



(51) International Patent Classification:

B61L 3/00 (2006.01) B61L 25/02 (2006.01)
B61L 15/00 (2006.01) B60W 40/068 (2012.01)

(21) International Application Number:

PCT/NL2018/050833

(22) International Filing Date:

12 December 2018 (12.12.2018)

(25) Filing Language:

English

(26) Publication Language:

English

(30) Priority Data:

2020072 12 December 2017 (12.12.2017) NL

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(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN,

HR, HU, ID, IL, IN, IR, IS, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:

— with international search report (Art. 21(3))

(54) Title: SYSTEM FOR ASSESSMENT OF TRACTION BETWEEN A RAIL AND A WHEEL AND METHOD FOR ASSESSMENT OF THE SAME

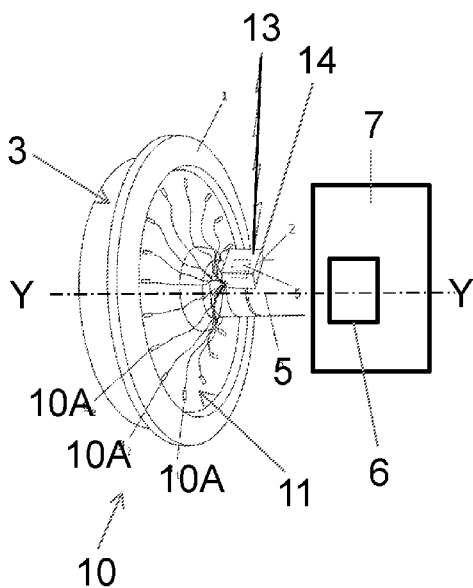


Fig. 2

(57) Abstract: Measurement system for assessment of available traction between a rail and a wheel on the rail, wherein the system is designed for assessment of at least a normal force of the wheel on the rail, a friction force between the wheel and the rail and a difference between the rotational speed of the wheel and a linear speed of the wheel relative to the rail, and a processing unit for processing data acquired by the system for calculating available traction.



Title: System for assessment of traction between a rail and a wheel and method for assessment of the same

5 The invention relates to methods and systems for assessment of traction between a rail and a wheel driven thereon.

Such systems are known in the art and are commonly referred to as tribometer. A known tribometer is a hand operated tribometer. This is a relatively simple device which can be hand held and can measure traction
10 with a very low accuracy and depends very much on the operator. A more elaborate system for assessment of rail traction is a rail vehicle specifically designed for the purpose and is known as a Tribo Train, designed by Network Rail. This train again is relatively inaccurate in traction assessment.

15 EP2899086 discloses a slip ratio estimation device and method, in which an estimation is made of slip. It has been found that the estimation will lead to significant errors in the outcome, which can lead to a deviation between the estimated slip and the actual slip of for example 1 % or more. Which will lead to a difference in for example braking distance at
20 operational speed of a train of 40 m/s of about 300 meters in low friction conditions, which is about the average station length of stations in Europe.

WO2009/113001 discloses a system and method for measuring i.a. slip of a wheel of a vehicle, using a Laser Surface Velocimeter (LSV) method, measuring laser light reflecting off a surface on which the relevant
25 wheel is driving.

An aim of the present disclosure is to provide for system for assessment of traction between a wheel and a rail. An aim of the present disclosure is to provide for a method for assessment of traction between a rail and a wheel driven thereon. An aim of the present disclosure is to
30 provide for a system and method for aiding in control of train management. An aim of the disclosure is to provide for a system and method for adjusting

engine management and/or brake management of a train based at least on traction assessment.

At least one of these aims is at least in part achieved with a method and/or system according to the disclosure.

5 In an aspect a system according to the disclosure can be characterized in that the system is designed for assessment of at least a normal force of the wheel on the rail, a friction force between the wheel and the rail and a difference between the rotational speed of the wheel and a linear speed of the wheel relative to the rail. A processing unit can be
10 provided for processing data acquired by the system for calculating available traction. For obtaining the required data related to normal force, friction force, rotational speed and linear speed sensor systems can be provided, which can be individual sensor systems for the forces and the speeds or combined sensors, for example a single sensor system for both rotational
15 and linear speed and a single sensor system for both normal force and friction force.

In an aspect the forces can be measured using stress and/or strain measurement in the wheel and/or an axes to which the wheel is connected. In an aspect speeds of the wheel relative to the rail can be measured using a
20 laser system, such as a Doppler based laser system. Such system is especially advantageous for measurement of accurate linear speed.

In an aspect the sensors for at least sensor systems for assessment of rotational speed and/or linear speed can be designed for measurement of or at least assessment of at least one of and preferably both of the rotational
25 speed and the linear speed at a contact area between the wheel and the rail.

In an aspect a method according to the disclosure can comprise assessment of traction between a rail and a wheel on the rail, wherein at least a normal force of the wheel on the rail, a friction force between the wheel and the rail and a difference between the rotational speed of the

wheel and a linear speed of the wheel relative to the rail are assessed. The data acquired by the system is used in calculating available traction.

In an aspect a method according to the disclosure can comprise assessing rotational speed of the wheel and/or linear speed of the wheel
5 using a laser Doppler based system, especially a laser Doppler anemometry based system, preferably for assessment of both rotational speed and linear speed.

In an aspect a method according to the disclosure can comprise assessment of traction or available traction between a wheel of a train and a
10 rail on which said wheel is driven, for example by assessing momentary slip between said wheel and said rail, and providing the outcome of said assessment to an engine management and/or braking management of said train and/or providing said outcome to a train track management system for managing multiple trains on a track system.

15 In an advantageous embodiment ground speed of the rail vehicle and especially a relevant wheel using a non-laser reflection based system, especially an image based system, such as a Correvit sensor, with which ground speed (V_2) can be measured by image analyses of sequential images taken of the rail.

20 In further elucidation of the present invention embodiments of the present disclosure, such as embodiments of methods and systems shall be described hereafter, with reference to the drawings. Herein shows:

Fig. 1A and B schematically show a wheel mounted on an axle, in perspective view (fig. 1A) and in side view (fig 1B) showing different forces
25 and speeds;

Fig. 2 shows in perspective side view schematically a wheel on an axle, provided with sensors;

Fig. 3 shows schematically a wheel on a rail, in side view, with sensors provided for measurement of at least one speed component;

Fig. 4 shows schematically part of a tribometer according to the disclosure, for off track measurements;

Fig. 5 shows schematically a Stribeck type curve;

Fig. 6 shows schematically a traction curve for a train;

5 Fig. 7 shows schematically a feedback display for traction; and

Fig. 8 shows schematically a mapping of historical data obtained with a system and/or method according to the disclosure;

Fig. 9 shows schematically a system according to the disclosure comprising a processing unit connected to a management system;

10 Fig. 10 shows schematically an alternative system for measuring ground speed (V_2) and rotational speed (V_1) of a wheel.

In this description embodiments of the invention will be described with reference to the drawings by way of example only. These embodiments should by no means be understood as limiting the scope of the disclosure. At
15 least all combinations of elements and features of the embodiments shown are also considered to have been disclosed herein. In this description the same or similar elements and features will be referred to by the same or similar reference signs.

In this description expressions of orientation such as top, bottom, vertical etcetera are used for convenience only and refer to the orientation of
20 a train in a normal, horizontal position as seen in the accompanying drawings. Such expressions are not to be regarded as limiting the orientation of elements of the system in use.

In this description a train has to be understood as a vehicle or a
25 series of coupled vehicles, driven on a track comprising at least one rail. A train wheel has to be understood as a wheel of such train, preferably a driven wheel. Such wheel can be a wheel mounted to, especially fixed to an end of a wheel axle. Such wheel can be fixed to the axle such that it cannot rotate relative to the axle. In such embodiment a force aiming to rotate the

wheel relative to the axle would result in torque in at least the axle. In embodiments the wheel and rail will be made of metal.

In a system 100 according to the disclosure, for assessment of available traction between a rail 2 and a wheel 1 on the rail 2, the system
5 can be designed for assessment of at least a normal force Q of the wheel 1 on the rail 2, a friction force X between the wheel 1 and the rail 2 and a difference between the rotational speed V_1 of the wheel 1 and a linear speed V_2 of the wheel 1 relative to the rail 2. A processing unit 101 can be provided for processing data acquired by the system 100 for calculating
10 available traction T .

In embodiments a first sensor system 9 for assessment of the normal force Q and the friction force X . In embodiments a second sensor system 12 can be provided for measuring the rotational speed V_1 and the linear speed V_2 . The second sensor system 12 can be provided for
15 assessment of slip S of the wheel 1 relative to the rail 2. In embodiments the processing unit 101 can be designed for receiving and processing data received from the sensor systems 9, 12, and calculating available traction T for the wheel 1 on the rail 2. A processing unit 101 has to be understood at least as a single unit or a series of cooperating units, for electronically
20 processing data received from one or more sensor systems. The processing unit 101 can be designed for determining a Stribeck curve for the wheel 1.

In embodiments the processing unit 101 can be coupled to a management system 102, for example an engine management system 103 and/or a brake management system 104, for at least aiding in operation of
25 an engine of the train and/or brakes of the train. Additionally and/or alternatively the data received and processed could be used in a train operating process, such as for example for planning, time table systems, track use, train assembling and the like.

In this disclosure contact between a wheel and a rail has to be
30 understood as including but not limited to direct contact, that is for example

metal on metal contact, or indirect contact, for example through a lubricant and/or friction lowering or increasing substance and/or dirt on the rail and/or the wheel.

In a system and method according to the present disclosure one or
5 more sensors are used for measuring at least a rotational speed V_1 of a wheel 1 and linear speed V_2 of the wheel 1 relative to a rail 2.

In this description rotational speed V_1 has to be understood as the speed, for example in meter/second (m/s), of a contact surface portion 3 of the wheel 1. A contact surface portion 3 may be defined as a portion of the
10 wheel which will make contact with the rail 2, at a contact area CA between the wheel 1 and the rail 2, at the relevant surface area 4 of the rail 2. The contact surface portion 3 will extend circumferentially around the wheel, and may have a width perpendicularly to the rail surface 4, substantially parallel to a longitudinal axis Y – Y of the axle. The contact area CA may be
15 substantially a point contact, a line contact or a small surface contact. The rotational speed can be measured directly by a relevant sensor system, or can be calculated based on other parameters measured, such as for example a rotating speed of the wheel or the axle, for example in degree or radial per second, and the diameter of the wheel measured at the contact surface
20 portion 3.

In this description linear speed V_2 has to be understood as a speed, for example in m/s, of the wheel 1 measured parallel to a longitudinal direction LD of the rail 2, measured at or near the contact area CA. Again, the linear speed V_2 can be measured directly or indirectly, or can be
25 calculated based on other parameters. Preferably a linear speed V_2 is measured directly by using a sensor system mounted on a train to which the wheel is attached, sensing displacement of at least one sensor along the rail in said longitudinal direction LD. V_2 can also be referred to as ground speed.

From the above it can follow that a difference in V_1 and V_2 is an indication of slip of the wheel 1 over the rail 2 in the contact area CA. This slip S can be calculated as $S=(2*|V_1-V_2|)/(V_1+V_2)$.

Slip S is the relative motion between a train wheel 1 and the rail surface 3 it is moving on. This slip S can be generated either by the wheels rotational speed being greater or less than the free-rolling speed. This is usually described as percent slip. In embodiments a difference in rotational speed between a free rotating axle and a braked/driven axle of a train can be used to detect slip with the use of tachometers. In alternative embodiments slip S can be determined based on the difference in speed of the train in the longitudinal direction LD of the rail measured using satellite based positioning, such as GPS, with rotating speed of the train-wheel, for example measured using a tachometer. A more accurate measurement can be obtained with an absolute measurement, especially by the use of a laser based sensor system, such as Laser Surface Velocimeters.

In this disclosure a normal force Q will be understood at least as a substantially vertical force, for example in Newton (N), substantially perpendicular to the longitudinal axis Y – Y of the axle 5 and substantially perpendicular to the contact area CA. In this disclosure a friction force X, for example measured in N, will be understood at least as a force due to friction between the wheel 1 and the rail 2 in or at the contact area CA, substantially parallel to the surface area 4 of the rail 2 at the contact area CA. The friction force will depend at least on the Coefficient of Friction between the wheel and the rail and/or any layer provided between the two in the contact area CA, and the normal force Q.

Fig. 1A and B schematically show a wheel 1 mounted on an axle 5, in perspective view (fig. 1A) and in side view (fig 1B) showing different forces Q, X and speeds V_1 and V_2 . In fig. 1A and B only one wheel 1 is shown, at one end 5A of the axle 5. In embodiments another wheel may be mounted to the opposite end of the axle 5 (not shown) which may or may not

be the same as the wheel as shown. In embodiments the wheel 1 can be a driven wheel 1, for example driven by an engine 6 of a train 7 to which the axle 5 is mounted, or by a different engine or motor, for example a motor dedicated to the measuring system 100 comprising the wheel 1 and relevant sensors 10, 15, 16 as will be discussed further hereafter.

Fig. 2 shows in perspective side view schematically a wheel on an axle, provided with sensors 10 of a first sensor system 9, for measuring the normal force Q and frictional force X . In this embodiment a plurality of first sensors 10 is fitted to the wheel, for example in or on a surface of the wheel 1, especially a side surface 11 thereof. The relevant side surface 11 can for example be a surface 11 facing the axle 5. The first sensors 10 can be designed for measuring stress and/or strain in the wheel. The sensors 10 can for example comprise or be formed by strain gauges 10A or the like, which can be spaced regularly, for example over the surface 11 of the wheel 1. The first sensors such as strain gauges 10 can be coupled to a control unit 13, for example provided in a closed housing 14, shielded from the environment. The control unit 13 can comprise a transmitter for wireless transmitting data obtained from the first sensors 10, as raw data and/or as data processed by the control unit, to the processing unit 101.

Processing data obtained from strain gauges 10A as shown in fig. 2 or similar sensors 10 in order to calculate at least a normal force Q and a friction force X is well known in the art and is for example disclosed in WO2006/128878, herein incorporated by reference for such arrangement and calculations. WO2006/1298878 discloses a mathematical process for calculating, among others, a vertical or normal force F_1 and a horizontal or friction force F_2 from data obtained from sensors as arranged in general as disclosed in fig. 2 of the present disclosure, especially from first sensors 10 as described, especially strain gauges 10A. In the present system for example such calculations can be used for defining the normal force Q and the friction force X , represented in WO2006/128878 as forces F_1 and F_2 . To

this end the first sensors 10, 10A and the control unit 13 can be designed according to WO2006/128878.

Fig. 3 shows schematically a wheel 1 on a rail 2, in side view, with sensors 15, 16 of a second sensor system 12, provided for measurement of at least one speed component, especially rotational speed V_1 and linear speed V_2 . As described before the second sensor system 12, especially the sensors 15, 16, which can be referred to as second and third sensor 15, 16 respectively, are preferably designed for direct measurement of the speeds V_1 and V_2 . The second and third sensors 15, 16 can for example be designed as laser based sensors 15, 16. For example laser surface velocimeters.

In fig. 3 by way of example the second and third sensor 15, 16 are designed as laser based velocimeters, using Doppler effect measurement as known in the art, which can also be referred to as Laser Doppler Anemometry (LDA).

Laser Doppler anemometry (LDA), is the technique of using a Doppler shift in a laser beam 17 of a laser 18 to measure velocity of a linear motion of opaque and or reflecting surfaces. The measurement with LDA can be absolute, linear with velocity and requires no pre-calibration.

In a simple and generally used form, LDA crosses two beams of collimated, monochromatic, and coherent laser light on a surface being measured. The two beams are preferably obtained by splitting a single beam 17 of a laser 18, ensuring coherence between the two beams. Lasers 18 with wavelengths in the visible spectrum are commonly allowing a beam path of the beam 17 or beams to be observed. A transmitting optics 16A, 17A focuses the beams 17 to intersect at a focal point, where they interfere and generate a set of straight fringes. As irregularities on the surface 3, 4 of which the relative speed V_1 , V_2 is to be measured move along the fringes, they reflect laser light from the beams 17 that is then collected by a receiving optics 15B, 16B of the relevant sensor 15, 16 and focused on a photodetector thereof.

The reflected light fluctuates in intensity, the frequency of which is equivalent to the Doppler shift between the incident and scattered light, and is thus proportional to the component of the surface velocity $V_{1,2}$ which lies in the plane of two laser beams 17.

5 In fig. 3 the second sensor 15 for measurement of the rotational speed V_1 is positioned next to the wheel 1, to the front of the wheel 1 or to the rear of the wheel 1, seen in a direction of movement F of the train moving "forward", in fig. 3 indicated as a direction F to the right of the drawing. The optics 15A, 15B are directed to the surface area 3 of the wheel
10 1, for example at a level L_1 crossing a centre C of the wheel 1. The laser beams 17 from the sensor 15 are thus directed directly onto the relevant surface area 3 of the wheel and thus the speed of said surface relative to the sensor 15 can be measured, as the rotational speed V_1 of the wheel 1.

In fig. 3 the third sensor 16 for measurement of the linear speed V_2
15 is positioned such that the optics 16A, 16B are directed such that the laser beams 17 are directed towards close by and preferably at the contact area CA between the wheel 1 and the rail 2. With this arrangement the relative speed of the rail 2 relative to the sensor 16 can be measured accurately.

The placement of the LDA sensors 15, 16 in regards to the surfaces 3,
20 4 can be determined by the dimensions of the wheel and can therefore be dependent on the wheel geometry. It is preferred to measure the linear speed, representative for the velocity of the train, close to the contact area CA of the wheel 1 to avoid inaccuracies which may result from creep forces. Relatively close should in this description preferably be understood as less than about the
25 radius R of the wheel 1, measured near the contact surface portion 3, more preferably less than about three quarters of said radius R , such as for example between halve and one eighth or less of said radius R .

When mounted on a train 7 the sensors 15, 16 will move relative to the rail 2 which will be in a fixed position. However, a similar system can be
30 used in a test system, in which for example a wheel 1 can be in a fixed

position, mounted on an axle 5, whereas a rail 2 can be moved relative to the wheel 1. Such system is schematically shown in fig. 4, in which schematically part of a tribometer 105 according to the disclosure is shown, for off track measurements.

5 The second and third sensors 15, 16 are connected to the processing unit 101 too, in order to transmit the relative data obtained with the LDA for processing.

Fig. 5 schematically shows a Stribeck type curve which can be established by the processing unit 101. With at least the sensors 10, 15 and 10 16 as described a basic Stribeck curve can be determined. This allows to determine in what type of lubrication regime a train is operating and what the optimal tractive effort is or can be. It is known that what the maximal tractive capacity a train is, is determined primarily, and especially as far as the present disclosure is concerned, by the regime in which a train is operating, which can 15 be distinguished as boundary lubrication BL, mixed lubrication ML or elasto-hydrodynamic lubrication EHL. Graphs can be calculated in a known manner for isothermal and for thermal circumstances. By knowing these parameters for a train, the traction effort can be optimized, especially maximized, for example in low friction environments. Additionally or alternatively the system can be 20 used to reduce wear and tear of the wheel-rail interface (Rolling Contact Fatigue), especially in high friction environments and/or it can be used to reduce the waste of energy, for example in medium-to-low friction environments, and/or to reduce the onset of rolling contact fatigue.

Fig. 6 schematically shows a traction curve for a train. Along the 25 vertical axis the Coefficient of friction (COF) is shown, whereas along the horizontal axis the slip S, especially percent slip S% is shown. The coefficient of friction (COF) can be defined as the usable force for traction divided by the force of the weight on the wheel, i.e. the normal force Q. The usable traction can hence be defined as the COF times the normal force Q. 30 In a system and method according to the disclosure a feedback system 107 can be used in which data obtained by and/or processed by the processing

unit 101 can be used for feedback to for example a train operator, for example for engine management and/or brake management, for control of the speed of the train, for example based on available traction and a traction curve as shown.

5 In a feedback system 107 towards for example an operator of a train, such as a driver of a rail operator, an optimal traction curve as shown can be determined for a given efficiency, capacity, maintenance and safety of the rail network. Each country historically has its own optimal range for a traction coefficient of a rail system. A range between μ 0.15 and μ 0.35 is most common
10 in use. A feedback system 107 can for example comprise a simple sound indicator and/or a visual indicator for the train driver when he approaches the for example 90% of a predetermined maximum COF and for example an another sound and/or visual signal at reaching the maximum COF (Δ). This can also or alternatively be used automated by directly inputting the signal(s) into
15 an engine and/or braking management system of a train. An auditive and/or visual feedback system 107 can be provided in the cabin of a driver, as for example as shown in figure 7. In such visual feedback system 107 as for example shown in fig. 7 different areas can be indicated, for example for a traction too low, a traction good and a traction too high. This provides the
20 driver or engine management system and/or braking system with information on the bases of which the train speed can be adjusted and/or traction can be improved, for example by applying friction increasing means to the wheel-rail interface or contact area CA, such as sand or gel, and/or cleaning the surface 4 of the rail 2 and/or the surface portion 3 of the wheel 1.

25 In a system and method according to the disclosure a train driver and/or rail-operator can be given a heatmap of historical data, as for example shown in fig. 8, which may at least in part be obtained with a system 100 according to the disclosure, to plan out a current driving strategy and/or an optimal daily routing for the rail operator. These
30 heatmaps can average out, for example to have a day by day or a week-by-week planning for the rail-planners and can be used to further minimize the

5 maintenance and maximize the efficiency, capacity, safety of the rail networks. The heatmap can for example be used for planning train schedules, optimizing train travel times, energy consumption and/or use of traction increasing means, such as for example gel, sand or rail cleaning equipment.

Fig. 9 shows schematically in a block diagram a system according to the disclosure comprising a processing unit 101 connected to a management system 106, for example a train operation management system, an engine management system and/or a brake management system. 10 The first and second sensor systems 9, 12 can be coupled to the processing unit 101, for example through a control unit as discussed, for example by wire or wireless. Alternatively or additionally such management system may comprise friction increasing means, such as a well known sand box for providing friction increasing sand or gel onto the rail surface for increasing 15 traction, or similar means.

Fig. 10 discloses an alternative embodiment of a part of a system according to the disclosure, similar to that of fig. 3, in which however in stead of using a laser based system 16 for measuring the linear or ground speed V2 a camera based system 160 is used. Preferably in combination 20 with a laser based system 15 as discussed for measuring the rotational speed V1 of the wheel.

When using an LSV system as disclosed in WO2009/113001 for rail based vehicles, the laser light is reflected of the rail. This is dangerous for both personnel and bystanders, for example because of the risk of eye 25 damage. When ground speed (V2) is measured with a laser, the light should be bright enough for when the rail is rusty (high light absorbing up to 90% of light), but when the rail is highly used, polished by the metal-metal contact of the wheels on the rail, the rail is highly reflective (absorbing less than 1%) a LSV capable of measuring on rusty rail uses too much power, or 30 loses significant accuracy. The high power laser light reflecting of the rail

will at least in part be reflected to the surroundings of the vehicle and possibly into the vehicle, resulting in said danger for injury.

Next to the safety factor, a further problem in using laser based systems on rails is that a rail track is not an 'unbroken' piece. There are
5 many infrastructure elements which increase the angle of the sensor-surface such as switches and expansions gaps. This renders the use of laser even more dangerous. For example if no light is detected reflecting on the sensor, this triggers a step up in power in state-of-the-art laser doppler sensors, which will then point at the general public who can come very close to the
10 laser spot, for example within one meter. For measuring the rotational speed, such problems are unlikely to be found and the LSV's benefit from the smooth surface to measure the rotational speed with very high accuracy.

Fig. 10 shows schematically such camera based system 160 for measuring ground speed V_2 , using a camera 161 connected to a grabber 162
15 and a vision system 163. Such camera based system can for example be based on a Correvit sensor, as for example provided by Kistler Group, Switzerland, and as for example described in US9221481. The system 160 comprises for example a digital camera 161 delivering a sequence of digital images of an environment of the vehicle, especially at least the rail and an
20 apparatus that determines the apparent motion of at least one visual index, called a primitive, between two images delivered by the image capture apparatus, so as to determine the apparent motion of said at least one visual index; and an apparatus that estimates speed and/or the position of the vehicle on the basis of the apparent motion of the at least one visual index.
25 In other words, a sequence of timed images is taken by the camera 161, of at least the rail 2 on which the wheel 3 is driving, which are fed into the grabber 162 and processed by the vision system 163, using an algorithm analysing the differences between the images and calculating the relative displacement and speed from the different images. This means that there is
30 no laser reflection of the rail 2 and ground speed V_2 measurements can be

made with high accuracy, irrespective of the condition of the rail surface, for example rusted or bright, or whether there are gaps in the rail, for example expansion gaps, switches, railroad crossings or the like. Since the speed V_2 can be calculated no estimation is necessary.

5 As discussed, a camera based sensor system 160 for measuring the ground speed V_2 can be combined with an LSV based system for measuring rotational speed V_1 , since here the reflection can easily be controlled, as well as the power of the laser, or with another type of sensor system 15 for measuring the rotational speed V_1 , for example also camera
10 based.

Combining these two methods, LSV for rotational speed V_1 and camera or vision based system such as but not limited to a Correvic system for measuring ground speed V_2 , gives an unprecedented accuracy in slip. Where at low slip values a 0.01% difference can have an impact of 0.01 μ
15 or 0.1 m/s^2 acceleration differences. When applied with the force measurement (Q normal force , X longitudinal force) most of the slippery track issues can be solved as it can now be measured accurately.

With a system according to the present disclosure also lateral force Y can be measured on a wheel 3. It has been found that this force Y
20 can provide valuable information about track condition as well. With a GPS sensor the actual position of a wheel on the track can be defined, whereas the ground speed V_2 can be calculated in that position. Each time the vehicle with the present system passes the same part of a track, all forces acting on the wheel and the track and how they interact can be registered,
25 besides information on the friction in the heat map. With this information, track alignment can be checked. Frequent high forces are early warning indicators for repairs regarding Rolling Contact Fatigue which determine the lifetime of a railway. Lateral forces Y can therein be used as an indicator for misalignment of tracks.

The invention is by no means limited to the embodiments as specifically disclosed herein. Many variations thereof are possible within methods or systems of the disclosure, within the scope as defined by the claims. For example different sensors can be used as first, second and/or
5 third sensors. For example a torque sensor can be used in stead of or next to strain gauges as first sensors. For assessment of the rotational speed alternatively or additionally the number of rotations of the wheel can be measured in a given time frame, on the bases of which the rotational speed can be calculated using the radius of the wheel at the desired contact
10 surface area 3 of the wheel. for linear speed alternatively or additionally other sensors or sensor systems can be used, such as for example tachometers or GPS based systems. In the embodiments shown sensors are shown of one wheel on an axle. However, also multiple wheels can be provided with some or all of such sensors, for example wheels on opposite
15 ends of an axle. Communication between sensors and a control unit and/or a processing unit and/or a management system can be obtained differently, for example by wire based systems, wireless based systems or combinations thereof, wherein at least two of the control unit, the processing unit and the management system can be integrated. In embodiments the or each wheel
20 can be provided on a dedicated measurement train or wagon for integration in a train. Alternatively the or each wheel can be the wheel of a further standard train, such as a passenger train or a freight train. In embodiments a train according to the disclosure could be a different type of rail bound vehicle, such as a crane, a monorail vehicle or a transport cart. In
25 embodiments the wheel can be a free rotating or "free floating" wheel, for example a rollercoaster cart, for which traction and especially negative traction may be relevant. With a system and method according to the present disclosure available traction can be assessed, for a wheel on a rail, both for acceleration and for deceleration of the wheel, for example for
30 braking.

These and many such variations are considered falling within the scope of the claims.

Claims

1. Measurement system for assessment of available traction between a rail and a wheel on the rail, wherein the system is designed for assessment of at least a normal force of the wheel on the rail, a friction force between the wheel and the rail and a difference between the rotational
5 speed of the wheel and a linear speed of the wheel relative to the rail, and a processing unit for processing data acquired by the system for calculating available traction.
2. Measurement system according to claim 1, wherein the system has a first sensor system for assessment of the normal force and the friction
10 force.
3. Measurement system according to claim 2, wherein the first sensor system comprises at least a strain sensor and/or a stress sensor, for assessment of strain and/or stress in the wheel and/or in an axle to which the wheel is attached.
- 15 4. Measurement system according to claim 1 or 2, wherein the first sensor system comprises a control unit, preferably mounted on an axle of the wheel, which control unit comprises a transmitter for transmitting data from the first sensor system to the processing unit, preferably wireless.
5. Measurement system according to any one of the previous claims,
20 wherein a second sensor system is provided for assessment of slip between the wheel and the rail, and a transmitter for transmitting data obtained by the second sensor system to the processing unit.
6. Measurement system according to claim 5, wherein the second sensor system comprises at least a sensor for assessment of rotational speed
25 of the wheel relative to the rail, preferably rotation speed assessed at the contact area between the wheel and the rail, and/or a sensor for linear speed of the wheel relative to the rail.

7. Measurement system according to claim 5 or 6, wherein at least one of the sensor for rotational speed of the wheel and the sensor for assessment of linear speed of the wheel comprises a laser based, especially a laser Doppler based system, especially a laser Doppler anemometry based system.
- 5
8. Measurement system according any one of claims 5 – 7, wherein the sensor for assessment of linear speed of the wheel comprises a vision based system, especially a vision based system including a camera and a vision system for analyzing a sequence of images taken by the camera and an algorithm for calculating speed of the vehicle based on said analyzing.
- 10
9. Measurement system according to any one of claims 5 – 8, wherein the sensor for measurement of rotational speed of the wheel comprises a laser surface velocimeter bases sensor system.
10. Measurement system according to any one of claims 5 – 9, wherein the sensors are designed for measurement of or at least assessment of at least one of and preferably both of the rotational speed and the linear speed at the contact area between the wheel and the rail.
- 15
11. Measurement system according to any one of the preceding claims, wherein the processing unit is adapted to determine a Stribeck curve based at least on data received from the sensors of the system.
- 20
12. Measurement system according to any one of the previous claims, wherein the processing unit is adapted to determine a traction curve, preferably an optimal traction curve for a train equipped with the wheel, based on at least the data received from the sensor systems of the system, especially based on a Stribeck curve provided by the processing unit, and a predetermined friction factor μ , wherein a feedback system is connected to the processing unit for providing feedback to an operator of the train when a threshold for a COF is reached, preferably different feedback signals for different predetermined thresholds.
- 25

13. Measurement system according to any one of the preceding claims, wherein the processing unit is connected to a train engine management system and/or a train braking system for at least partly controlling the engine and/or brakes of the train.
- 5 14. Measurement system according to any one of the preceding claims, wherein the processing unit is designed for planning a train operating process based on at least data from a data base of data acquired by the sensor systems of the measurement system.
15. A method for assessment of traction between a rail and a wheel on
10 the rail, wherein at least a normal force of the wheel on the rail, a friction force between the wheel and the rail and a difference between the rotational speed of the wheel and a linear speed of the wheel relative to the rail are assessed and wherein the data acquired by the system is used in calculating available traction.
- 15 16. A method of claim 15, wherein at least one of the normal force and the friction force are assessed based on a measurement of strain and/or stress in the wheel and/or an axis to which the wheel is connected.
17. A method according to claim 15 or 16, wherein rotational speed of the wheel and linear speed of the wheel are assessed using a laser Doppler
20 based system, especially a laser Doppler anemometry based system, preferably for assessment of both rotational speed and linear speed.
18. A method according to any one of claims 15 – 17, wherein a vision based system, especially a camera based system is used for calculating linear speed of the wheel, wherein with a camera a sequence of images is
25 taken of a part of an environment of the wheel, preferably including the rail, and wherein with a vision system the sequence of images taken by the camera is analyzed, such that linear speed of the wheel is calculated.
19. Method according to any one of claims 15 – 18, wherein rotational speed of the wheel is assessed using a laser surface velocimeter based sensor
30 system.

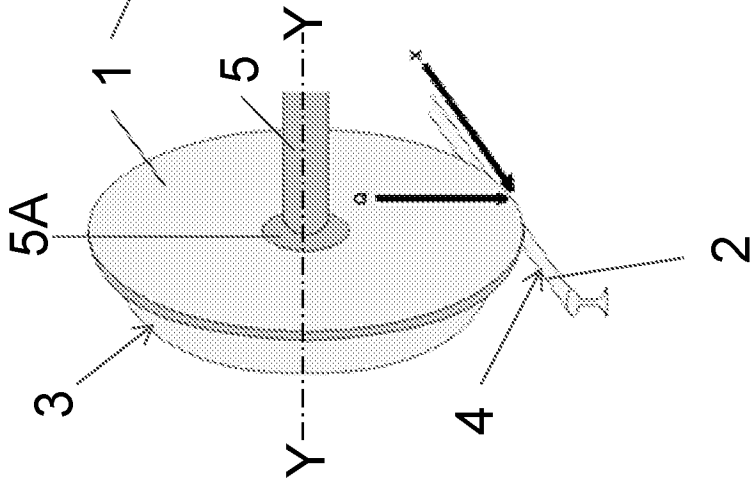


Fig. 1A

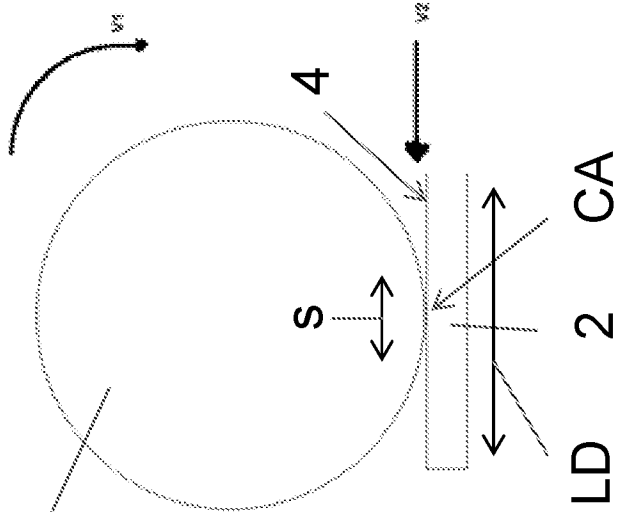


Fig. 1B

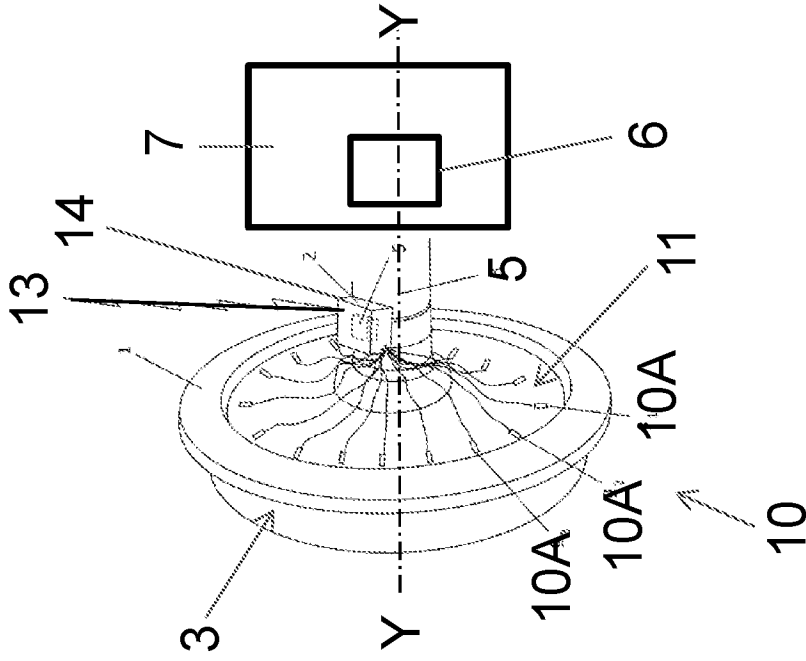


Fig. 2

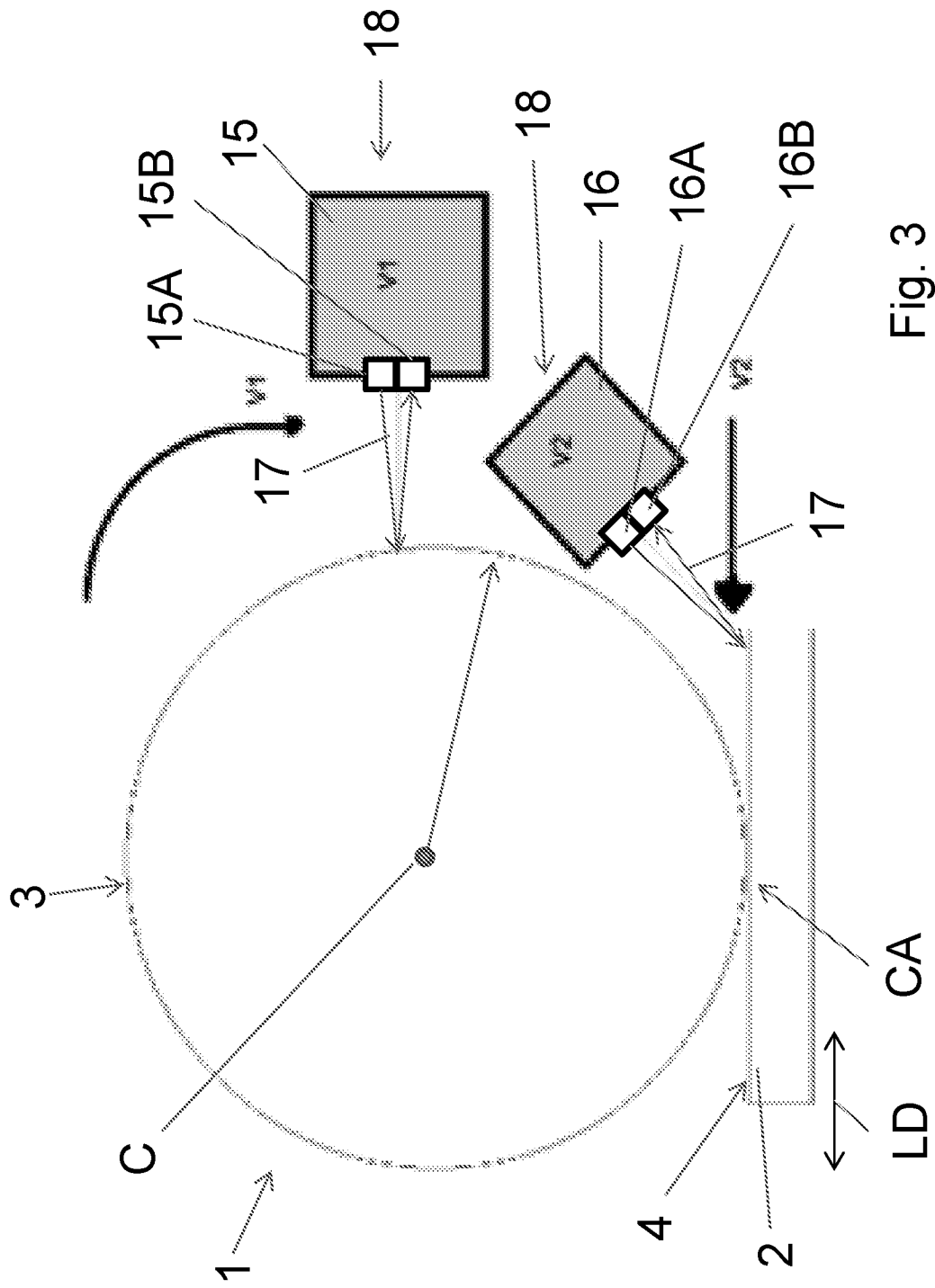


Fig. 3

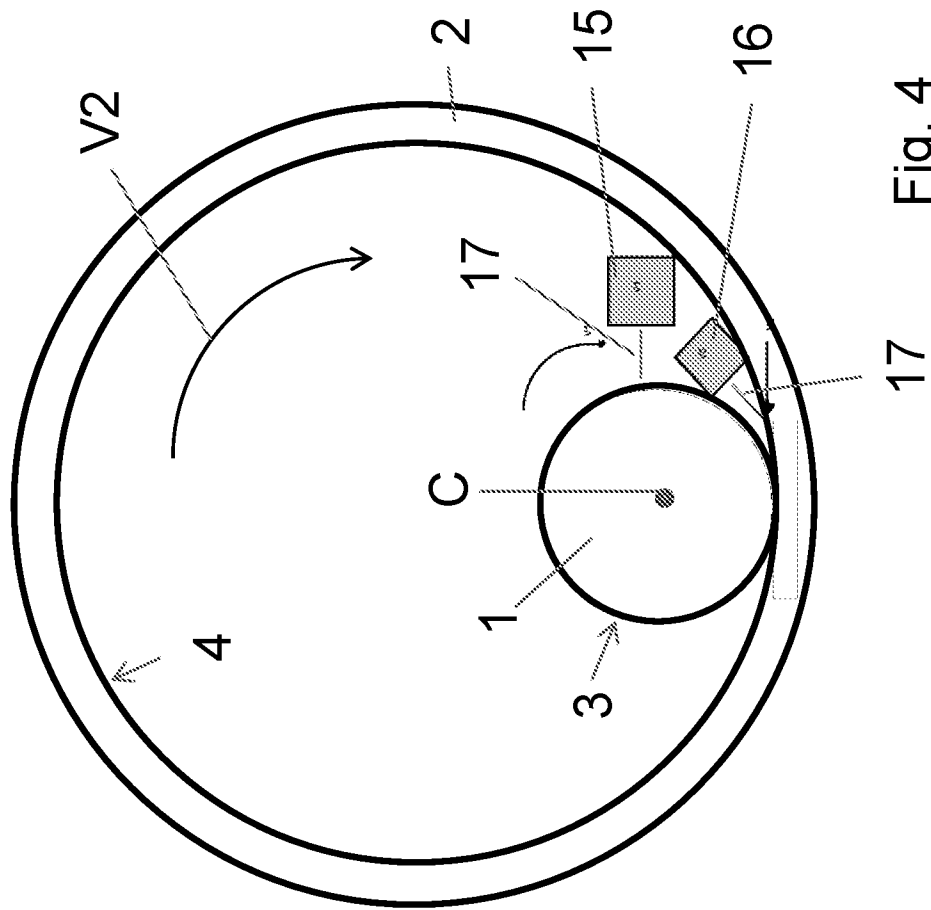


Fig. 4

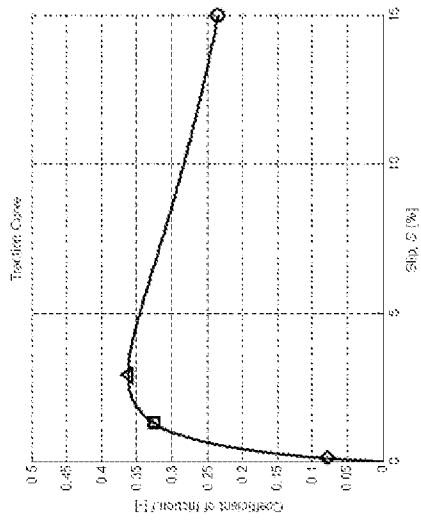


Fig. 6

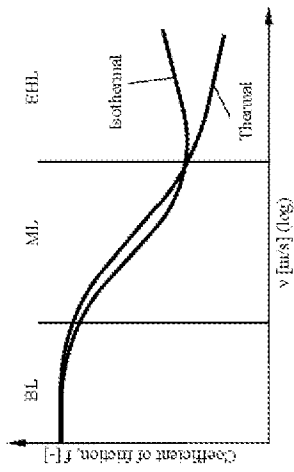


Fig. 5

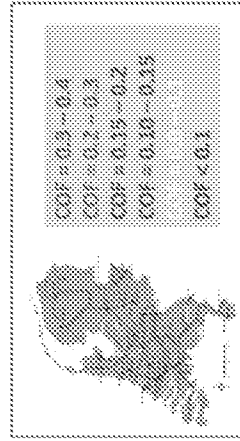


Fig. 8

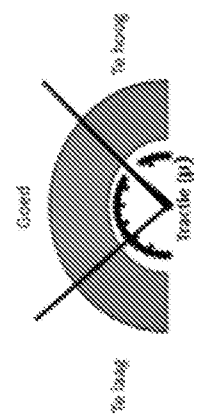


Fig. 7

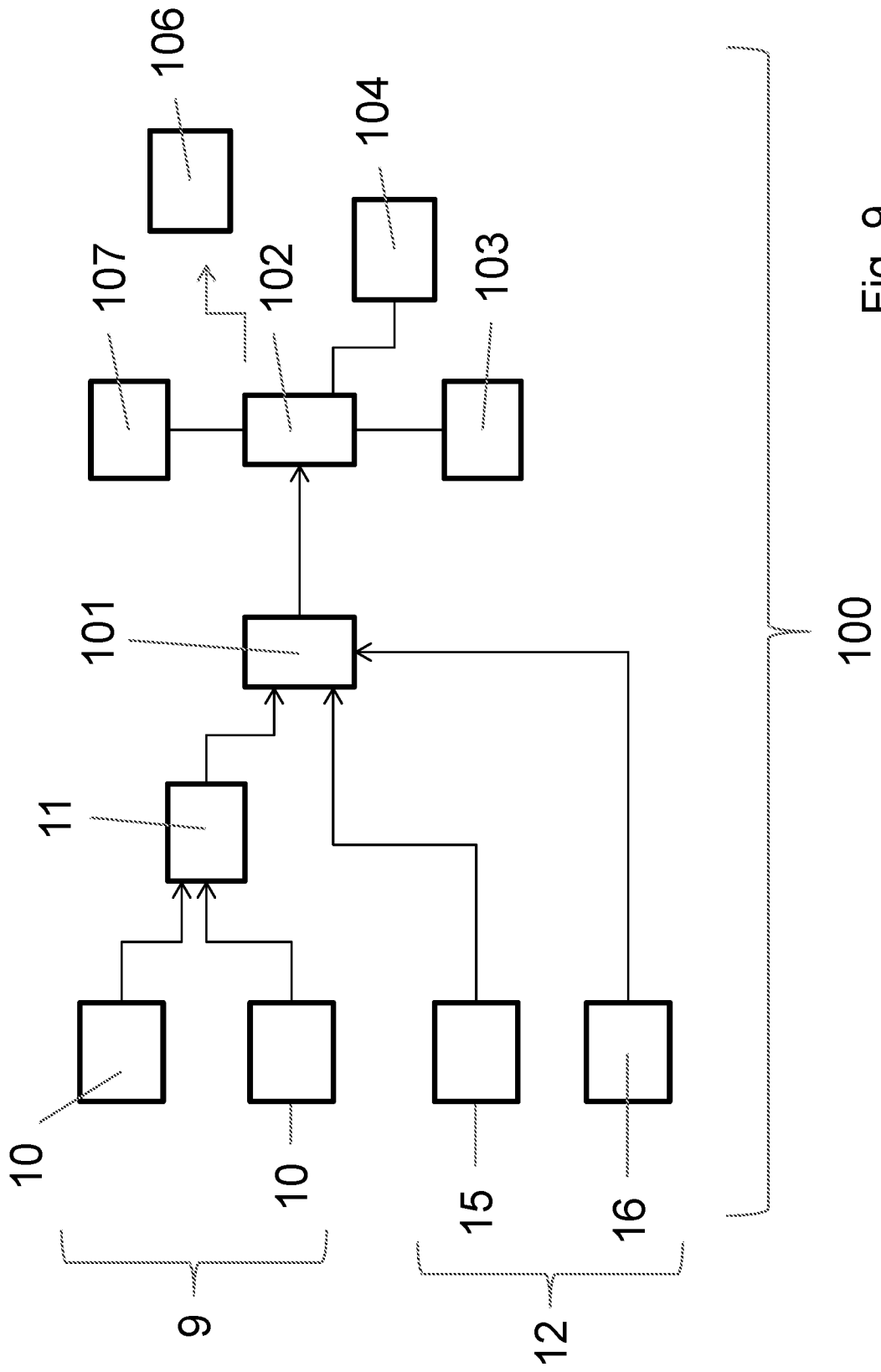


Fig. 9

INTERNATIONAL SEARCH REPORT

International application No
PCT/NL2018/050833

A. CLASSIFICATION OF SUBJECT MATTER
INV. B61L3/00 B61L15/00 B61L25/02 B60W40/068
ADD.
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED
Minimum documentation searched (classification system followed by classification symbols)
B61L B60W

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

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2009/113001 A1 (PHILIPS INTELLECTUAL PROPERTY [DE]; KONINKL PHILIPS ELECTRONICS NV [NL] 17 September 2009 (2009-09-17)	1-7, 9-17,19
Y	page 1, line 7 - line 11 page 6, line 12 - page 7, line 16 page 8, line 15 - page 9, line 12 page 10, line 8 - page 11, line 2 page 12, line 29 - page 15, line 24 page 18, line 15 - line 22 figure 6	8,18
Y	----- GB 2 527 330 A (GOBOTIX LTD [GB]) 23 December 2015 (2015-12-23) figure 4	8,18
A	----- EP 2 873 574 A1 (GOODRICH CORP [US]) 20 May 2015 (2015-05-20) paragraph [0012] - paragraph [0014] ----- -/--	1-17

Further documents are listed in the continuation of Box C.

See patent family annex.

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Date of the actual completion of the international search 22 March 2019	Date of mailing of the international search report 01/04/2019
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Authorized officer Janssen, Axel

INTERNATIONAL SEARCH REPORT

International application No
PCT/NL2018/050833

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP 2 899 086 A1 (PIONEER CORP [JP]) 29 July 2015 (2015-07-29) paragraph [0009] - paragraph [0010] paragraph [0020] figures 1-3 paragraph [0030] - paragraph [0034] -----	1-17

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/NL2018/050833

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2009113001	A1	17-09-2009	
		CN 101970274 A	09-02-2011
		EP 2257454 A1	08-12-2010
		JP 5631748 B2	26-11-2014
		JP 2011515665 A	19-05-2011
		KR 20100135800 A	27-12-2010
		US 2011035093 A1	10-02-2011
		WO 2009113001 A1	17-09-2009

GB 2527330	A	23-12-2015	NONE

EP 2873574	A1	20-05-2015	
		EP 2873574 A1	20-05-2015
		US 2015142217 A1	21-05-2015

EP 2899086	A1	29-07-2015	
		EP 2899086 A1	29-07-2015
		JP 5882484 B2	09-03-2016
		JP WO2014045365 A1	18-08-2016
		US 2015251658 A1	10-09-2015
		WO 2014045365 A1	27-03-2014
