



(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
01.05.2024 Bulletin 2024/18

(51) International Patent Classification (IPC):
B61L 23/04 ^(2006.01) **B61L 27/53** ^(2022.01)
B61L 1/06 ^(2006.01)

(21) Application number: **22203763.2**

(52) Cooperative Patent Classification (CPC):
B61L 27/53; B61L 1/06; B61L 23/045

(22) Date of filing: **26.10.2022**

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC ME MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA
Designated Validation States:
KH MA MD TN

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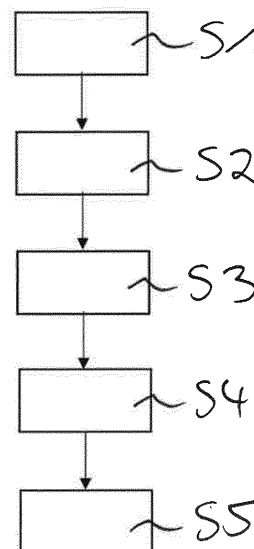
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(54) **METHOD AND DEVICE FOR DETECTING ANOMALIES ALONG A RAILWAY TRACK**

(57) A method for detecting anomalies along a railway track (20) is provided, the method comprising detecting at least one first sensor signal (F) by a fiber optic sensor (21) for a measurement segment (22) of the fiber optic sensor (21), the fiber optic sensor (21) being arranged along the railway track (20), detecting at least one second sensor signal (S) by the fiber optic sensor (21) for the measurement segment (22) after detecting the first sensor signal (F), determining a first difference signal (FD) where the first difference signal (FD) relates to the difference between an average sensor signal (AS) and the first sensor signal (F), wherein the average sensor signal (AS) relates to an average of previous sensor signals detected by the fiber optic sensor (21) for the measurement segment (22) before detecting the first sensor signal (F), determining a second difference signal (SD) where the second difference signal (SD) relates to the difference between the average sensor signal (AS) and the second sensor signal (S), and providing an alarm signal (AL) for the case that a confidence condition is fulfilled, wherein the confidence condition requires at least that the first difference signal (FD) and the second difference signal (SD) are each larger than a predefined threshold signal or the confidence condition requires at least that the absolute value of the first difference signal (FD) and the absolute value of the second difference signal (SD) are each larger than a predefined threshold signal. Furthermore, a device (24) for detecting anomalies along a railway track (20) is provided.

FIG. 1



Description

[0001] A method for detecting anomalies along a railway track and a device for detecting anomalies along a railway track are provided.

[0002] Fiber optic sensors can be employed in railway monitoring. For this purpose, a laser pulse is fed into an optical fiber extending along a railway track. By analyzing the backscattered signal noise on and around the railway track can be detected. Noise can relate to anomalies along the railway track. The backscattered signal can be employed to determine different parameters of the railway track or of the movement of the rail vehicles. For example the velocity or the position of the rail vehicles or defects of the railway track can be determined.

[0003] However, parameters determined from backscattered signals might have an error rate. This leads to inaccuracies in the monitoring.

[0004] It is an objective to provide a method for detecting anomalies along a railway track with an improved accuracy. It is further an objective to provide a device for detecting anomalies along a railway track with an improved accuracy.

[0005] These objectives are achieved with the independent claims. Further embodiments are the subject of dependent claims.

[0006] According to at least one embodiment of the method for detecting anomalies along a railway track, the method comprises detecting at least one first sensor signal by a fiber optic sensor for a measurement segment of the fiber optic sensor, the fiber optic sensor being arranged along the railway track. The first sensor signal can comprise a backscattered signal or backscattered signals of an input signal which is provided to the fiber optic sensor. The fiber optic sensor can comprise an optical fiber. The optical fiber can be arranged within the ground close to the railway track. It is further possible that the optical fiber is arranged above the ground close to the railway track. The optical fiber can extend approximately parallel to the railway track. The input signal can be an optical signal, for example a laser pulse. The input signal can be provided to the optical fiber at an input of the optical fiber. A small part of the laser light is reflected back to the input since the laser light is scattered at scatter sites, as for example impurities in the optical fiber which can be natural or artificial. Changes in the backscattered signal are related to physical changes in the optical fiber which can be caused by noise, structure-borne noise, vibrations or soundwaves along the optical fiber. Therefore, a backscattered signal can be detected when a rail vehicle is moving on the railway track. By evaluating the backscattered signal, the location of the noise or the rail vehicle along the optical fiber can be determined.

[0007] The length of the fiber optic sensor can amount to several kilometers or several hundreds of kilometers. The fiber optic sensor can be divided into a plurality of measurement segments. The measurement segment can be one of the plurality of measurement segments.

Each measurement segment corresponds to a predefined length along the fiber optic sensor. This means, each measurement segment directly adjoins another measurement segment. The measurement segments can all have the same length. For example the measurement segments each have a length of a few meters, for example less than 10 m.

[0008] The first sensor signal can comprise backscattered signals from the measurement segment. This can mean that the first sensor signal comprises backscattered signals originating from the measurement segment. In other words, the first sensor signal comprises backscattered signals that were scattered at the position of the measurement segment.

[0009] The method further comprises detecting at least one second sensor signal by the fiber optic sensor for the measurement segment after detecting the first sensor signal. The second sensor signal can comprise a backscattered signal or backscattered signals of an input signal which is provided to the fiber optic sensor. The second sensor signal can comprise backscattered signals from the measurement segment. This can mean that the second sensor signal comprises backscattered signals originating from the measurement segment. In other words, the second sensor signal comprises backscattered signals that were scattered at the position of the measurement segment. The second sensor signal can be detected at a later point in time than the first sensor signal.

[0010] The method further comprises determining a first difference signal where the first difference signal relates to the difference between an average sensor signal and the first sensor signal, wherein the average sensor signal relates to an average of previous sensor signals detected by the fiber optic sensor for the measurement segment before detecting the first sensor signal. The average sensor signal can be stored on a memory device or in a database. The previous sensor signals can be detected in the same way as the first sensor signal. The previous sensor signals can all comprise backscattered signals originating from the measurement segment. The average sensor signal can relate to the average of at least ten sensor signals detected by the fiber optic sensor for that measurement segment for which the first sensor signal is detected. The average sensor signal can relate to the average of the amplitude of the previous sensor signals. The previous sensor signals can be detected during a calibration phase. The first difference signal can relate to the difference between the amplitude of the average sensor signal and the amplitude of the first sensor signal.

[0011] The method further comprises determining a second difference signal where the second difference signal relates to the difference between the average sensor signal and the second sensor signal. The second difference signal can relate to the difference between the amplitude of average sensor signal and the amplitude of the second sensor signal.

[0012] The method further comprises providing an

alarm signal for the case that a confidence condition is fulfilled, wherein the confidence condition requires at least that the first difference signal and the second difference signal are each larger than a predefined threshold signal or the confidence condition requires at least that the absolute value of the first difference signal and the absolute value of the second difference signal are each larger than a predefined threshold signal. The first sensor signal can be smaller or larger than the average sensor signal. The second sensor signal can be smaller or larger than the average sensor signal. The alarm signal can be provided to a person or to a railway monitoring or coordination division. The alarm signal can comprise the information that the confidence condition is fulfilled. The alarm signal can further comprise the information where the measurement segment is located along the optical fiber. The alarm signal can comprise the information which position along the railway track is the closest to the measurement segment. The threshold signal can be a measure for a situation deviating from normal operation of railway traffic.

[0013] The predefined threshold signal can be determined by an optimization program. This can mean, that an algorithm can be employed to determine the predefined threshold signal. The value of the predefined threshold signal can be determined in such a way that if a difference signal is larger than the threshold signal, an anomaly took place along the railway track with a certain probability. It is also possible that the threshold signal is determined manually.

[0014] Fiber optic sensing can be employed to monitor different conditions of the railway track or to monitor railway traffic. By analyzing the backscattered signals detected by fiber optic sensing different situations occurring at the measurement segment or in the vicinity of the measurement segment can be differentiated. However, different impacts can lead to errors in determining which situation took place during the detection of the backscattered signals. In order to improve the accuracy of determining which situation took place during the detection of the backscattered signals, the confidence condition is introduced in the method described herein.

[0015] A particular situation to be determined can be identified from the difference between the average sensor signal and the first sensor signal or the second sensor signal. The average sensor signal gives the value of backscattered signals detected under normal circumstances, this means for example without any defects or undesired events. If the first sensor signal deviates by more than the predefined threshold value from the average sensor signal, it can be assumed that an unusual or undesired event, this can mean an anomaly, took place during the detection of the first sensor signal. If the second sensor signal deviates by more than the predefined threshold value from the average sensor signal, it can be assumed that an unusual or undesired event, this can mean an anomaly, took place during the detection of the second sensor signal. However, there is a certain prob-

ability for each of the first sensor signal and the second sensor signal that there is a false alarm. This can mean, that for each of the first sensor signal and the second sensor signal it is possible that they deviate by more than the predefined threshold value from the average sensor signal but no anomaly took place.

[0016] In order to increase the accuracy of determining if an anomaly took place, it is assumed that only if both the first difference value and the second difference value are larger than the predefined threshold value, an anomaly took place. Therefore, by introducing the confidence condition, the accuracy of detecting anomalies along the railway track is increased. The alarm signal is only provided under the condition that confidence is built up by the confidence condition being fulfilled.

[0017] According to at least one embodiment of the method an anomaly can be at least one of the following: a defect of the railway track at the position that is the closest to the measurement segment, a change of the condition of the railway track at the position that is the closest to the measurement segment, mechanical vibrations at or around the position of the railway track that is the closest to the measurement segment. That there is a defect of the railway track can mean that there is a defect of the rail of the railway track. If the railway track has a defect, the backscattered signal detected during the passage of a rail vehicle over the defect can be different from the average sensor signal for the same position. For example, if a defect is present, the amplitude of the backscattered signal can be increased. This can lead to a difference signal being larger than the threshold signal. In this way, the anomaly can be identified.

[0018] A change in the condition of the railway track can be a change of the condition of the rail or of other components of the railway track. The condition of the rail can be a condition of wear of the rail. For different conditions of the railway track, the backscattered signal can deviate from the average sensor signal. In this way, the anomaly can be identified.

[0019] Mechanical vibrations at or around the railway track can be caused by at least one of movements of vehicles, footsteps of persons, manual or machine digging, working parties, movement of animals or environmental events such as rock falls or landslides. Other examples are theft or vandalism. If mechanical vibrations occur at or around the railway track, the backscattered signal is different from the backscattered signal of the situation where no mechanical vibrations occur. In this way, the anomaly can be identified.

[0020] For all these different types of anomalies it might be desired to detect if they occurred. For example, in case of a defect at the rail, the passage of rail vehicles at this position can only be allowed after the rail is repaired. This increases the safety in railway traffic. As another example, if a rock fall is detected, rail vehicles that are supposed to pass the position of the rock fall can be warned or stopped from passing this position.

[0021] According to at least one embodiment of the

method the first sensor signal and the second sensor signal are detected during the passage of a rail vehicle over the position of the railway track that is the closest to the measurement segment. This can mean, that the first sensor signal is detected during the passage of a part of the rail vehicle that is different from another part of the rail vehicle, wherein the second sensor signal is detected during the passage of the other part of the rail vehicle. The passage of the rail vehicle causes mechanical vibrations. The mechanical vibrations change the backscattered signal detected by the fiber optic sensor. Detecting the first sensor signal and the second sensor signal during the passage of a rail vehicle has the advantage that defects and/or changes of the railway track, in particular of the rail, can be detected. From the average sensor signal it is known how the backscattered signal looks like for the measurement segment. If there is a defect or a change of the railway track, the first sensor signal and the second sensor signal will deviate from the average sensor signal. If the first sensor signal and the second sensor signal deviate by more than the threshold signal from the average sensor signal, a defect or change of the railway track is regarded as severe enough so that it should be noted in order to avoid accidents. Without the rail vehicle passing over the position of the defect or change, the defect or change might not be recognized, since the defect or change itself in most cases do not change the backscattered signal. An advantage of detecting the first sensor signal and the second sensor signal during the passage of only one rail vehicle is, that the confidence condition can be fulfilled after the passage of only one rail vehicle. It is thus not necessarily required to wait for another rail vehicle to pass the position that is the closest to the measurement segment.

[0022] According to at least one embodiment of the method the first sensor signal is detected during the passage of a rail vehicle over the position of the railway track that is the closest to the measurement segment and the second sensor signal is detected during the passage of a further rail vehicle over the position of the railway track that is the closest to the measurement segment. This can mean, that two rail vehicles are employed to fulfill the confidence condition. With this, the influence of the particular rail vehicle on the backscattered signals from which it is determined if the confidence condition is fulfilled, is reduced.

[0023] According to at least one embodiment of the method the alarm signal indicates that an anomaly is detected along the measurement segment. This can mean, that the alarm signal indicates that an anomaly is detected along the measurement segment with a particular certainty. The information that an anomaly is detected is thus advantageously provided. It is therefore possible to take necessary action in order to avoid accidents.

[0024] According to at least one embodiment of the method the steps of the method are carried out for a plurality of different measurement segments along the fiber optic sensor. The steps of the method can be carried

out for the plurality of different measurement segments in the same way as for the measurement segment. This enables to detect anomalies along the whole railway track.

[0025] According to at least one embodiment of the method the confidence condition further requires that the first difference signal and the second difference signal are each larger than the predefined threshold signal for the first sensor signal and the second sensor signal being detected within a predefined time frame. This can mean that for determining if an anomaly occurred, the principle of erosion in time, in particular time based erosion in time, can be employed. Thus, for the confidence condition to be fulfilled, the first sensor signal and the second sensor signal have to be detected within a predefined time frame. The length of the predefined time frame can depend on the frequency of expected anomalies to be detected. It is also possible that the length of the predefined time frame depends on the frequency of rail vehicles passing the measurement segment. With the first sensor signal and the second sensor signal being required to be detected within the predefined time frame, the accuracy of determining if an anomaly occurred can be increased. Only if the first sensor signal and the second sensor signal are detected in a particular temporal proximity, the confidence condition is regarded to be fulfilled. With this, backscattered signals that deviate from the average sensor signal and that are detected at considerably different points in time, do not fulfill the confidence condition since these backscattered signals might have been detected in two different situations that do not relate to the same anomaly.

[0026] According to at least one embodiment of the method the confidence condition further requires that between detecting the first sensor signal and detecting the second sensor signal less than three third sensor signals are detected by the fiber optic sensor for the measurement segment, wherein a third difference signal, which relates to the difference between the average sensor signal and the third sensor signal, respectively, is smaller than the threshold signal for each third sensor signal. The third sensor signal can be detected in the same way as the first sensor signal and the second sensor signal. The confidence condition can further require that between detecting the first sensor signal and detecting the second sensor signal the less than three third sensor signals are the only signals detected. This can mean, that between the first sensor signal and the second sensor signal no other signals except for less than three third sensor signals are detected. In this way, it is guaranteed that the detection of the first sensor signal and the detection of the second sensor signal are not spaced too far from each other in time which increases the probability that they relate to the same anomaly.

[0027] According to at least one embodiment of the method the confidence condition further requires that between detecting the first sensor signal and detecting the second sensor signal less than five or less than ten third

sensor signals are detected by the fiber optic sensor for the measurement segment, wherein a third difference signal, which relates to the difference between the average sensor signal and the third sensor signal, respectively, is smaller than the threshold signal for each third sensor signal.

[0028] According to at least one embodiment of the method the confidence condition further requires that during detection of the first sensor signal a part of a rail vehicle passes over the position of the railway track that is the closest to the measurement segment and that during detection of the second sensor signal another part of the same rail vehicle passes over the position of the railway track that is the closest to the measurement segment. In this way, advantageously it is possible to fulfill the confidence condition with only one rail vehicle.

[0029] According to at least one embodiment of the method a counter is incremented once for each difference signal being larger than the threshold signal and decremented once for each difference signal being smaller than the threshold signal. The difference signal can be a first difference signal or a second difference signal. For determining if an anomaly occurred along the railway track the principle of erosion in time, in particular counter based erosion in time, can be employed. By incrementing the counter for each difference signal being larger than the threshold signal once and by decrementing the counter for each difference signal being smaller than the threshold signal once, the situations where the difference signal is larger than the threshold signal and where the difference signal is smaller than the threshold signal are equally weighted. In other words, a symmetric counter can be employed. By employing the counter, confidence is built up before the alarm signal is provided.

[0030] According to at least one embodiment of the method a counter is incremented at least once for each difference signal being larger than the threshold signal and decremented at least once for each difference signal being smaller than the threshold signal.

[0031] According to at least one embodiment of the method a counter is incremented twice for each difference signal being larger than the threshold signal and decremented once for each difference signal being smaller than the threshold signal. By incrementing the counter for each difference signal being larger than the threshold signal twice and by decrementing the counter for each difference signal being smaller than the threshold signal once, the situations where the difference signal is larger than the threshold signal and where the difference signal is smaller than the threshold signal are weighted differently. In other words, an asymmetric counter can be employed. By employing the counter, confidence is built up before the alarm signal is provided.

[0032] According to at least one embodiment of the method the confidence condition further requires that the counter reaches three counts. Thus, the alarm signal is only provided if the difference signal is larger than the threshold signal at least twice or at least three times. With

this, confidence is built up before the alarm signal is provided. This increases the accuracy of detecting anomalies.

[0033] According to at least one embodiment of the method the confidence condition further requires that the counter reaches at least three counts or more than three counts or more than ten counts.

[0034] According to at least one embodiment of the method a counter is incremented at least one more time for each difference signal being larger than the threshold signal than for each difference signal being smaller than the threshold signal. This can mean, that the number by which the counter is incremented for each difference signal being larger than the threshold signal is larger by least one than the number by which the counter is incremented for the difference signal being smaller than the threshold signal. It is also possible that the counter is incremented at least one more time for each difference signal being larger than the threshold signal than the counter is decremented for each difference signal being smaller than the threshold signal. Thus, the counter can be incremented by any number for each difference signal being larger than the threshold signal. The counter can be decremented by any number for each difference signal being smaller than the threshold signal. By employing the counter, confidence can be built up before the alarm signal is provided.

[0035] According to at least one embodiment of the method the threshold signal is larger than the variance or standard deviation of the average sensor signal. The threshold signal can therefore be a measure for how much the backscattered signals usually deviate from their average value. The threshold signal can then be slightly larger than the variance or the standard deviation of the average sensor signal. In this way, unusual deviations from the average sensor signal are detected. This enables to detect anomalies along the railway track.

[0036] Furthermore, a device for detecting anomalies along a railway track is provided. The device for detecting anomalies along a railway track can preferably be employed in the method described herein. This means all features disclosed for the method for detecting anomalies along a railway track are also disclosed for the device for detecting anomalies along a railway track and vice-versa.

[0037] According to at least one embodiment of the device for detecting anomalies along a railway track, the device comprises an evaluation unit that is connectable to a fiber optic sensor being arranged along the railway track. This can mean, that the evaluation unit is configured to be connected to the fiber optic sensor.

[0038] The evaluation unit comprises a detection unit that is configured to receive at least one first sensor signal detected by the fiber optic sensor for a measurement segment of the fiber optic sensor and to receive at least one second sensor signal detected by the fiber optic sensor for the measurement segment after detecting the first sensor signal. The evaluation unit can comprise an input for receiving the first sensor signal and the second sensor

signal.

[0039] The evaluation unit comprises a subtraction unit that is configured to determine a first difference signal where the first difference signal relates to the difference between an average sensor signal and the first sensor signal, and to determine a second difference signal where the second difference signal relates to the difference between the average sensor signal and the second sensor signal, wherein the average sensor signal relates to an average of previous sensor signals detected by the fiber optic sensor for the measurement segment before detecting the first sensor signal.

[0040] The evaluation unit comprises an alarm unit that is configured to provide an alarm signal for the case that a confidence condition is fulfilled, wherein the confidence condition requires at least that the first difference signal and the second difference signal are each larger than a predefined threshold signal.

[0041] As the device for detecting anomalies along a railway track can be employed in the method described herein, the device for detecting anomalies along a railway track has the same advantages as the method for detecting anomalies along a railway track.

[0042] According to at least one embodiment of the device for detecting anomalies along a railway track, the device comprises a counter that is configured to be incremented once or twice for each difference signal being larger than the threshold signal and decremented once for each difference signal being smaller than the threshold signal. The counter can be connected with the alarm unit. Thus, an alarm signal can be provided if the confidence condition is fulfilled.

[0043] The following description of figures may further illustrate and explain exemplary embodiments. Components that are functionally identical or have an identical effect are denoted by identical references. Identical or effectively identical components might be described only with respect to the figures where they occur first. Their description is not necessarily repeated in successive figures.

With figure 1 an exemplary embodiment of the method for detecting anomalies along a railway track is described.

Figure 2 shows an exemplary embodiment of a device for detecting anomalies along a railway track.

Figure 3 shows a fiber optic sensor.

With figures 4 and 5 further exemplary embodiments of the method for detecting anomalies along a railway track are described.

Figure 6 shows the principle of fiber optic sensing.

With figure 7 it is shown how the principle of fiber optic sensing is employed in the method for detecting

anomalies along a railway track 20.

[0044] With figure 1 an exemplary embodiment of the method for detecting anomalies along a railway track 20 is described. The method comprises detecting at least one first sensor signal F by a fiber optic sensor 21 for a measurement segment 22 of the fiber optic sensor 21 in a first step S1. The fiber optic sensor 21 is arranged along the railway track 20.

[0045] In a second step S2, at least one second sensor signal S is detected by the fiber optic sensor 21 for the measurement segment 22 after detecting the first sensor signal F. The first sensor signal F and the second sensor signal S can be detected during the passage of a rail vehicle over the position of the railway track 20 that is the closest to the measurement segment 22. This can mean that, the confidence condition further requires that during detection of the first sensor signal F a part of a rail vehicle passes over the position of the railway track 20 that is the closest to the measurement segment 22 and that during detection of the second sensor signal S another part of the same rail vehicle 32 passes over the position of the railway track 20 that is the closest to the measurement segment 22. Alternatively, the first sensor signal F can be detected during the passage of a rail vehicle over the position of the railway track 20 that is the closest to the measurement segment 22 and the second sensor signal S can be detected during the passage of a further rail vehicle over the position of the railway track 20 that is the closest to the measurement segment 22.

[0046] In a third step S3, a first difference signal FD is determined where the first difference signal FD relates to the difference between an average sensor signal AS and the first sensor signal F, wherein the average sensor signal AS relates to an average of previous sensor signals detected by the fiber optic sensor 21 for the measurement segment 22 before detecting the first sensor signal F.

[0047] In a fourth step S4, a second difference signal SD is determined where the second difference signal SD relates to the difference between the average sensor signal AS and the second sensor signal S.

[0048] In a fifth step S5, an alarm signal AL is provided for the case that a confidence condition is fulfilled, wherein the confidence condition requires at least that the first difference signal FD and the second difference signal SD are each larger than a predefined threshold signal or the confidence condition requires at least that the absolute value of the first difference signal FD and the absolute value of the second difference signal SD are each larger than a predefined threshold signal. The alarm signal AL indicates that an anomaly is detected along the measurement segment 22.

[0049] An anomaly can be at least one of the following: a defect of the railway track 20 at the position that is the closest to the measurement segment 22, a change of the condition of the railway track 20 at the position that is the

closest to the measurement segment 22, mechanical vibrations at or around the position of the railway track 20 that is the closest to the measurement segment 22.

[0050] The steps of the method can be carried out for a plurality of different measurement segments 22 along the fiber optic sensor 21.

[0051] The confidence condition can further require that the first difference signal FD and the second difference signal SD are each larger than the predefined threshold signal for the first sensor signal F and the second sensor signal S being detected within a predefined time frame. The threshold signal can be larger than the variance or standard deviation of the average sensor signal AS.

[0052] Figure 2 shows an exemplary embodiment of the device 24 for detecting anomalies along a railway track 20. The device 24 comprises an evaluation unit 25 that is connectable to a fiber optic sensor 21 being arranged along the railway track 20. The evaluation unit 25 comprises a detection unit 26 that is configured to receive at least one first sensor signal F detected by the fiber optic sensor 21 for a measurement segment 22 of the fiber optic sensor 21 and to receive at least one second sensor signal S detected by the fiber optic sensor 21 for the measurement segment 22 after detecting the first sensor signal F. The evaluation unit 25 comprises a subtraction unit 27 that is configured to determine a first difference signal FD where the first difference signal FD relates to the difference between an average sensor signal AS and the first sensor signal F, and to determine a second difference signal SD where the second difference signal SD relates to the difference between the average sensor signal AS and the second sensor signal S, wherein the average sensor signal AS relates to an average of previous sensor signals detected by the fiber optic sensor 21 for the measurement segment 22 before detecting the first sensor signal F. The evaluation unit 25 comprises an alarm unit 28 that is configured to provide an alarm signal AL for the case that a confidence condition is fulfilled, wherein the confidence condition requires at least that the first difference signal FD and the second difference signal SD are each larger than a predefined threshold signal. Optionally, the device 24 comprises a counter 23 that is configured to be incremented once or twice for each difference signal FD, SD being larger than the threshold signal and decremented once for each difference signal FD, SD being smaller than the threshold signal.

[0053] Figure 3 shows a fiber optic sensor 21 arranged along a railway track 20. The fiber optic sensor 21 comprises an optical fiber 30 that extends along the railway track 20. The optical fiber 30 comprises at least one measurement segment 22. Furthermore, fiber optic sensor 21 comprises a detection component 29. The detection component 29 is connected with the device 24 for detecting anomalies along a railway track 20.

[0054] With figure 4 another exemplary embodiment of the method for detecting anomalies along a railway

track 20 is described. A counter 23 is incremented twice for each difference signal FD, SD being larger than the threshold signal and decremented once for each difference signal FD, SD being smaller than the threshold signal. Thus, the counter 23 is incremented at least one more time for each difference signal FD, SD being larger than the threshold signal than for each difference signal FD, SD being smaller than the threshold signal.

[0055] On the x-axis the time is plotted and on the y-axis the value of the counter 23 is plotted.

[0056] In figure 4, at first a first sensor signal F is detected. The first difference signal FD is larger than the threshold signal. Therefore, the counter 23 is incremented twice. In a next step, a third sensor signal T is detected. A third difference signal TD, which relates to the difference between the average sensor signal AS and the third sensor signal T is smaller than the threshold signal for each third sensor signal T. Thus, the counter 23 is decremented once. In a next step, a second sensor signal S is detected. The second difference signal SD is larger than the threshold signal. Therefore, the counter 23 is incremented twice. The confidence condition further requires that the counter 23 reaches three counts. This is achieved after detecting the second sensor signal S. Consequently, after detecting the second sensor signal S, the alarm signal AL is provided.

[0057] With figure 5 another exemplary embodiment of the method for detecting anomalies along a railway track 20 is described. The confidence condition further requires that between detecting the first sensor signal F and detecting the second sensor signal S less than three third sensor signals T are detected by the fiber optic sensor 21 for the measurement segment 22, wherein a third difference signal TD, which relates to the difference between the average sensor signal AS and the third sensor signal T, respectively, is smaller than the threshold signal for each third sensor signal T. On the x-axis the time is plotted.

[0058] In figure 5, at first three third sensor signals T are detected. Therefore, the confidence condition is not fulfilled. At next, a first sensor signal F is detected. Afterwards, three third sensor signals T are detected. Therefore, again the confidence condition is not fulfilled. At next, a first sensor signal F is detected. In a next step, a third sensor signal T is detected. Afterwards, a second sensor signal S is detected. Consequently, the confidence condition is fulfilled and an alarm signal AL is provided.

[0059] With figure 6 the principle of fiber optic sensing is shown. As in figure 3, the optical fiber 30 extends along the railway track 20. The detection component 29 is connected with the optical fiber 30. It is schematically shown that on the railway track 20 a rail vehicle 32 can move. The diagram in the top part of figure 6 shows backscattered signals detected by the fiber optic sensor 21. On the x-axis the distance along the optical fiber 30 is plotted and on the y-axis the amplitude of the backscattered signals is plotted. At a first position x1 along the optical fiber

30 a person 31 is walking. Thus, the amplitude of the backscattered signals is higher at the first position x1 than at other positions where no mechanical vibrations occur. At a second position x2 along the optical fiber 30 a rail vehicle 32 is moving. Thus, the amplitude of the backscattered signals is higher at the second position x2 than at the first position x1 where less mechanical vibrations occur.

[0060] With figure 7 it is shown how the principle of fiber optic sensing is employed in the method for detecting anomalies along a railway track 20. Figure 7 shows a similar situation as in figure 6. The optical fiber 30 extends along the railway track 20. The detection component 29 is connected with the optical fiber 30. The diagram in the top part of figure 7 shows backscattered signals detected by the fiber optic sensor 21. On the x-axis the distance along the optical fiber 30 is plotted and on the y-axis the amplitude of the backscattered signals is plotted. At a first position x1 along the optical fiber 30 a rail vehicle 32 is moving. Thus, the amplitude of the backscattered signals is higher at the first position x1 than at other positions where no mechanical vibrations occur. At a second position x2 along the optical fiber 30 another rail vehicle 32 is moving. Below the position where the rail vehicle 32 is moving, there is a track defect 33, this means the rail of the railway track 20 has a defect. A track defect 33 is one example for an anomaly along the railway track 20. The backscattered signal detected during the passage of the rail vehicle 32 over the track defect 33 is different from the average sensor signal AS for the same position. In this example, the amplitude of the backscattered signal is increased at the position of the track defect 33. This can lead to a difference signal FD, SD being larger than the threshold signal. In this way, the anomaly can be identified.

Reference numerals

[0061]

20	railway track
21	fiber optic sensor
22	measurement segment
23	counter
24	device for detecting anomalies along a railway track
25	evaluation unit
26	detection unit
27	subtraction unit
28	alarm unit
29	detection component
30	optical fiber
31	person
32	rail vehicle
33	track defect
AL	alarm signal
AS	average sensor signal
FD	first difference signal

SD	second difference signal
F	first sensor signal
S	second sensor signal
S1-S5	steps
x1	first position
x2	second position

Claims

1. Method for detecting anomalies along a railway track (20), the method comprising:

- detecting at least one first sensor signal (F) by a fiber optic sensor (21) for a measurement segment (22) of the fiber optic sensor (21), the fiber optic sensor (21) being arranged along the railway track (20),
- detecting at least one second sensor signal (S) by the fiber optic sensor (21) for the measurement segment (22) after detecting the first sensor signal (F),
- determining a first difference signal (FD) where the first difference signal (FD) relates to the difference between an average sensor signal (AS) and the first sensor signal (F), wherein the average sensor signal (AS) relates to an average of previous sensor signals detected by the fiber optic sensor (21) for the measurement segment (22) before detecting the first sensor signal (F),
- determining a second difference signal (SD) where the second difference signal (SD) relates to the difference between the average sensor signal (AS) and the second sensor signal (S), and
- providing an alarm signal (AL) for the case that a confidence condition is fulfilled, wherein the confidence condition requires at least that the first difference signal (FD) and the second difference signal (SD) are each larger than a predefined threshold signal or the confidence condition requires at least that the absolute value of the first difference signal (FD) and the absolute value of the second difference signal (SD) are each larger than a predefined threshold signal.

2. Method for detecting anomalies along a railway track (20) according to claim 1, wherein an anomaly can be at least one of the following:

- a defect of the railway track (20) at the position that is the closest to the measurement segment (22),
- a change of the condition of the railway track (20) at the position that is the closest to the measurement segment (22),
- mechanical vibrations at or around the position

of the railway track (20) that is the closest to the measurement segment (22).

3. Method for detecting anomalies along a railway track (20) according to one of the preceding claims, wherein the first sensor signal (F) and the second sensor signal (S) are detected during the passage of a rail vehicle over the position of the railway track (20) that is the closest to the measurement segment (22). 5
4. Method for detecting anomalies along a railway track (20) according to one of claims 1 or 2, wherein the first sensor signal (F) is detected during the passage of a rail vehicle over the position of the railway track (20) that is the closest to the measurement segment (22) and the second sensor signal (S) is detected during the passage of a further rail vehicle over the position of the railway track (20) that is the closest to the measurement segment (22). 10
5. Method for detecting anomalies along a railway track (20) according to one of the preceding claims, wherein the alarm signal (AL) indicates that an anomaly is detected along the measurement segment (22). 15
6. Method for detecting anomalies along a railway track (20) according to one of the preceding claims, wherein the steps of the method are carried out for a plurality of different measurement segments (22) along the fiber optic sensor (21). 20
7. Method for detecting anomalies along a railway track (20) according to one of the preceding claims, wherein the confidence condition further requires that the first difference signal (FD) and the second difference signal (SD) are each larger than the predefined threshold signal for the first sensor signal (F) and the second sensor signal (S) being detected within a predefined time frame. 25
8. Method for detecting anomalies along a railway track (20) according to one of the preceding claims, wherein the confidence condition further requires that between detecting the first sensor signal (F) and detecting the second sensor signal (S) less than three third sensor signals (T) are detected by the fiber optic sensor (21) for the measurement segment (22), wherein a third difference signal (TD), which relates to the difference between the average sensor signal (AS) and the third sensor signal (T), respectively, is smaller than the threshold signal for each third sensor signal (T). 30
9. Method for detecting anomalies along a railway track (20) according to one of the preceding claims, wherein the confidence condition further requires that during detection of the first sensor signal (F) a part of a rail vehicle passes over the position of the railway 35

track (20) that is the closest to the measurement segment (22) and that during detection of the second sensor signal (S) another part of the same rail vehicle passes over the position of the railway track (20) that is the closest to the measurement segment (22) .

10. Method for detecting anomalies along a railway track (20) according to one of the preceding claims, wherein a counter (23) is incremented once or twice for each difference signal (FD, SD) being larger than the threshold signal and decremented once for each difference signal (FD, SD) being smaller than the threshold signal. 40
11. Method for detecting anomalies along a railway track (20) according to the preceding claim, wherein the confidence condition further requires that the counter (23) reaches three counts. 45
12. Method for detecting anomalies along a railway track (20) according to one of claims 1 to 9, wherein a counter (23) is incremented at least one more time for each difference signal (FD, SD) being larger than the threshold signal than for each difference signal (FD, SD) being smaller than the threshold signal. 50
13. Method for detecting anomalies along a railway track (20) according to one of the preceding claims, wherein the threshold signal is larger than the variance or standard deviation of the average sensor signal (AS). 55
14. Device (24) for detecting anomalies along a railway track (20), the device (24) comprising:
 - an evaluation unit (25) that is connectable to a fiber optic sensor (21) being arranged along the railway track (20), wherein
 - the evaluation unit (25) comprises a detection unit (26) that is configured to receive at least one first sensor signal (F) detected by the fiber optic sensor (21) for a measurement segment (22) of the fiber optic sensor (21) and to receive at least one second sensor signal (S) detected by the fiber optic sensor (21) for the measurement segment (22) after detecting the first sensor signal (F),
 - the evaluation unit (25) comprises a subtraction unit (27) that is configured to determine a first difference signal (FD) where the first difference signal (FD) relates to the difference between an average sensor signal (AS) and the first sensor signal (F), and to determine a second difference signal (SD) where the second difference signal (SD) relates to the difference between the average sensor signal (AS) and the second sensor signal (S), wherein the average sensor signal (AS) relates to an average of previous sensor

signals detected by the fiber optic sensor (21) for the measurement segment (22) before detecting the first sensor signal (F), and
- the evaluation unit (25) comprises an alarm unit (28) that is configured to provide an alarm signal (AL) for the case that a confidence condition is fulfilled, wherein the confidence condition requires at least that the first difference signal (FD) and the second difference signal (SD) are each larger than a predefined threshold signal.

15. Device (24) for detecting anomalies along a railway track (20) according to the preceding claim, wherein the device (24) comprises a counter (23) that is configured to be incremented once or twice for each difference signal (FD, SD) being larger than the threshold signal and decremented once for each difference signal (FD, SD) being smaller than the threshold signal.

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FIG. 1

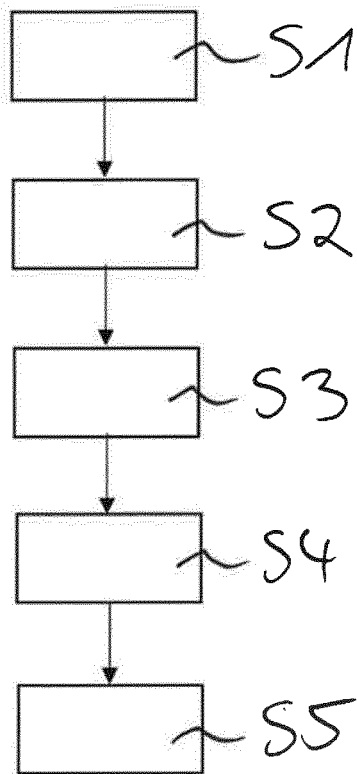


FIG. 2

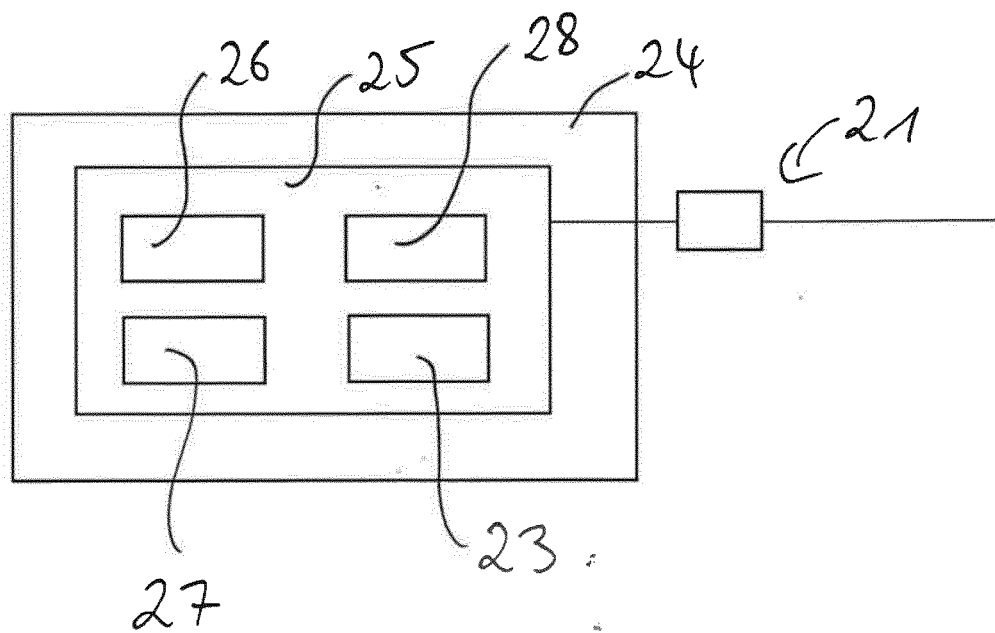


FIG. 3

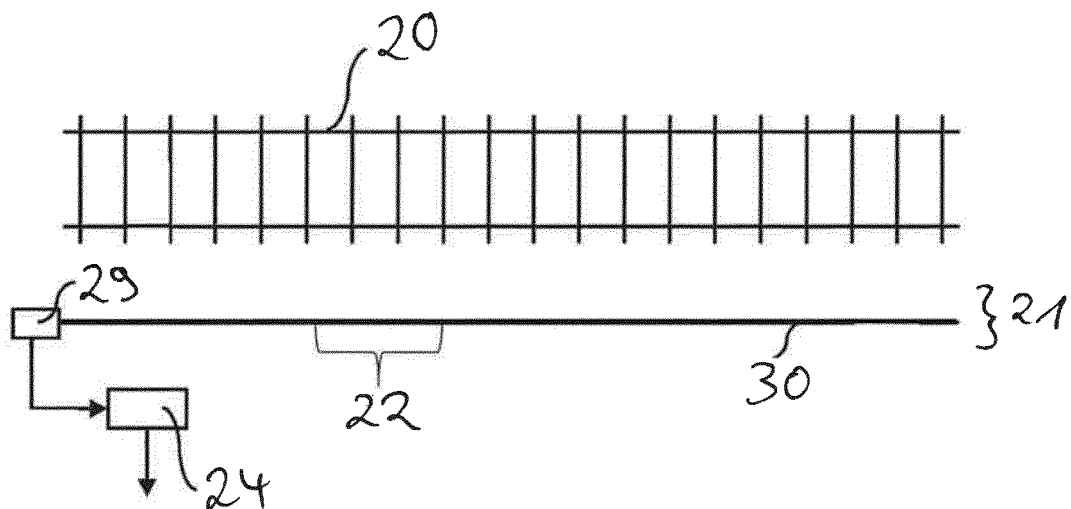


FIG. 4

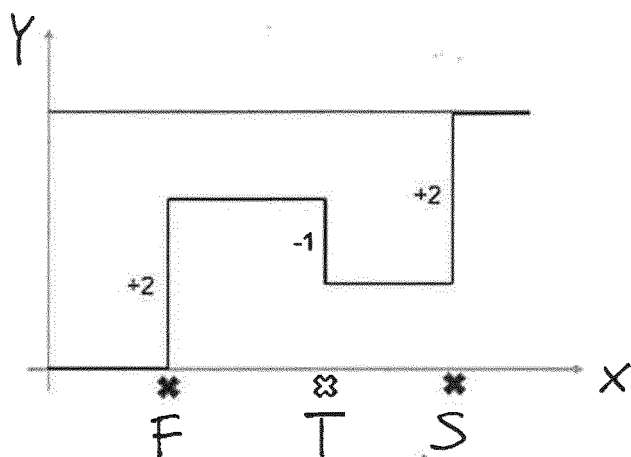


FIG. 5

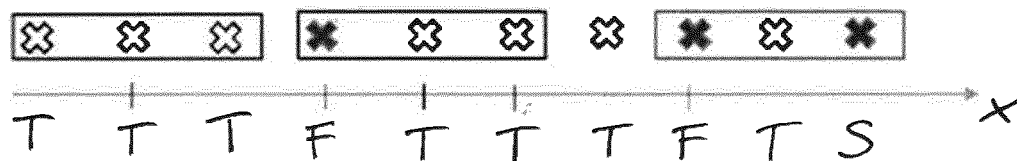


FIG. 6

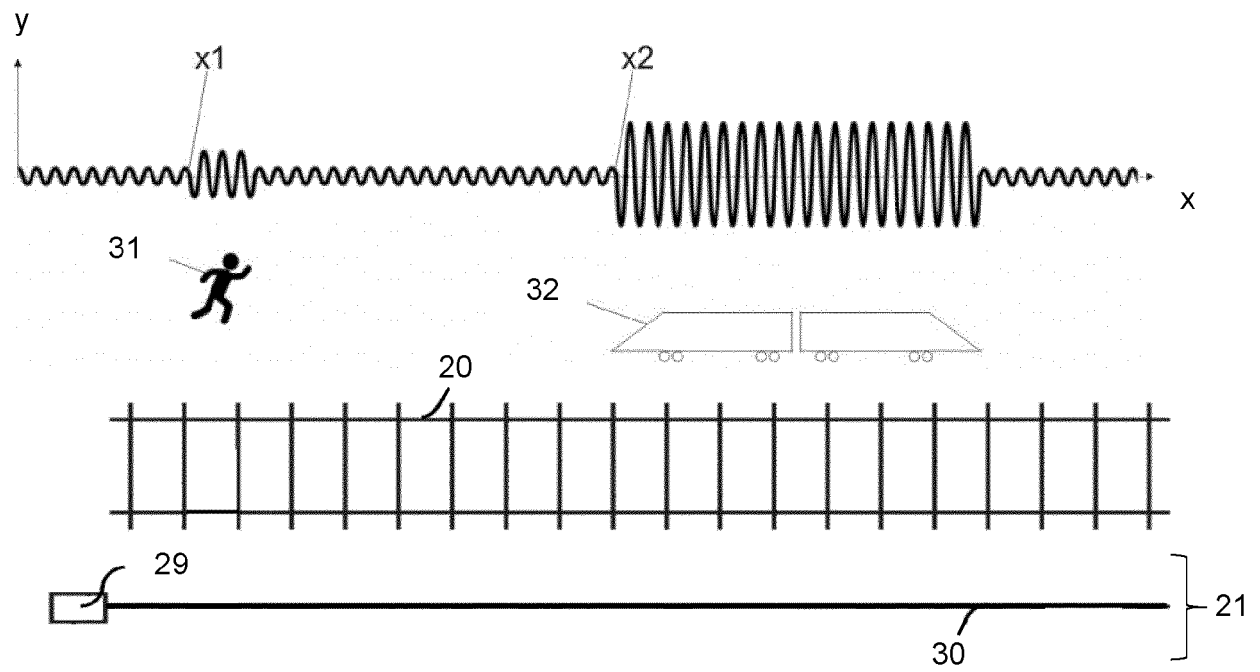
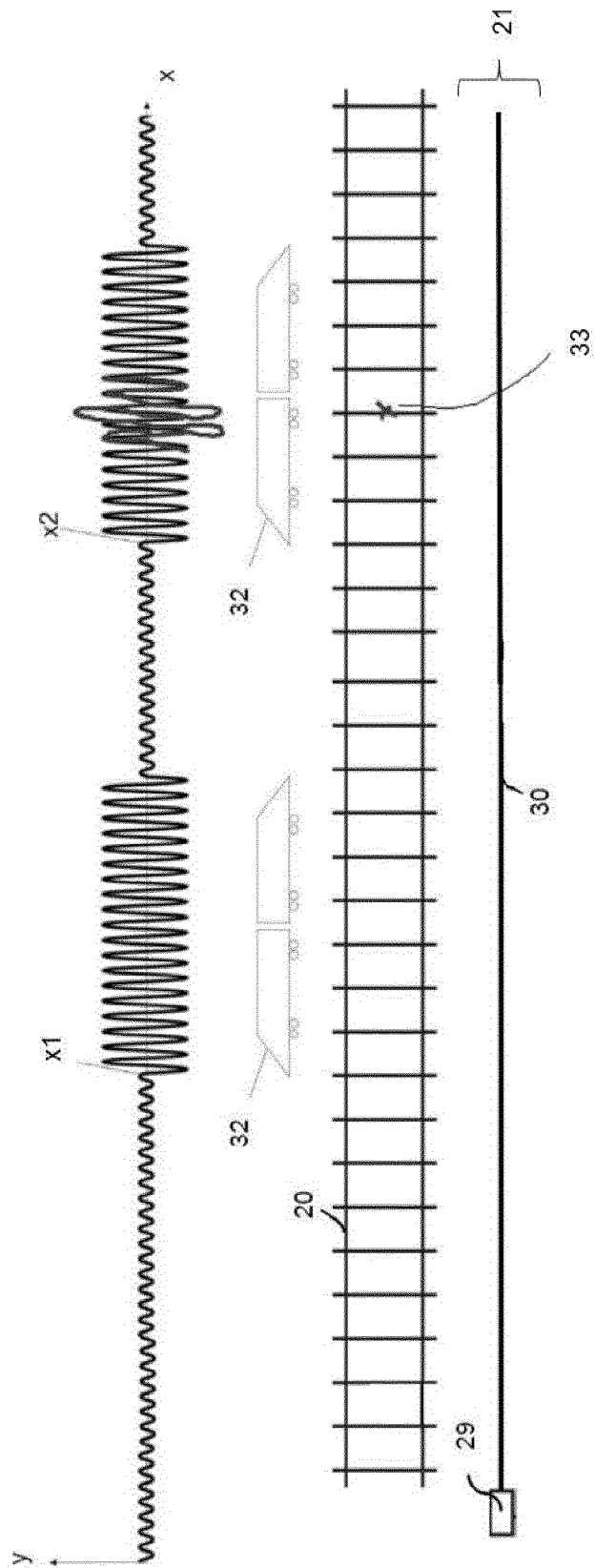


FIG. 7





EUROPEAN SEARCH REPORT

Application Number

EP 22 20 3763

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X	WO 2022/018388 A1 (SERCEL RECH CONST ELECT [FR]) 27 January 2022 (2022-01-27) * paragraph [0001] * * paragraph [0057] - paragraph [0064]; figures 1b,3b, 3c * * paragraph [0077] - paragraph [0080] *	1-15	
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The present search report has been drawn up for all claims			
Place of search Munich		Date of completion of the search 17 March 2023	Examiner Pita Priegue, Miguel
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document		T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document	

**ANNEX TO THE EUROPEAN SEARCH REPORT
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5 This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
The members are as contained in the European Patent Office EDP file on
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17-03-2023

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