signals Sg, Sr over at least a minimum overlap time period To while the tone either rises or falls continuously and progressively, the detected frequency difference Δf based on the continuously rising or falling tone will remain constant over the overlap time period To (if the rate of change of the generated signal Sg is constant), or otherwise will vary with a rate of change corresponding to that of the generated signal Sg. This reliably distinguishes the return signal Sr over low frequency noise which has a constant or randomly varying tone, and so if beaten together with the generated signal Sg would generate a varying component of the frequency difference Δf which is excluded (e.g. rejected, ignored or filtered out) as representing noise, because it does not correspond to the rate of change of the frequency of the transmitted signal St.

[0072] Signal processing may be simplified by generating the signal Sg with a constant rate of change.

[0073] Producing the return signal Sr at a passive reflector ensures that the system will always be configured correctly, because the brake pipe must be closed at the tail end of the train in order for the braking system to function correctly, and the closure (e.g. a valve) will form the reflector.

[0074] Alternatively, by generating the return signal Sr by a second sonic transmitter and receiver unit, the second unit may be arranged to transmit the return signal Sr at a higher amplitude than the transmitted signal St as received at the second unit, which improves signal detection over noise on a long train.

[0075] By generating the return signal Sr at an identical frequency to the transmitted signal St received at the second unit, signal processing may be simplified.

[0076] Alternatively, the return signal Sr may be generated at a different frequency to the transmitted signal, which may assist in detecting the return signal Sr. In this case, the frequency difference Δf may be determined as the average of first and second frequency differences Δf1, Δf2. The first and second frequency differences Δf1, Δf2 are determined, respectively, during a first time period over which the generated and return signals Sg, Sr progressively increase in frequency, and during a second time period over which the generated and return signals Sg, Sr progressively reduce in frequency. In this way, the frequency difference Δf will not be affected by any relative frequency drift between the oscillators of the first and second units.

[0077] If the second unit is configured to process the received signal digitally, then the signal processing at the second unit may introduce a time delay. The signal processor that beats together the return signal Sr at the first unit with the generated signal Sg may apply an offset to compensate for this time delay.

[0078] However, to further simplify signal processing, the second unit may be arranged as an analogue transmitter and receiver which do not digitally process the signal and so do not introduce any time delay. Similarly, to avoid a time delay, the second unit may include an analogue transverter which is configured to re-emit the transmitted signal St, when received, as an amplified return signal Sr, at the same or a different frequency.

[0079] In summary, the length and integrity of a train 1 may be determined based on the frequency difference Δf obtained at a transmitting and receiving unit 10 between a transmitted sonic FMCW signal St and a corresponding sonic return signal Sr sent along the length L of a pipe 5 between opposite ends of the train.

[0080] The apparatus may include a temperature sensor and/or other sensors, and apply a correction factor or factors to the signals or calculated values based on the sensor input to compensate for variations in signal speed resulting from variations in temperature or other system parameters. Many further adaptations of the disclosed method and apparatus are possible within the scope of the claims.

[0081] In the claims, reference numerals and characters which appear in parentheses are provided purely for ease of reference, and should not be construed as limiting features.

LIST OF ELEMENTS

TITLE: ON-BOARD APPARATUS AND METHOD FOR DETERMINING TRAIN INTEGRITY BY LENGTH

[0082] FILE: 19-1231 EP01

1	Train
2	Leading unit of train
3	Intermediate unit of train
4	Trailing unit of train
5	Pipe
6	Flexible coupling portion

7	Passive reflector
8	Brake control unit of train
9	Control unit of train
10	First unit
11	First sonic transmitter
12	First sonic receiver
13	Signal generating and processing unit
14	Controller
15	Warning signal
100	Second unit
101	Second sonic transmitter
102	Second sonic receiver
103	Analogue transverter
A	Amplitude
BW	Bandwidth
BW1	Frequency band
BW2	Frequency band
f	Frequency
fla, f1b	Minimum and maximum frequencies
f2a, f2b	Minimum and maximum frequencies
L	Length
Le	Expected value of length
Sg	Generated signal
Sr	Return signal
St	Transmitted signal
t	Time
T1	First time period
T2	Second time period
Td	Delay time interval
Tm	Modulation time period
To	Overlap time period
Δf	Frequency difference
Δf1	First frequency difference
Δf2	Second frequency difference
Δfe	Expected value of frequency difference

Claims

1. A method for determining integrity of a train (1) based on a length L of a pipe (5), the pipe (5) extending from a first end of the train (1) to a second end of the train (1); the method including:

arranging a first unit (10) including a first sonic transmitter (11) and receiver (12) at the first end of the train (1) to transmit and receive sonic signals through the pipe (5);
generating a signal Sg and transmitting the signal Sg as a sonic signal St through the pipe (5), from the first unit (10), to produce a corresponding sonic return signal Sr in the pipe (5) at the second end of the train (1); and
receiving the return signal Sr through the pipe (5) at the first unit (10) after a delay time interval Td from said transmitting, the delay time interval Td corresponding to a combined time of flight of the transmitted and return signals St, Sr through the pipe (5) over the length L of the pipe (5); wherein
the signals Sg, St, and Sr are frequency modulated continuous wave signals, and the method further includes:

combining the return signal Sr received at the first unit (10) with the generated signal Sg to determine a frequency difference Δf indicative of the time of flight; and
making a determination of train integrity based on the frequency difference Δf, said determination including:

confirming train integrity if the frequency difference Δf corresponds to an expected value Δfe, wherein the expected value Δfe corresponds to an expected value Le of the length L of the pipe (5); and, if train integrity is not confirmed, generating an indication that train integrity is compromised.

2. A method according to claim 1, wherein the signals St, Sr are transmitted and returned in a frequency range below 500Hz.

3. A method according to claim 2, wherein the frequency range is between 10Hz and 400Hz.

4. A method according to claim 1, further including:

either increasing or decreasing the frequency of the generated signal Sg, continuously and progressively over a modulation time period Tm, wherein the modulation time period Tm exceeds the delay time interval Td by at least a minimum overlap time period To;
combining the return signal Sr with the generated signal Sg to determine the frequency difference Δf over at least the minimum overlap time period To; and
excluding from said determination of train integrity any component of the frequency difference Δf not having a rate of change, over said at least the minimum overlap time period To, corresponding to a rate of change of the frequency of the generated signal Sg.

5. A method according to claim 4, wherein said rate of change of the frequency of the generated signal Sg is constant, and corresponds to a zero rate of change of the frequency difference Δf.

6. A method according to claim 1, wherein the return signal Sr is produced by reflecting the transmitted signal St from a passive reflector (7) at the second end of the train.

7. A method according to claim 1, wherein the return signal Sr is generated, responsive to receiving the transmitted signal St, by a second unit (100) including a second sonic transmitter (101) and receiver (102) at the second end of the train (1).

8. A method according to claim 7, wherein the second unit (100) is configured to generate the return signal Sr at the same frequency as the transmitted signal St received at the second unit (100).

9. A method according to claim 7, wherein the second unit (100) is configured to generate the return signal Sr at a different frequency to the transmitted signal St received at the second unit (100).

10. A method according to claim 9, further including:

determining the frequency difference Δf as an average of a first frequency difference Δf1 and a second frequency difference Δf2;
the first frequency difference Δf1 being determined during a first time period (T1) over which the generated and return signals Sg, Sr progressively increase in frequency;
the second frequency difference Δf2 being determined during a second time period (T2) over which the generated and return signals Sg, Sr progressively reduce in frequency.

11. A method according to claim 7, wherein the second sonic transmitter (101) and receiver (102) are an analogue transmitter and receiver.

12. A method according to claim 7, wherein the second unit (100) includes an analogue transverter (103).

13. An apparatus for determining integrity of a train (1) based on a length L of a pipe (5), the pipe (5) extending from a first end of the train (1) to a second end of the train (1); the apparatus including:

a first unit (10) including a first sonic transmitter (11) and receiver (12), the first unit (10) configured to be arranged in use at the first end of the train (1) to transmit and receive sonic signals through the pipe (5);
the apparatus being operable:

to generate a signal Sg and to transmit the signal Sg as a sonic signal St through the pipe (5), from the first unit (10), to produce a corresponding sonic return signal Sr in the pipe (5) at the second end of the train (1); and
to receive the return signal Sr through the pipe (5) at the first unit (10) after a delay time interval Td from

said transmitting, the delay time interval Td corresponding to a combined time of flight of the transmitted and return signals St, Sr through the pipe (5) over the length L of the pipe (5); wherein
the signals Sg, St, and Sr are frequency modulated continuous wave signals, and the apparatus is further operable:

to combine the return signal Sr received at the first unit (10) with the generated signal Sg to determine a frequency difference Δf indicative of the time of flight; and
to make a determination of train integrity based on the frequency difference Δf, said determination including:

confirming train integrity if the frequency difference Δf corresponds to an expected value Δfe, wherein the expected value Δfe corresponds to an expected value Le of the length L of the pipe; and, if train integrity is not confirmed,
generating an indication that train integrity is compromised.

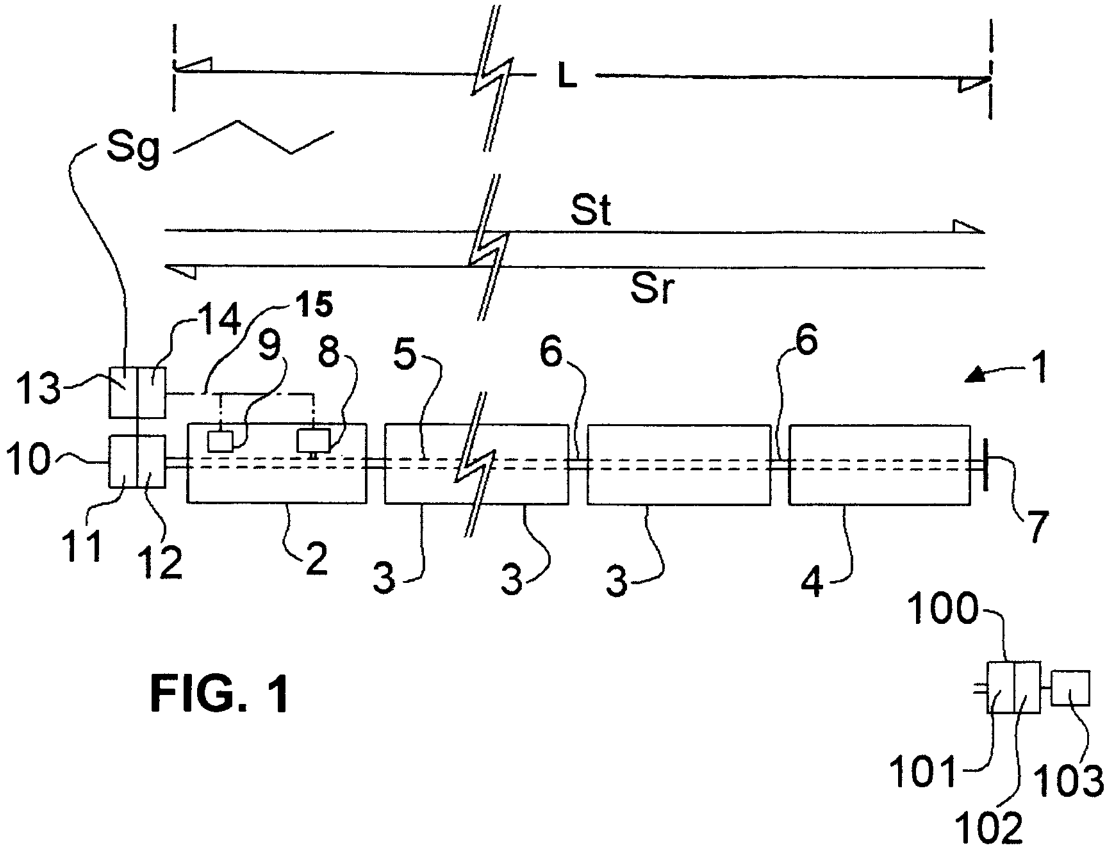


FIG. 1

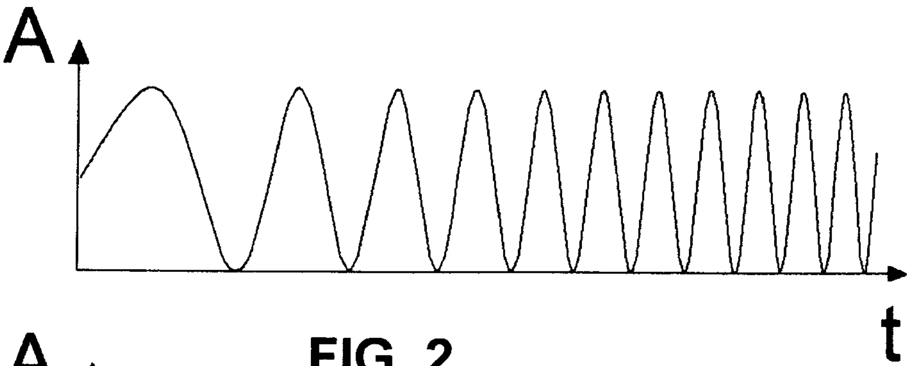


FIG. 2

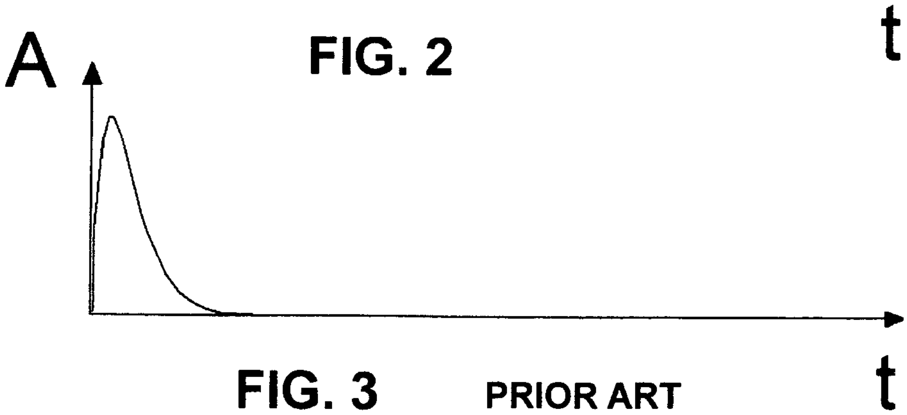


FIG. 3 PRIOR ART

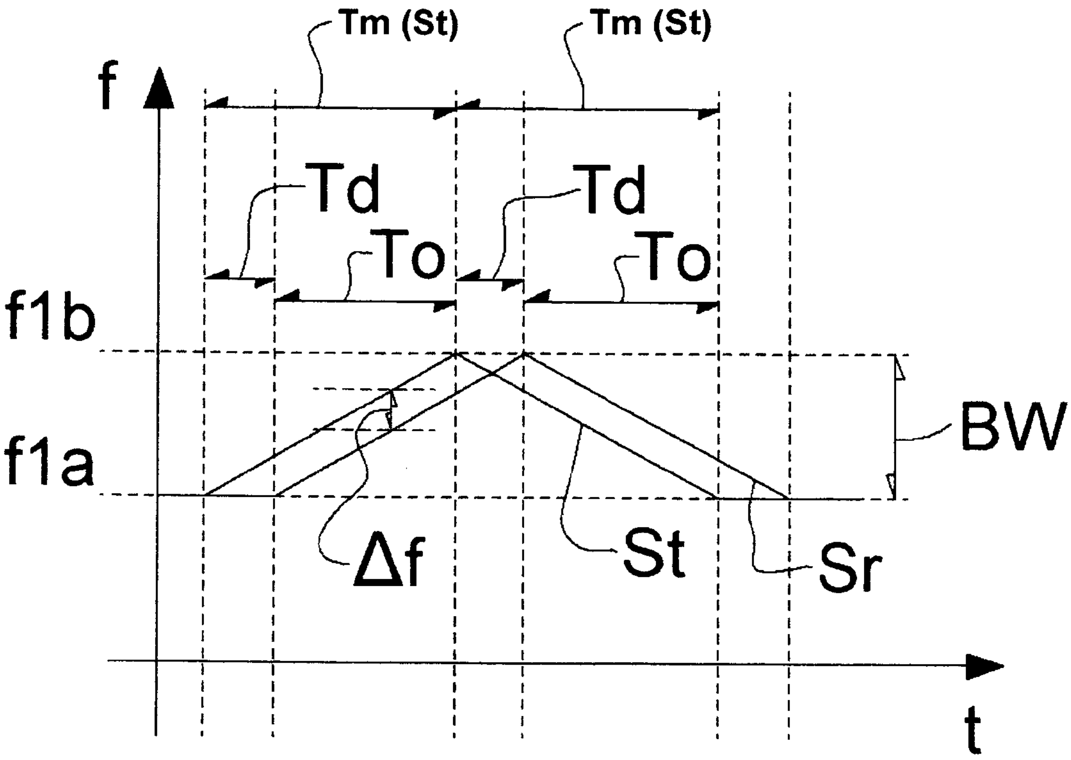
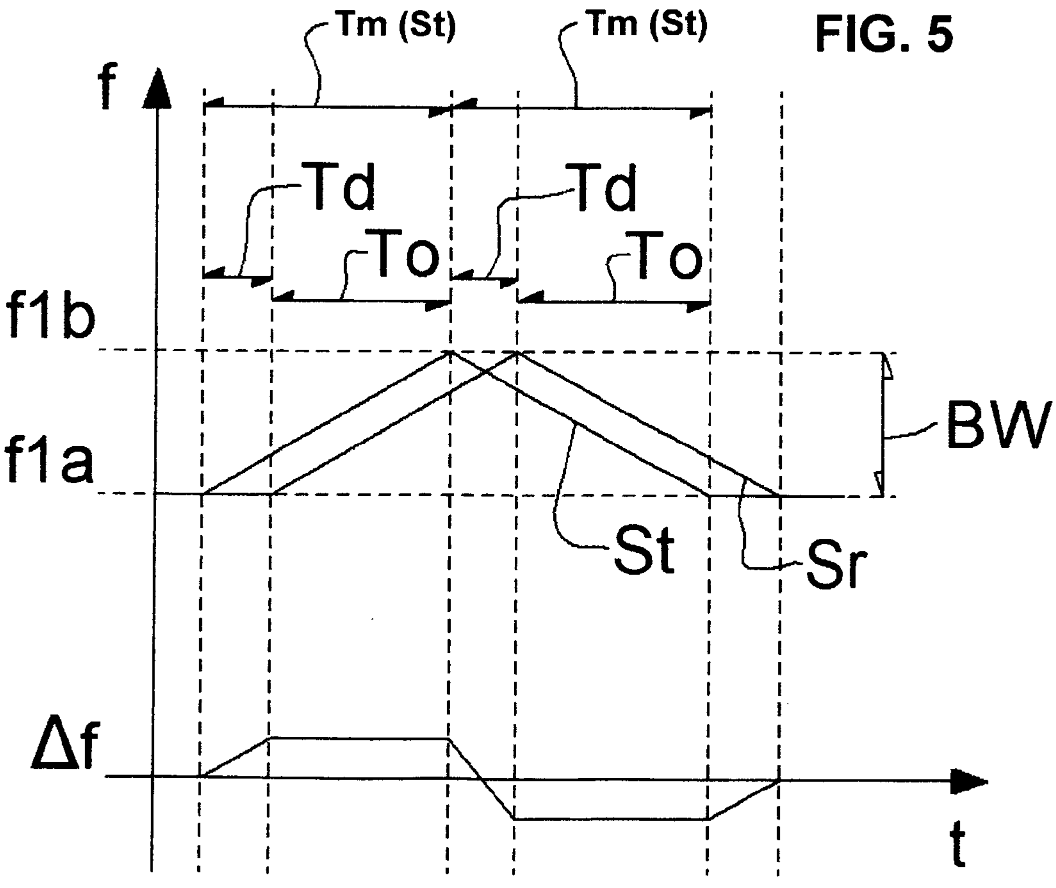

Tm (St)
Tm (St)
f
Td
To
Td
To
f1b
f1a
BW
Δf
St
Sr
t

FIG. 4

FIG. 5


Tm (St)
Tm (St)
f
Td
To
Td
To
f1b
f1a
BW
St
Sr
Δf
t

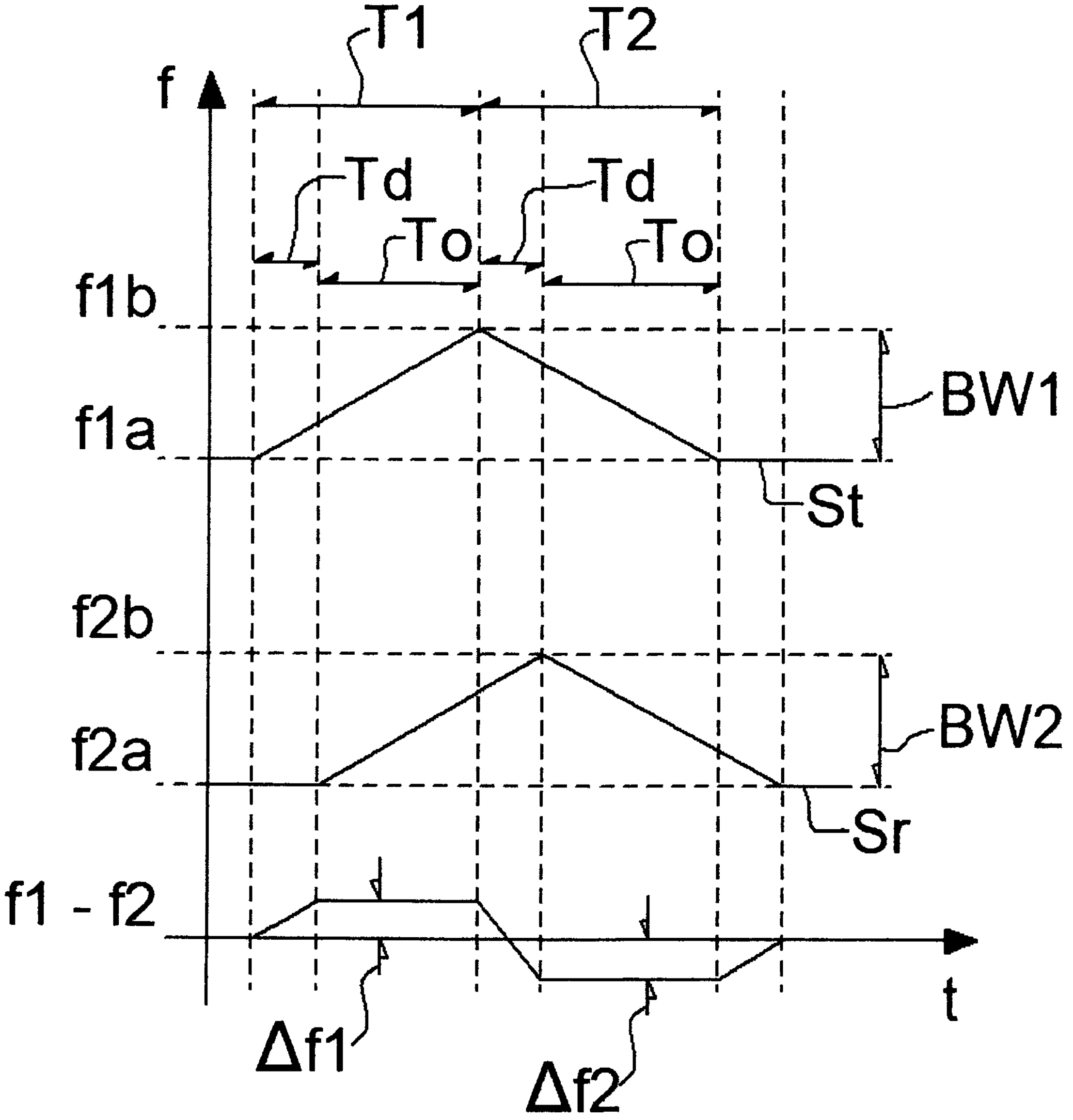


FIG. 6

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EUROPEAN SEARCH REPORT

Application Number
EP 20 42 5040

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
A	DE 10 2014 215791 A1 (SIEMENS AG [DE]) 11 February 2016 (2016-02-11) * abstract; figure * * paragraphs [0001], [0008] - [0014] * * paragraphs [0017], [0018] * * paragraph [0028] * * paragraphs [0031], [0035] * -----	1-13	INV. B61L15/00
A	AT 413 973 B (JOANNEUM RES FORSCHUNGSGESELLS [AT]) 15 July 2006 (2006-07-15) * abstract; figure 1 * * page 2, line 40 - page 3, line 8 * * page 3, line 36 - page 4, line 28 * * page 5, lines 8-29 * -----	1-13	
A,D	DE 199 46 168 A1 (SIEMENS AG [DE]) 26 April 2001 (2001-04-26) * abstract; figures 1,2 * * column 2, line 19 - column 3, line 56 * * column 5, lines 1-2 * -----	1-13	TECHNICAL FIELDS SEARCHED (IPC)
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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
Munich	26 November 2020	Robinson, Victoria

CATEGORY OF CITED DOCUMENTS

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26-11-2020

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

REFERENCES CITED IN THE DESCRIPTION

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