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- (54) Benævnelse: **Fremgangsmåde til vurdering af diameteren af et hjul samt tilhørende vurderingsindretning**
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Generally speaking, the present invention relates to the procedures for the evaluation of the diameter of the wheel of a vehicle, in particular the wheel of a railway vehicle.

5 How to measure the diameter or external perimeter of the wheels of a stationary train (in the engine shed, for example) is well known. Such a measurement is subsequently entered manually into the railway vehicle data and currently is commonly used to calculate the velocity and the distance covered by the vehicle, in combination with the measurement of the number of wheel rotations.

10 Moreover, railway signaling systems frequently use data involving the distance of the train from certain points on the track and the maximum permissible speed. It is therefore particularly important to be constantly informed of the position and velocity of the train, with a high level of accuracy and certainty. In order to achieve this, one must be certain to have at one's disposal on an ongoing basis accurate and reliable data
15 pertaining to the diameter of the wheel, this diameter being used in the evaluations that determine the position and the velocity of the train.

Documents JP2 293667 A, US 2004/181320 A1 and EP 1 197 419 A1 describe devices and methods of measuring the diameter of a wheel.

20 In this context, the invention aims to propose a method that makes it possible to evaluate on an ongoing basis a characteristic value for the diameter of the wheel with a high level of accuracy and without the manual intervention of an operator (a potential source of error).

To this end, the invention relates to a method for evaluation comprising of the following steps :

- 25 - acquisition of a first measurement representing the derivative of the angular acceleration of the wheel;
 - acquisition of a second measurement representing the derivative of the acceleration of the vehicle ;
 - evaluation of the characteristic value of the diameter of the wheel based on the
30 first and second measurements.

Certain sensors used for measuring the acceleration of the vehicle, inertial sensors for example, present in fact a measurement error, which is more or less constant over short periods of a few minutes. The derivative of the measurement from such a sensor is not tarnished by errors because of the relative constancy of this error. The procedure

therefore makes possible an automatic, ongoing and frequent estimate of the value characterizing the wheel's diameter with a high level of accuracy.

The value characterizing the wheel's diameter labeled characteristic value in the reminder of the description is generally the diameter of the wheel, its circumference, the square of the diameter, a corrective coefficient of the diameter or circumference, or any other value characterizing the wheel's diameter that can be used for example in a software programme for calculating the position and the velocity of the train or other vehicle.

Typically, the vehicle in question is a train, a high speed train for example or an intercity train or a regional train, or even a suburban train, a subway train or a tram. By way of a variant, the vehicle may be any other type of vehicle for which the diameter of wheel may vary.

Typically, the wheel is made of metal. By way of a variant, the wheel may be of another type.

Advantageously, the first value is evaluated with a sensor measuring the angular movement of the wheel.

Trains are equipped with such sensors, so the first value can be calculated from the signal supplied by these sensors.

For example, the said sensor is made up of a fixed cogwheel turning with the wheel and a detector that counts the number of cogs passing in front of it in a given time. The cogwheel is either fixed directly on the vehicle's wheel or is fixed to a shaft turning with the wheel. The detector is a magnetic or optical detector.

The cogs are regularly spaced around the cogwheel. The first value is determined by calculation, from the number of cogs passing in front of the detector in each interval of time. This first value is, for example, the derivative of the angular acceleration or of the tangential acceleration of the wheel.

Typically, the second value is evaluated using an inertial sensor.

This type of sensor is also known as an accelerometer. This type of sensor is particularly well suited for evaluating the acceleration of the vehicle and its derivative.

By way of a variant, the derivative of the acceleration of the vehicle can be calculated from data acquired by use of a GPS, or by use of any other adequate system, such as a Doppler effect radar, a laser rangefinder, a lidar or a camera (calculation of the distance by image analysis).

Typically, the inertial sensor records the primary acceleration of the vehicle along a primary direction parallel to the normal direction of movement of the vehicle, the second value being evaluated from this primary acceleration.

By way of a variant of this method, the procedure uses solely the primary acceleration. The derivative of the vehicle's acceleration is calculated from the values of the primary acceleration picked up periodically by the inertial sensor. This variant is particularly simple and durable.

However, this variant is marred by errors in a small number of cases:

- when the gradient of the track on which the vehicle is running varies ;
- when the primary acceleration is measured along a primary direction which is not exactly parallel to the movement of the vehicle;
- in bends, especially when the track is cambered, that is to say, sloped downwards towards the centre of the bend;
- with the use of Doppler radar, when going over a metal bridge or at a relatively low speed;
- with the use of a laser rangefinder or a lidar, when there is no fixed object along the track;
- with the use of a camera, when there is a change in contrast, for example at both ends of a tunnel;
- with the use of GPS, when going under a bridge or in a tunnel.

Advantageously, the inertial sensor acquires a secondary speed of rotation of the vehicle around a secondary direction, the secondary direction being substantially parallel to the plane of movement of the vehicle and perpendicular to the primary direction, the second value being evaluated from the primary acceleration and from the secondary speed of rotation.

This makes it possible to improve the accuracy of the method in zones where the track gradient is not constant.

In effect, in zones where the track is not flat and where there is therefore a gradient (upwards or downwards), gravity contributes to the acceleration of the vehicle in the primary direction. In other words, gravity is a non-negligible component in the primary direction. At the moment when the track gradient changes, the contribution of gravity is modified, which impacts on the measured derivative of the acceleration of the vehicle.

The modification of the track's gradient is detected from the data picked up by the inertial sensor and corresponding to the secondary speed of rotation of the vehicle.

To calculate the second value, the method therefore uses the primary acceleration, measured along the primary direction, corrected for the contribution of gravity. Alternatively, the step of evaluation of the characteristic value of the wheel's diameter is not carried out when the inertial sensor detects any variation in the track's gradient.

5 According to another variant of the embodiment, the inertial sensor acquires the primary, secondary and tertiary speeds of rotation of the vehicle respectively around the primary direction, around a secondary direction more or less parallel to the plane of movement of the vehicle and perpendicular to the primary direction, and around a tertiary direction substantially perpendicular to the plane of movement of the vehicle, the second value being evaluated from the primary acceleration and from the primary, secondary and tertiary speeds of rotation.

10 Taking into account the primary, secondary and tertiary speeds of rotation makes it possible to improve the accuracy of the method, by identifying the orientation of the vehicle. Notably, at the start and at the finish of a bend, the camber increases or decreases. The behaviour of the vehicle is then close to its behaviour when the track gradient varies. Acquiring primary, secondary and tertiary rotation speeds makes it possible to distinguish between a cambered bend and a variation in track gradient during the step of evaluation of the characteristic value of the diameter of the wheel. Alternatively, the step of evaluation of the characteristic value of the diameter of the wheel is not carried out when the inertial sensor detects that the vehicle is on a cambered bend.

15 In yet another variant of the embodiment, the inertial sensor acquires a secondary acceleration of the vehicle along a secondary direction substantially parallel to the plane of movement of the vehicle and perpendicular to the primary direction, and / or acquires a tertiary acceleration along a tertiary direction substantially perpendicular to the plane of movement of the vehicle, the second value being evaluated from the primary acceleration and from the secondary and / or tertiary accelerations.

20 This makes it possible to improve the accuracy of the procedure, especially when the primary acceleration is measured in a direction which does not correspond exactly to the normal direction of movement of the vehicle. This is the case when the inertial sensor is mounted with an orientation slightly offset relative to the direction of movement of the train. Normally, the primary direction corresponds exactly to the direction of the normal movement of the vehicle. However, the primary direction may be offset at an angle parallel to the plane of movement compared with the direction of movement of the vehicle. It may also be offset like an arrow, upwards or downwards compared with the direction of movement, that is to say, not be parallel to the plane of movement.

The act of recording the measured acceleration following the secondary direction makes it possible to evaluate the offset of the inertial sensor in the first case, that is to say, in the case where the primary direction is offset relative to the direction of movement of the vehicle but still parallel to the plane of movement. The act of recording the tertiary acceleration makes it possible to evaluate the offset of the sensor in the second case. These offsets can then be taken into account in the evaluation of the second value.

It should be noted that these offsets are more or less constant. They do not need to be evaluated on an ongoing basis. For example, they can be evaluated periodically, when the vehicle leaves a station moving along in a straight line.

In another aspect of the invention, the procedure includes a step for checking the absence of skidding or jamming of the wheel.

Skidding and jamming are two cases where the wheel slides along the surface, for example along the rail in the case of a railway vehicle. The sliding may or may not be accompanied by rotation. In other words, these are two cases in which the linear velocity of the wheel is inferior or superior to the velocity of movement of the vehicle along the primary direction.

In the case of detection of skidding or jamming of the wheel, the method does not calculate the characteristic value of the diameter of the wheel. In effect, in this case there is no longer proportionality between the derivation of angular acceleration of the wheel and the derivation of the acceleration of the vehicle.

The information concerning the absence or the presence of skidding or jamming is acquired directly from the vehicle's piloting system where it is present.

Advantageously, the method includes a step for comparison of the second value with a predetermined limit, in such a way as to prevent the evaluation of the characteristic value of the diameter of the wheel from the first and second values when the second value is lower than the predetermined limit.

In effect, during this evaluation, a comparison is made between the first value and the second, this latter being the denominator. When the second value is very low, or zero, the calculation is impossible or the margin of error is extremely high.

In other words, the method is particularly accurate during phases of acceleration and deceleration of the vehicle, for example when moving off or when approaching a halt.

Advantageously, the procedure includes a step for filtering the characteristic value of the diameter of the wheel.

According to a second aspect, the invention provides for an assembly for evaluations of the characteristic value of the diameter of the wheel of a vehicle, the assembly comprising of the following :

- a device for the acquisition of a first value representing the derivative of the angular acceleration of the wheel;
- a device for the acquisition of a second value representing the derivation of the acceleration of the vehicle;
- a device for the evaluation of the characteristic value of the diameter of the wheel based on the first and second values.

Other characteristic features and advantages of the invention will become clear from the detailed description that has been provided here below, which is meant for illustrative purposes only and is by no means limiting, with reference to the figures in the appendices, amongst which:

- Figure 1 is a step diagram showing in a schematic manner the principal stages of the method;
- Figure 2 is a simplified schematic representation of a vehicle equipped with the invention's devices ;
- Figure 3 is a simplified schematic representation of a sensor designed to measure the speed of rotation of the vehicle's wheels;
- Figure 4 is a simplified schematic representation of a vehicle moving along a track with variable gradient; and
- Figure 5 is a schematic representation showing the offset in orientation between the primary acceleration and the direction of movement of the vehicle.

The method illustrated in Figure 1 aims to evaluate the diameter of the wheel of a vehicle and, more particularly that of a railway vehicle equipped with metal wheels.

The diameter of the wheels of such a vehicle change, usually due to periodic machining in the engine shed and to modifications to the profile of the wheel resulting from, for example, jamming of the wheel during braking.

Typically, a train has a large number of wheels, for example four or eight wheels per carriage. The procedure is applied to each wheel of the train. By way of a variant, the method is applied only to certain wheels of the train, for example one wheel per carriage. For each wheel involved a first value representing the derivative of the angular acceleration of the wheel is acquired. On the other hand, the same second value is used, representing the derivative of the acceleration of the vehicle, for all the wheels of the train.

The diameter of the wheel as evaluated by the method of the invention corresponds to an average diameter, taking into account a part of the perimeter of the wheel or the whole perimeter.

5 The method constantly implements the steps shown in Figure 1 on an ongoing basis.

In the description that follows, α' , α'' and α''' symbolise respectively the angular velocity and its primary and secondary derivatives. x' , x'' and x''' symbolise respectively the linear velocity of the vehicle along the x axis, and its primary and secondary derivatives.

10 The method consists of the following steps:

- 1) checking for the absence of skidding and jamming of the wheel;
- 2) acquisition of a first value representing the derivative of the angular acceleration of the wheel α''' ;
- 3) acquisition of a second value representing the derivative of the acceleration of the vehicle x''' ;
- 15 4) checking that the second value is higher than a predetermined limit;
- 5) evaluation of the characteristic value of the diameter of the wheel based on the first and second values;
- 6) filtering of the characteristic value of the diameter of the wheel.

20 Steps 1) and 2) are initiated simultaneously, or almost simultaneously.

To acquire the first value, a sensor is used to measure the angular movement of the wheel over a period of time. To acquire the second value, an inertial sensor on board the vehicle is used.

25 Figure 2 shows the vehicle 10, this vehicle being a carriage or a locomotive represented in a very schematic manner. This vehicle is made up of a body 11 supported by four wheels 12, 13, 14, 15. The track 16 on which the vehicle moves comprises two rails 17 on which roll the wheels 12, 13, 14 and 15. The method is designed to evaluate the diameter of the wheel 14.

30 The sensor 18 used for measuring the angular movement of the wheel over a period of time is shown in Figure 3. This sensor is made up of a cogwheel 19 turning with the wheel 14 and a detector 20. The cogwheel 19 comprises a hub 21 and a number of teeth 22 protruding out radially relative to the hub 21. The detector 20 is integrally fixed to the body of the carriage, and is disposed close to the cogwheel 19. The sensor 18 is designed to count each time a tooth 22 passes in front of the detector 20.

The first value, representing the derivative of the angular acceleration of the wheel α'' , is the derivative of the tangential acceleration of the wheel d'' .

The tangential velocity d' of the wheel at the instant T_i can be calculated with the aid of the following formula:

$$d' = n_i / N \times D \pi / \Delta t$$

where Δt is the time period of measurement, N is the total number of teeth on the cogwheel 19, n_i is the number of teeth detected by the detector 20 at the instant T_i during the period Δt , and D is the theoretical diameter of the wheel. The tangential acceleration d'' can be calculated using the following formula:

$$d'' = (n_i - n_{i-1}) / N \times D \pi / \Delta t^2$$

where n_{i-1} is the number of teeth detected at T_{i-1} , that is to say at the preceding sampling.

The derivative of the tangential acceleration can be calculated using the following formula:

$$d''' = (n_i - 2 \times n_{i-1} + n_{i-2}) / N \times D \pi / \Delta t^3.$$

where n_{i-2} is the number of teeth detected at the instant T_{i-2} .

In practice, the sensor 18 transmits data to a calculator 23 mounted on board the vehicle, this calculator carries out the calculations which make it possible to determine the tangential acceleration of the wheel d''' .

The inertial sensor 24 is also mounted on board the vehicle. In the first embodiment of the invention, the inertial sensor 24 is mounted in such a manner as to measure the acceleration x'' of the vehicle along a primary direction parallel to the normal direction of movement of the vehicle. The primary direction, corresponding to the normal direction of movement of the vehicle towards the front, is represented by the arrow x in Figure 2. In this figure, the direction y corresponds to the transversal direction, directions x and y defining a plane parallel to the plane of movement of the vehicle. Direction z is perpendicular to the plane of movement.

In the first embodiment, it is supposed that the primary direction x is perfectly parallel with the direction of movement F of the vehicle, and no account is taken of the error possibly arising from a poor installation of the sensor 24, and in particular of a poor alignment of this primary direction x relative to the direction of movement F of the vehicle.

The derivative of the acceleration of the vehicle is calculated as follows:

$$x''' = (x''_i - x''_{i-1}) / \Delta t$$

where Δt is the period of sampling, x''^i is the acceleration measured by the sensor 24 at the instant T_i , and x''^{i-1} is the acceleration measured by the sensor 24 at the instant T_{i-1} immediately preceding the instant T_i .

In practice, the values measured by the sensor 24 are transmitted to the calculator - computer 23, which calculates the derivative of the acceleration.

In step 3, checking that there is neither skidding nor jamming is carried out by querying the calculator - computer that controls the vehicle, which may be the calculator - computer 23. This information is present in the calculator - computer as it is generally used in other algorithms programmed in the calculator - computer .

In step 4, the calculator - computer compares the derivation of the acceleration of the vehicle x''' acquired in step 2 with a predetermined limit L . In effect, if this derivation is too low, the following steps of the calculation cannot be carried out with sufficient accuracy.

If x''' is below the limit, the next steps are not carried out.

In step 5, the sensor divides d''' by x''' and thus calculates the corrected diameter D_{real} of the wheel. It uses the following equation:

$$\lambda = d''' / x'''$$

$$D_{real} = D / \lambda$$

where D is the theoretical diameter of the wheel used for calculating d''' .

This measurement of D_{real} contains a certain amount of error due to the effects of measuring. Step 6 makes it possible to filter this value over the long term in order to obtain a more accurate value (the diameter of the wheel not varying over the long term). For example, this filtering can be carried out by using a sliding average for the value of D_{real} obtained in step 5.

By way of a variant, the filtering can be carried out by using a Kalman filter.

A second embodiment of the invention will now be described, with reference to Figure 4.

Only the points whereby the second embodiment differs from the first will be detailed below. Identical elements and those with the same functions in both embodiments will be designated by the same reference numerals.

In the second embodiment, the inertial sensor 24 records not only the acceleration of the vehicle along the primary direction (primary acceleration x''), but also records at the same instant the angular velocity of the vehicle around a secondary direction y (secondary angular velocity $\theta y'$).

This value is taken into account in step 5 for the determination of the diameter of the wheel. This makes it possible to improve the accuracy of the calculations for the portions of the track where there is a change of slope, that is to say a variation of the gradient, as shown in Figure 4.

5 In this figure, a track profile is shown with a first section going downhill 26, a second flat section 28, a break of slope 30 intervening between sections 26 and 28. When the vehicle 10 moves on section 26, the weight P of the vehicle is a component which tends to accelerate the vehicle along the direction x. The inertial sensor 24, when it records the acceleration value x'' along the primary direction, measures a total value of
10 acceleration which includes the contribution of gravity. As long as the slope is constant, the contribution of gravity is also constant, and the derivation x''' is not affected by the fact that the vehicle is on a sloped section of the track. This is equally true for the horizontal section 28. On the other hand, at the point 30 there is a break of slope and the contribution of gravity in the primary direction changes. The result of this is that the
15 contribution of gravity to the value x''' is no longer zero.

 Such a break of slope can be detected by the accelerometer 24, because $\theta y'$ varies at the point 30. The calculator - computer can then take into account for the estimation of the second value, not only x''' , but also $\theta y'$. To be more precise, it corrects the value of x''' as a function of $\theta y'$. For example, it adds to x''' the contribution of gravity,
20 which is equal to $\theta y' g \cos\theta y$, where g is the acceleration due to gravitational effects.

 As a variant, the calculator - computer does not carry out step 5 when it detects that the variation of $\theta y'$ is above a predetermined value.

 A third embodiment of the invention will now be described.

 Only the points where the third embodiment differs from the first will be detailed
25 below. Identical elements and those with the same functions in both embodiments will be designated by the same reference numerals.

 In the third embodiment, the inertial sensor 24 records not only the acceleration of the vehicle along the primary direction x'' , but also records the angular velocity of the vehicle around the primary direction x, the secondary direction y and the tertiary direction
30 z, these angular velocities being noted respectively $\theta x'$, $\theta y'$ and $\theta z'$.

 These values are then taken into account for calculating the second value, representing the derivative of the acceleration of the vehicle.

 This is particularly useful when the procedure is applied when the vehicle is on a section of track on a bend with camber.

Alternatively, the calculator - computer does not carry out step 5 when it detects that the variations of $\theta x'$ or $\theta z'$ are above a predetermined value.

A fourth embodiment of the invention will now be described, with reference to Figure 5.

5 Only the points where the fourth mode of use differs from the first will be detailed below. Identical elements and those with the same functions in both embodiments will be designated by the same reference numerals.

10 As shown in Figure 5, the sensor 24 is not generally installed with the primary direction x exactly parallel to the normal direction of movement of the vehicle F . The orientation of the primary direction x is offset relative to F . This offset can be broken down into two angular offsets β and γ :

- an angular offset β parallel to the plane of movement P ,
- an angular offset upwards or downwards compared with the plane of movement P , called a deflection.

15 It should be noted that one or both of these angular offsets may not be equal to zero.

In this case, the acceleration x'' measured along the primary direction by the inertial sensor 24 is not exactly equal to the acceleration of the vehicle in the direction F .

20 In the fourth embodiment, the inertial sensor 24 periodically measures the values of y'' and z'' , as well as x'' . These values are used to estimate the angular offsets β and γ .

The calculation of the λ parameter is modified as follows:

$$\lambda = d''' \cos \beta \cos \gamma / x'''$$

The other calculations are identical.

P a t e n t k r a v

1. Fremgangsmåde til vurdering af en størrelse, som kendetegner diameteren af et hjul (14) af et køretøj (10), når dette er i bevægelse, hvor fremgangsmåden omfatter følgende trin:
- 5 - opnåelse af en første størrelse, som repræsenterer afledningen af vinkelaccelerationen (α''') af hjulet (14);
- opnåelse af en anden størrelse, som repræsenterer afledningen af accelerationen af køretøjet (10);
- 10 - vurdering af den størrelse, som kendetegner diameteren af hjulet (14) ud fra den første og anden størrelse.
2. Fremgangsmåde ifølge krav 1, **kendetegnet ved, at** den første størrelse vurderes med en sensor (18) ved at måle vinkelbevægelse af hjulet (14).
- 15 3. Fremgangsmåde ifølge krav 1 eller 2, **kendetegnet ved, at** den anden størrelse vurderes med en inertisensor (24).
4. Fremgangsmåde ifølge krav 3, **kendetegnet ved, at** inertisensoren (24) opnår en første acceleration (x'') af køretøjet i en første retning (x) parallelt med den normale bevægelsesretning (F) af køretøjet (10), hvor den anden størrelse vurderes ud fra den første acceleration (x'').
- 20 5. Fremgangsmåde ifølge krav 4, **kendetegnet ved, at** inertisensoren (24) opnår en anden rotationshastighed ($\theta y'$) af køretøjet (10) omkring en anden retning (y), i det væsentlige parallelt med køreplanet (P) af køretøjet (10) og vinkelret på den første retning (x), hvor den anden størrelse vurderes ud fra den første acceleration (x'') og ud fra den anden rotationshastighed ($\theta y'$).
- 25 6. Fremgangsmåde ifølge krav 5, **kendetegnet ved, at** inertisensoren (24) opnår en første og tredje rotationshastighed ($\theta x'$, $\theta y'$) af køretøjet (10) omkring
- 30

henholdsvis den første retning (x) og omkring en tredje retning (z) i det væsentlige vinkelret på køreplanet (P) af køretøjet (10), hvor den anden størrelse vurderes ud fra den første acceleration (x'') og ud fra den første, anden og tredje rotationshastighed ($\theta'x$, $\theta'y$, $\theta'z$).

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7. Fremgangsmåde ifølge et hvilket som helst af kravene 4 til 6, **kendetegnet ved, at** inertisensoren (24) opnår en anden acceleration (y'') af køretøjet (10) i en anden retning (y) i det væsentlige parallelt med køreplanet (P) af køretøjet (10) og vinkelret på den første retning (x), og/eller opnår en tredje acceleration (z'') i en tredje (z) retning i det væsentlig vinkelret på køreplanet (P) af køretøjet (10), hvor den anden størrelse vurderes ud fra den første acceleration (x'') og ud fra den anden og/eller tredje acceleration (y'' , z'').

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8. Fremgangsmåde ifølge et hvilket som helst af de foregående krav, **kendetegnet ved, at** den omfatter et trin med kontrol af manglende skridning eller blokering af hjulet (14).

15

9. Fremgangsmåde ifølge et hvilket som helst af de foregående krav, **kendetegnet ved, at** den omfatter et trin (4) med sammenligning af den anden størrelse med en forudbestemt grænse (L) for at forhindre vurderingen af den størrelse, der kendetegner diameteren af hjulet (14) ud fra den første og anden størrelse, når den anden størrelse er mindre end den forudbestemte grænse (L).

20

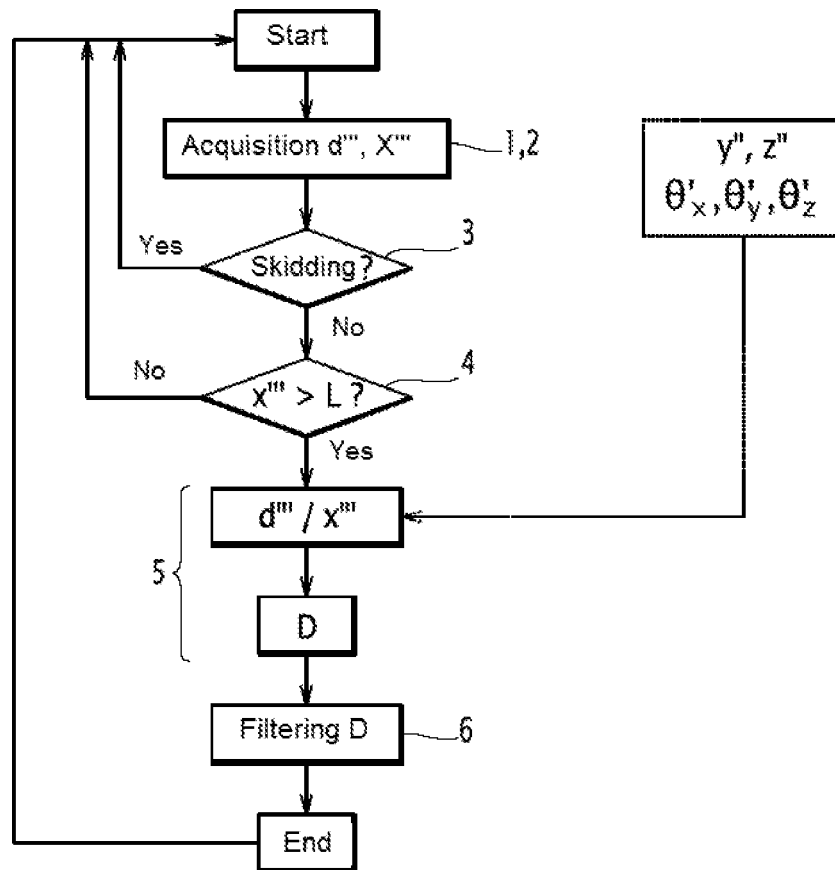
10. Fremgangsmåde ifølge et hvilket som helst af de foregående krav, **kendetegnet ved, at** den omfatter et trin (6) med filtrering af den størrelse, der kendetegner diameteren af hjulet (14).

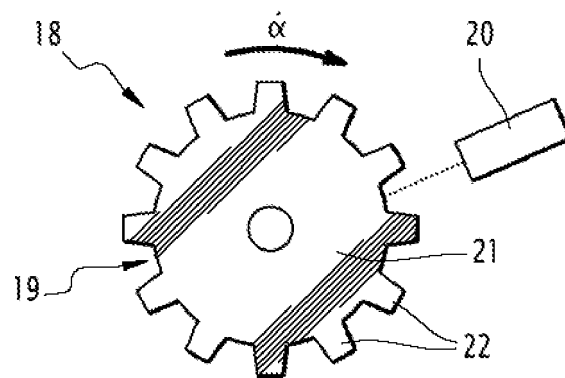
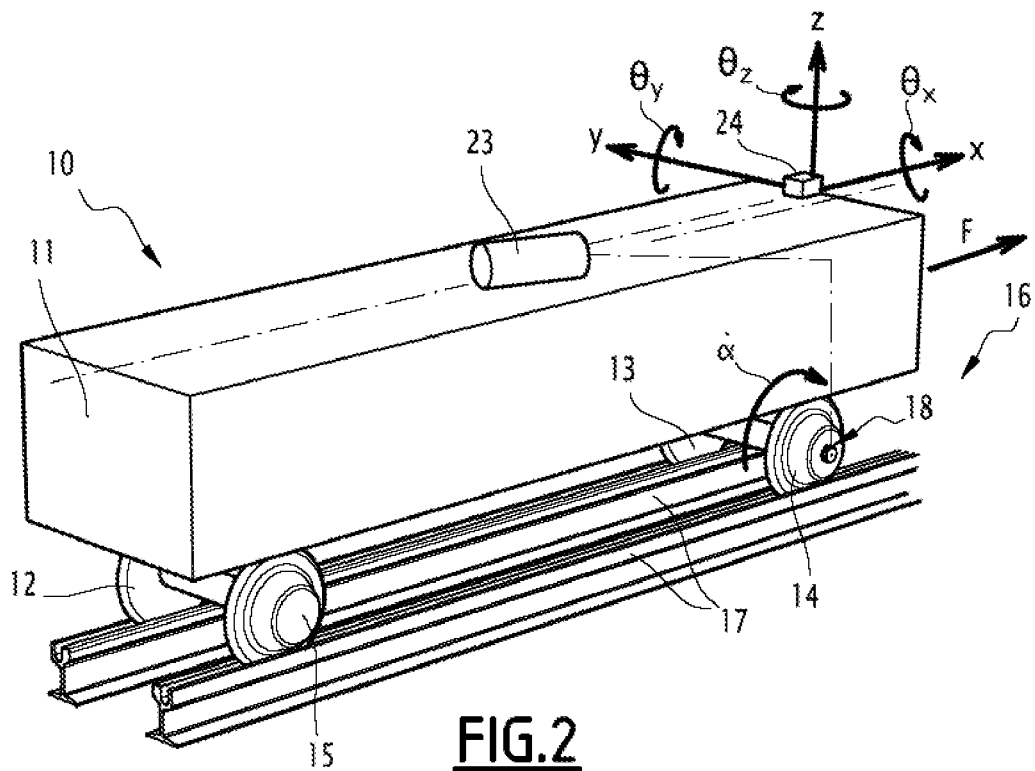
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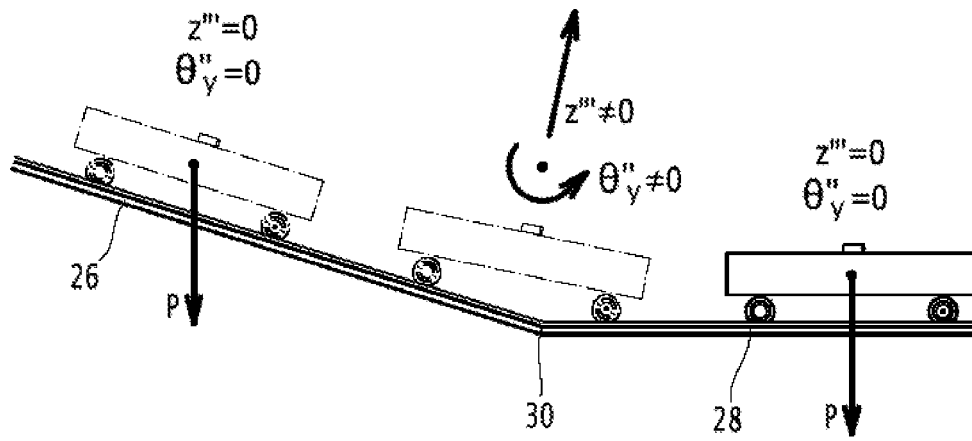
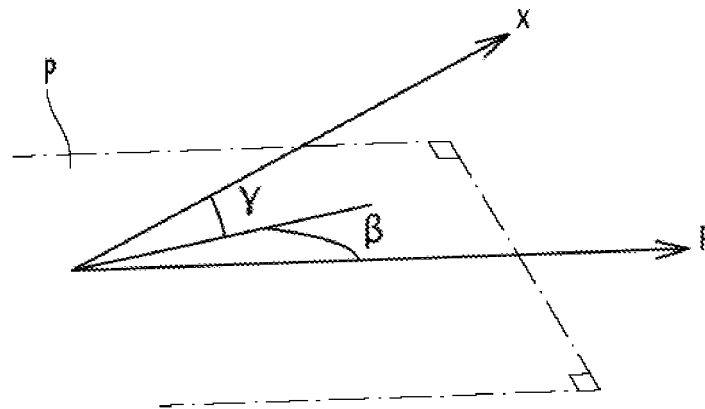
11. Indretning til vurdering af en størrelse, som kendetegner diameteren af et hjul (14) af et køretøj (10), hvor enheden omfatter:
- en indretning til opnåelse af en første størrelse, som repræsenterer afledningen af vinkelaccelerationen (α''') af hjulet (10);

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- en indretning til opnåelse af en anden størrelse, som repræsenterer afledningen af accelerationen af hjulet (10);
- en indretning til vurdering af den størrelse, som kendetegner diameteren af hjulet (14) ud fra den første og anden størrelse.

**FIG.1**



**FIG.4****FIG.5**