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(54) Title: A VEHICLE WHEEL STEERING MECHANISM AND A METHOD OF OPTIMIZING THE VEHICLE WHEEL STEERING MECHANISM

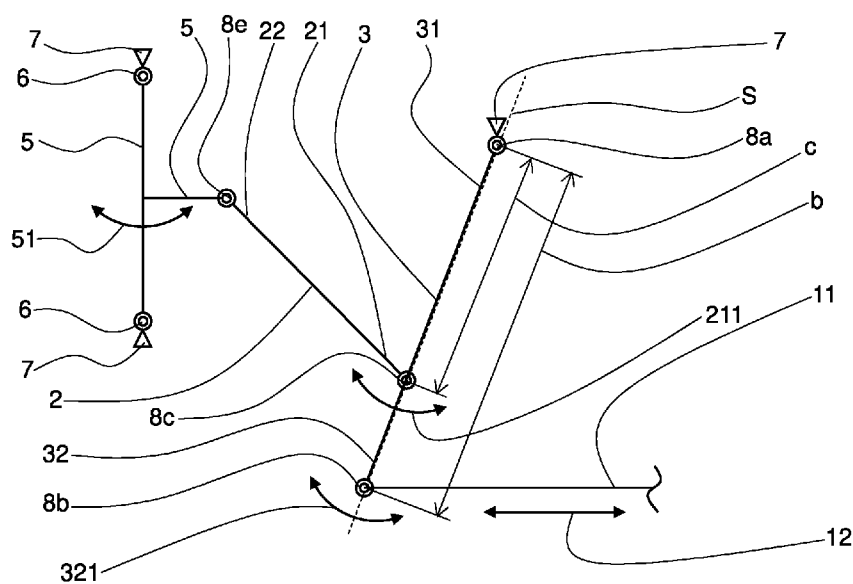


Fig. 1

(57) Abstract: The invention relates to a vehicle wheel steering mechanism which comprises a linear actuator (1), which is provided with a sliding rod (11) which is coupled by a connecting rod (2) to a vehicle wheel hub carrier (5), wherein between the sliding rod (11) and the connecting rod (2) is inserted a transfer lever (3) which is rotatably mounted in the vehicle frame (7) by its first end (31), wherein by its second end (32) it is rotatably coupled to the end of the sliding rod (11) of the linear steering actuator (1), wherein the transfer lever (3) is between both its ends (31, 32) rotatably connected to the connecting rod (2). In addition, the invention relates to a method of optimizing the vehicle wheel steering mechanism, when for predefined vehicle parameters, the lengths of the individual elements of the mechanism and the distances of the rotatable mountings and connections of the individual elements of the mechanism are determined, then the outer wheel steering angles for different inner wheel steering angles of the same axle are successively determined and the degree of compliance of the vehicle steering with the Ackermann steering condition for different inner wheel steering angles of the



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axle is evaluated.

A vehicle wheel steering mechanism and a method of optimizing the vehicle wheel steering mechanism

Technical field

5 The invention relates to a vehicle wheel steering mechanism which comprises a linear actuator which is provided with a sliding rod which is coupled to a vehicle wheel hub carrier, wherein a transfer lever is inserted between the sliding rod and a connecting rod (tie rod), the transfer lever being rotatably mounted in a frame of the vehicle.

10 In addition, the invention relates to a method of optimizing the vehicle wheel steering mechanism.

Background art

15 In a conventional vehicle, the inaccuracy of steering the wheels of a vehicle with a conventional wheel steering mechanism is corrected while turning by the human driver of the vehicle. However, such inaccuracy of steering a vehicle can be a serious drawback in the automatic steering control of autonomous vehicles, where steering inaccuracy and the associated deviation of the vehicle from the predetermined direction of the vehicle motion requires correction of the planned
20 path of the autonomous vehicle, which burdens the steering control system of the autonomous vehicle.

 A wheel steering mechanism commonly used to convert the linear motion of a steering actuator, such as a rack and pinion steering, into a rotary motion of a wheel of a vehicle, such as an automobile or agricultural machine, comprises a
25 connecting rod which is connected at one end by a ball stud to the end of a sliding rod of the linear steering actuator and at the other end by a ball stud) to a wheel hub carrier which is suspended in a frame, e.g. in axle arms, in steering pins, etc. As the wheel rotates, the rectilinear motion of the end of the sliding rod of the steering actuator and the associated first end of the connecting rod is transferred

by this rod to the wheel hub carrier which rotates about the axis of the wheel suspension steering pins of the axle arms. This type of common vehicle wheel steering mechanism does not allow to get close with sufficient accuracy to the Ackermann condition of directional steering of a vehicle, which says that the intersection of the axes of the wheels should lie at one common point, i.e. that, for a single axle steering vehicle, the intersection of the axes of the wheels of the rotating axle should lie on the extended wheel centreline of the rear axle of the vehicle, and for a multi-axle steering vehicle, it should lie at a common point which is the intersection of the axes of all the wheels of the vehicle. If the Ackermann condition is fulfilled, the direction of the motion of the rolling wheels of the vehicle is the same as the direction of the motion of the vehicle and skidding of the wheels on the road while turning the vehicle is minimized. Although in fact, due to the elasticity of the axle mechanism and wheel suspension, it is impossible to fulfil the Ackermann condition, it can be approached by increasing the steering precision of the vehicle wheels.

US 10836424B2 discloses steering wheels of a rear axle with a transfer lever which is pivotally connected at its first end to a sliding inner tie rod, its other opposite end is rotatably connected to a connecting rod and is pivotally connected between its ends to a frame of the vehicle. The sliding inner connecting rod, which is at the first end pivotally connected to the transfer lever is at the second end fixedly connected, e.g., welded, to the end of a sliding rod of a linear steering actuator. The connecting rod which is rotatably connected at its first end to the transfer lever is at its second end pivotally connected to a hub carrier of a vehicle wheel. The transfer lever is between its ends pivotally mounted in the axle frame so that its first end extends rearward relative the rear axle and its second end extends forward relative the rear axle. This leads to an arrangement of the elements of the wheel steering apparatus, where the linear steering drive is mounted on the rear side of the rear axle, while the connecting rod is connected to the wheel hub carrier in front of the rear axle, which according to US 10836424B2 allows to achieve, within a wheel rotation range of 2° to 12° , a better percentage compliance with the Ackermann steering condition than in conventional rear axle

wheel steering systems and also allows the rear wheels to be driven by cardan drive mounted on the front of the driven rear axle. The wheel steering apparatus according to US 10836424B2 operates in such a manner that it transfers the linear displacement of the linear actuator to the rotary motion of the wheel hub carrier, wherein the linear displacement of the linear actuator is, by means of elastic deformation of the actuator sliding rod and the sliding inner connecting rod transferred to the rotary motion of the transfer lever which is transferred to the connecting rod by which it is further transferred to the rotary motion of the wheel hub carrier.

One of the disadvantages of a wheel steering apparatus known from US 10836424B2 is the fact that it allows only a small range of wheel angle from 0 ° to 12 °, so it is only suitable for rear axles of vehicles with asymmetrically steered rear axle but cannot be used to steer the front axle of vehicles or for vehicles with symmetrically steered front and rear axle. Another disadvantage is the fact that during the steering of the wheel using the above-described steering apparatus, the ends of the transfer lever move in opposite directions, e.g., when the end of the linear actuator and the end of the transfer lever associated with it move towards the wheel hub carrier, the second opposite end of the transfer lever moves, draws away from the wheel hub carrier and vice versa, which requires considerable installation space for the rotation of the transfer lever. Moreover, it follows from the above-mentioned facts that for a steering actuator equipped with this apparatus, a conventional transmission rack driven by a conventional steering bar cannot be used, since the apparatus described in US 10836424B2 would rotate the wheel of the vehicle in a direction opposite to the direction of rotation of the steering wheel, so while turning the steering wheel to the left, the wheels would turn to the right and vice versa. Another disadvantage of the above-described steering apparatus is that the transfer lever is formed by a two-arm lever mounted in the middle, whose two excessively long arms are elastically deformed under stress during the vehicle wheel rotation, thereby reducing the wheel steering precision.

Although in the above-mentioned patent US 10836424B2 there is a mention that by adjusting the ratio of the lengths of the arms of the transfer lever and by adjusting the position of the mounting of the lever in the vehicle frame, the ratios of the transfer of the motion of linear steering actuator to the rotary motion of the vehicle wheel, the document does not specify how to adjust these ratios or optimize the steering apparatus of a specific vehicle to approach the ideal Ackermann steering condition.

The above-mentioned disadvantages are eliminated or at least minimized by the present invention of a vehicle wheel steering mechanism.

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Principle of the invention

The invention relates to a vehicle wheel steering mechanism which in a first exemplary embodiment comprises a linear actuator which is provided with a sliding rod which is coupled by a connecting rod to a vehicle wheel hub carrier, wherein between the sliding rod and the connecting rod is inserted a transfer lever which is by its first end rotatably mounted in a frame of the vehicle, by its second end it is rotatably coupled to the end of the sliding rod of the linear actuator and between both its ends it is rotatably connected to the connecting rod, thus forming a vehicle wheel steering mechanism, which allows precise and individual setting of the steering of the wheels of a vehicle which is provided with one or more pairs of such vehicle wheel steering mechanisms.

The vehicle wheel steering mechanism may be provided with an advantageous variant of a rotatable connection of the transfer lever to the connecting rod. This rotatable connection is located at a distance from the straight line connecting the rotatable connections of the two ends of the transfer lever and the frame and the end of the sliding rod, such that it has a perpendicular distance greater than zero from the straight line connecting the rotatable connections of the ends of the transfer lever and the frame and the end of the sliding rod, which introduces an additional element to the wheel steering mechanism that can be

used for precise and individual setting of the mechanism and for facilitating the optimization of the mechanism for a specific vehicle.

The rotatable connections of the above-described first embodiment of the vehicle wheel steering mechanism are implemented in such a manner that the
5 rotatable connection of the transfer lever to the vehicle frame is implemented by a rotatable connecting element with at least one degree of freedom of rotary motion, wherein the rotatable connection of the transfer lever to the end of the sliding rod is implemented by a rotatable connecting element with at least three degrees of freedom of rotary motion and the rotatable connection of the transfer lever to the
10 connecting rod is implemented by a rotatable connecting element with at least three degrees of freedom of rotary motion. Such a combination of rotatable connecting elements is not only suitable due to precise transfer of motions of individual elements of the wheel steering mechanism, but also due to the fact that it introduces into the mechanism a total of more degrees of freedom of rotary
15 motion than is theoretically necessary for the correct functioning of the kinematics of the mechanism, compensates for possible manufacturing inaccuracies and elastic deformations of the stressed elements of the mechanism, which prevents the mechanism from jamming and leads to reducing wear of its components.

In a second exemplary embodiment of the vehicle wheel steering
20 mechanism, the second end of the transfer lever is rotatably connected to a first end of an auxiliary arm which is by its second end rotatably connected to the sliding rod of the linear actuator, thereby the wheel steering mechanism is extended by another element usable for adjusting the mechanism to achieve a high percentage compliance with the ideal Ackermann steering condition, at least in the
25 range of wheel rotation from 0 ° to 25 °.

In the second embodiment, the rotatable connections of the vehicle wheel steering mechanism with the auxiliary arm are preferably implemented in such a manner that the rotatable connection of the transfer lever to the vehicle frame is implemented by a rotatable connecting element with at least one degree of
30 freedom of rotary motion, the rotatable connection of the transfer lever to the auxiliary arm is implemented by a rotatable connecting element with at least one

degree of freedom of rotary motion, the rotatable connection of the transfer lever to the connecting rod is implemented by a rotatable connecting element with at least three degrees of freedom of rotary motion and the rotatable connection of the auxiliary arm to the sliding rod is implemented by a rotatable connection with at least three degrees of freedom of rotary motion. The wheel steering mechanism thus implemented in the second embodiment can be used to achieve a high percentage compliance with the ideal Ackermann steering condition, at least in the range of wheel rotation from 0 ° to 25 °, without elastic deformation of any of its elements being necessary for the mechanism to function properly. Such a combination of the rotatable connecting elements introduces into the mechanism a total of more degrees of freedom of rotary motion than is theoretically necessary for the correct functioning of the kinematics of the mechanism, compensates for possible manufacturing inaccuracies and elastic deformations of the stressed elements of the mechanism, thus preventing the mechanism from jamming and reducing wear of its components.

In a preferred embodiment, the transfer lever of the vehicle wheel steering mechanism comprises at least two parallel plates which are spaced apart from each other and between which are arranged rotatable connections and rotatable mountings for coupling the transfer lever to the other elements of the mechanism. The transfer lever is formed by parallel plates and is strong enough for testing needs and optimization of the wheel steering mechanism. Furthermore, its production does not require the use of castings, 3D printing or other financially and/or time-consuming production technologies suitable for mass production of vehicles.

In addition, the invention relates to a method of optimizing the above-described vehicle wheel steering mechanism, which is performed by determining, for predefined vehicle parameters, the lengths of the individual elements of the mechanism and the distances of the rotatable mountings and connections of the individual elements of the mechanism, whereupon the outer wheel steering angles for different inner wheel steering angles of the same axle are successively determined and the degree of compliance of the vehicle steering with the

Ackermann steering condition for different inner wheel steering angles of the axle is evaluated. If necessary, this method of optimization is repeated in essentially any number of iterations until the desired vehicle steering compliance with the ideal Ackermann steering condition is achieved.

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Description of drawings

The invention is schematically represented in the drawings, wherein Fig. 1 shows a kinematic diagram of a first embodiment of a wheel steering mechanism according to the present invention, provided with a first variant of a rotatable connection of a transfer lever and a connecting rod (tie rod), Fig. 2 shows a
10 kinematic diagram of the first embodiment of the wheel steering mechanism with a second variant of the rotatable connection of the transfer lever and the connecting rod, Fig. 3 shows a kinematic diagram of a second embodiment of the wheel steering mechanism, Fig. 4 shows a schematic side view of the second
15 embodiment of the wheel steering mechanism of Fig. 3, Fig. 5 shows a schematic view of wheels steering system of a vehicle axle with a pair of wheel steering mechanisms, Fig. 6 is a graph comparing the angular deviation of an outer wheel from an ideal steering angle for different wheel steering geometries according to the present invention, Fig. 7 is a graph comparing the percentage fulfilment of the
20 Ackermann condition of a wheel steering system equipped with a pair of wheel steering mechanisms according to the present invention with a percentage fulfilment of the Ackermann condition achievable by a conventional wheel steering system.

Examples of embodiment

Since a large number of technical solutions for wheel suspension, axle mounting and mounting of a steering mechanism with a linear actuator 1 in vehicles are known, in all parts of this patent application for invention where it is stated that a component is mounted in a frame 7 of a vehicle, it is understood that

the component may be mounted in the vehicle frame 7 directly or indirectly, e.g. by being mounted in an axle frame which mounted in the vehicle frame 7, etc.

In a first exemplary embodiment (Figs. 1, 2), the vehicle wheel steering mechanism comprises a linear actuator 1, e.g., a rack and pinion actuator, an electric linear actuator, a hydraulic cylinder, a pneumatic cylinder, etc. provided with a sliding rod 11 which is coupled by a connecting rod 2 to a hub carrier 5 of the vehicle wheel. Between the sliding rod 11 and the connecting rod 2 is inserted a transfer lever 3 which is rotatably mounted by its first end 31 in the vehicle frame 7, wherein by its second opposite end 32 it is rotatably coupled to the end of the sliding rod 11 of the linear actuator 1 and the transfer lever 3 is between both its ends 31, 32 rotatably connected to the connecting rod 2.

In the first exemplary embodiment of the vehicle wheel steering mechanism (Figs. 1, 2), the transfer lever 3 is connected by its first end 31 to the vehicle frame 7 by a rotatable connection which is implemented as a rotatable connecting element 8a with at least one degree of freedom of rotary motion, e.g., a ball stud, roller bearing, etc., by its second end 32 it is connected to the end of the sliding rod 11 of the linear actuator 1 by a rotatable connection implemented as a rotatable connecting element 8b with at least three degrees of freedom of rotary motion, e.g., a ball stud. Between its ends, 31, 32 the transfer lever 3 is connected to the first end 21 of the connecting rod 2 by a rotatable connection implemented as a rotatable connecting element 8c with at least three degrees of freedom of rotary motion, e.g., a ball stud.

The vehicle wheel steering mechanism in a second exemplary embodiment (Fig. 3, 4) comprises, similar to the first exemplary embodiment, a linear actuator 1 provided with a sliding rod 11 which is coupled by the connecting rod 2 to the hub carrier 5 of the vehicle wheel, between the sliding rod 11 and the connecting rod 2 is inserted the transfer lever 3 which is rotatably mounted by its first end 31 in the vehicle frame 7 and by its second opposite end 32 it is rotatably coupled to the end of the sliding rod 11 of the linear actuator 1, and between the two ends 31, 32 it is rotatably connected to the connecting rod 2. In the second exemplary embodiment

of the vehicle wheel steering mechanism (Fig. 3, 4), the transfer lever 3, unlike the first exemplary embodiment, is rotatably connected by its second end 32 to a first end 41 of an auxiliary arm 4 which is rotatably connected by a second end 42 to the sliding rod 11 of the linear actuator 1.

5 In the second exemplary embodiment of the vehicle wheel steering mechanism (Fig. 3), the rotatable connection of the transfer lever 3 with the vehicle frame 7, similar to the first exemplary embodiment, is implemented by the rotatable connecting element 8a with at least one degree of freedom of rotary motion and the rotatable connection of the transfer lever 3 to the connecting rod 2 is
10 implemented by the rotatable connecting element 8c with at least three degrees of freedom of rotary motion. However, in the second exemplary embodiment, unlike the first exemplary embodiment, the transfer lever 3 is rotatably coupled to the sliding rod 11 such that it is by its second end 32 connected to the first end 41 of the auxiliary arm 4 by a rotatable connection implemented as a rotatable
15 connecting element 8f with at least one degree of freedom of rotary motion, wherein the auxiliary arm 4 is by its second end 42 connected to the end of the sliding rod 11 by a rotatable connection implemented as a rotatable connecting element 8d with at least three degrees of freedom of rotary motion.

Preferably, the transfer lever 3 may in any of the above-described
20 embodiments of the vehicle wheel steering mechanism comprise at least two parallel plates which are spaced apart from each other and between which rotatable connections and rotatable mountings are arranged for coupling the transfer lever 3 to the other elements of the mechanism.

Optionally, the transfer lever 3 may comprise a third plate, transversely
25 arranged between the two above-mentioned parallel plates, for the transverse connection of the parallel plates and the reinforcement of the transfer lever 3.

Optionally, the transfer lever 3 may further comprise a fourth plate arranged in parallel or substantially parallel with the two above-mentioned parallel plates to reinforce the mounting of the rotatable connection of the transfer lever 3 to the
30 connecting rod 2.

In another unillustrated exemplary embodiment, the transfer lever 3 can be implemented as weldment of metal rods, a metal casting, a metal machined piece, a metal component made by 3D printing, or in another suitable manner.

Like the above-described transfer lever 3, also the auxiliary arm 4 (Fig. 4) in
5 the second exemplary embodiment of the vehicle wheel steering mechanism comprises at least two parallel plates which are spaced apart from each other and between which are arranged the rotatable connecting element 8f to connect the transfer lever 3 to the auxiliary arm 4 and the rotatable connecting element 8d to connect the auxiliary arm 4 to the sliding rod 11.

10 The rotatable connection of the transfer lever 3 to the connecting rod 2, implemented in the above-described exemplary embodiments as the rotatable connecting element 8c, is in the first variant (Fig. 1) mounted in the transfer lever 3 on a straight line S connecting the rotatable connections of the ends 31, 32 of the transfer lever 3 and the vehicle frame 7 and the end of the sliding rod 11 of the
15 linear actuator 1, so that all these three rotatable connections of the transfer lever 3 lie in one line or substantially in one line.

In the second variant (Fig. 2, 3, 4), the rotatable connection of the transfer lever 3 to the connecting rod 2 is mounted in the transfer lever 3 such that it does not lie on the straight line S connecting the rotatable connections of the ends 31,
20 32 of the transfer lever 3 and the frame 7 and the end of the sliding rod 11, but it is situated at a distance from the straight line S connecting the rotatable connections of the two ends 31, 32 of the transfer lever 3 and the frame 7 and the end of the sliding rod 11, so that it has a perpendicular distance d greater than 0 (zero) from the straight line S connecting these two rotatable connections, by which means, in
25 contrast to the first variant of a rotatable connection of the transfer lever 3, another element in the wheel steering mechanism is created, whose length can be modelled while optimizing the vehicle wheel steering mechanism as described below.

Both the above-described variants of the rotatable connection of the transfer lever 3 to the connecting rod 2 may be used in the first and the second above-described embodiments of the vehicle wheel steering mechanism.

5 In the optimization of the vehicle wheel steering mechanism according to the present invention described below, in addition to the perpendicular distance d described above, the length b of the transfer lever 3, the length c of the transfer lever 3 arm and the length a of the auxiliary arm 4 are also determined.

10 In both the variants of the rotatable connection of the transfer lever 3 and the connecting rod 2, as well as in both the above-described exemplary embodiments of the vehicle wheel steering mechanism, the length b (Fig. 1) of the transfer lever 3 is the length of the straight line S connecting the rotatable connection of the first end 31 of the transfer lever 3 to the vehicle frame 7 and the rotatable connection of the second end 32 of the transfer lever 3 to the sliding rod 11 or with the auxiliary arm 4.

15 In the first variant of the rotatable connection of the transfer lever 3 to the connecting rod 2, in which three rotatable connections of the transfer lever 3 lie in one line (Fig. 1), in both the exemplary embodiments of the vehicle wheel steering mechanism, the length c of the transfer lever 3 arm is the length of the straight connecting line between the rotatable connection of the first end 31 of the transfer lever 3 to the frame 7 and the rotatable connection of the transfer lever 3 to the first end 21 of the connecting rod 2.

25 In the second variant of the rotatable connection of the transfer lever 3 to the connecting rod 2, in which the three rotatable connections of the transfer lever 3 do not lie in one line (Figs. 2, 3, 4), in both the exemplary embodiments of the vehicle wheel steering mechanism, the length c of the transfer lever 3 arm is the length of the straight connecting line between the rotatable connection of the first end 31 of the transfer lever 3 to the frame 7 and perpendicular projection of the rotatable connection of the transfer lever 3 to the first end 21 of the connecting rod 2 onto the straight line S connecting the rotatable connections of the ends 31, 32 of the transfer lever 3.

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In the second exemplary embodiment of the vehicle wheel steering mechanism, the length a of the auxiliary arm 4 is the length of the straight connecting line between the rotatable connection of the second end 32 of the transfer lever 3 to the first end 41 of the auxiliary arm 4 and the rotatable connection of the second end 42 of the auxiliary arm 4 to the end of the sliding rod 11 of the linear actuator 1.

Fig. 5 schematically shows vehicle wheels steering system with a linear actuator 1 arranged between a pair of the vehicle wheel steering mechanisms according to the present invention, wherein each of the two opposite ends of the sliding rod 11 of the linear steering actuator 1 is by the rotatable transfer lever 3 coupled to the respective connecting rod 2, which is rotatably connected to the hub carrier 5 of the vehicle wheel.

The above-described vehicle wheel steering mechanism (Fig. 3) operates in such a manner that when the unillustrated vehicle steering wheel rotates, the end of the sliding rod 11 of the linear steering actuator 1 moves in a rectilinear direction 12 aligned with the steering wheel, thereby acting on the first end 31 of the rotatable transfer lever 3 and rotates it in a direction 321 oriented in the same direction as the direction of rotation of the steering wheel, about the rotatable connection of the second end 32 of the transfer lever 3 to the vehicle frame 7, wherein the transfer lever 3 acts on the first end 21 of the connecting rod 2 and rotates it in a direction 221 oriented in the same direction as the direction of rotation of the steering wheel, wherein the connecting rod 2 acts by its second end 22 on the hub carrier 5 and rotates it together with the vehicle wheel in a direction 51 oriented in the same direction as direction of rotation of the steering wheel, about the steering pins 6 of the vehicle wheel.

The advantage of the above-described vehicle wheel steering mechanism is that it may be used also for a conventional rack and pinion steering actuator controlled by a conventional steering wheel.

Another advantage of the above-described vehicle wheel steering mechanism is the fact that it enables to precisely set of the transmission of the

speed of the linear displacement of the end of the sliding rod 11 and the angular speed of rotation of the hub carrier 5, which increases or decreases depending on the angle of rotation of the wheel. Or, in other words, it enables to precisely set the vehicle wheel steering mechanism so that the ratio of the length of the linear displacement of the end of the sliding rod 11 and the angular rotation of the wheel rod 5 gradually changes, increasing or decreasing, during the rotation of the wheel in a defined manner depending on the length of the displacement of the end of the sliding rod 11.

Yet another advantage of the above-described vehicle wheel steering mechanism according to the present invention is that when manufacturing or modifying the steering of a particular vehicle, it allows to optimize a pair of steering mechanisms on one axle of the vehicle, or to optimize several pairs of steering mechanisms of the vehicle wheel mounted on several steered axles of one vehicle, for a predefined axle kinematics of a particular vehicle and thus come closer to satisfying the ideal Ackermann steering condition more than conventional vehicle wheel steering mechanisms, both for vehicles with one steered axle and for vehicles with two or more axles symmetrically and asymmetrically steered, for both the positive Ackermann condition and the negative Ackermann condition.

The above-described vehicle wheel steering mechanism is optimized for a particular vehicle by determining, for predefined vehicle parameters, the lengths of the individual elements of the mechanism and the distances of the rotatable mountings and connections of the individual elements of the mechanism. Then the outer wheel steering angles for different inner wheel steering angles of the same axle are successively determined and the degree of compliance of the vehicle steering with the Ackermann steering condition for different inner wheel steering angles of the axle is evaluated. This is performed, for example, by setting the length b of the transfer lever 3, the length c of the arm of the transfer lever 3, the perpendicular distance d of the rotatable connection of the transfer lever 3 to the connecting rod 2 from the straight line S connecting the rotatable connections of the ends 31, 32 of the transfer lever 3 and optionally, in the embodiment of the

mechanism with the auxiliary arm 4, also the length a of the auxiliary arm 4 for predefined values of the axle wheelbase, the wheel track, angle of rotation of the wheels, the difference in rotation of the inner and outer wheels of the axle, the location of the mounting of the steering pins 6 in the vehicle frame 7, the location of the mounting of the steering actuator 1 in the vehicle frame 7, the location of the mounting transfer lever 3 of the vehicle wheel steering mechanism in the vehicle frame 7, the orientation of the plane in which the transfer lever 3 mounted in the vehicle frame 7 rotates, etc.. Then, the angles of rotation of the outer wheel of the axle for different angles of rotation of the inner wheel of the same axle are successively determined, and the degree of compliance of the vehicle steering with the Ackermann steering condition for different angles of rotation of the inner wheel of the steered axle is evaluated.

The optimization method described above can be performed by changing one or more elements of the mechanism, and this is carried out in essentially any number of iterations until the desired vehicle steering compliance with the ideal Ackermann steering condition is achieved.

As an example of optimization of the vehicle wheel steering mechanism, the following table shows five selected variants of the wheel steering geometry of a specific autonomous vehicle with two symmetrically steered axles provided with pairs of vehicle wheel steering mechanisms in the second exemplary embodiment, with the auxiliary arm 4, in the variant with non-zero perpendicular distance d of the rotatable connection of the transfer lever 3 to the connecting rod 2 from the straight line S connecting the rotatable connections of the ends 31, 32 of the transfer lever 3. The columns of the table show values of the length a of the auxiliary arm 4, the length b of the transfer lever 3, the length c of the transfer lever 3 arm and the perpendicular distance d of the rotatable connection of the transfer lever 3 to the connecting rod 2 from the straight line S connecting the rotatable connections of the ends 31, 32 of the transfer lever 3.

Variant	a (mm)	b (mm)	c (mm)	d (mm)
V6_1	130	220	70	5
V7_1	130	220	70	8
V7_2	110	220	70	5
V7_5	138	220	70	5
V8_2	138	220	80	5

If the vehicle is provided with the wheel steering system with a positive Ackermann condition, the outer wheel of the rotating axle forms a smaller angle with the axis of the vehicle than the inner wheel. The theoretical ideal compliance of the steering with the positive Ackermann condition is usually conventionally expressed as + 100%. However, the compliance with or deviation from the positive Ackermann ideal steering condition can also be expressed, for a single axle of the vehicle, as the difference between the actual angle which the outer wheel forms with the vehicle axis, when the axle is rotated and the theoretical ideal angle that the outer wheel would form with the vehicle axis when the Ackermann condition is 100 % fulfilled. The following table presents the ideal values of the angles of rotation of the wheels of one axle of the above-mentioned specific autonomous vehicle with two symmetrically steered axles with theoretical 100% fulfilment of the positive Ackermann condition.

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Angle of rotation of inner wheel (°)	2.5	5	10	15	20	22	23	24	25
Angle of rotation of outer wheel (°)	2.37	4.51	8.21	11.33	14.01	14.99	15.46	15.92	16.37

As an example of optimization of the vehicle wheel steering mechanism, the graph in Fig. 6 shows comparison of five selected variants of the wheel steering geometry of a specific autonomous vehicle. The geometries of the five variants are described in the table above. The horizontal axis of the graph shows the angle of rotation of the inner wheel of the axle while turning the vehicle, the vertical axis of the graph shows the angular deviation of rotation of the outer wheel of the same

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axle from the ideal angle of rotation of the outer wheel with 100% fulfilment of the positive Ackermann condition. The closer the angular deviation approaches zero, the better the axle steering satisfies the Ackermann steering condition.

The graph in Fig. 7 compares the percentage fulfilment of the Ackermann condition of the wheel steering system of a vehicle equipped with a pair of vehicle wheel steering mechanisms according to the present invention, in the above-described variant V7_5 (see Fig. 6 and the above table with variants of geometries of the vehicle wheel steering mechanism), with the percentage fulfilment of the Ackermann condition by a vehicle with conventional wheel steering system, and with ideal theoretical compliance with the Ackermann steering condition for steering with the positive Ackermann. The graph in Fig. 7 clearly shows that wheel steering system provided with a pair of vehicle wheel steering mechanisms according to the present invention (solid curved line) for the angles of rotation of the inner wheel of the steered axle in the range of 5° to 25° gets close to the ideal Ackermann condition (dotted line) in percentage terms significantly more than conventional wheel steering system (dashed curved line).

List of references

	1	Linear steering actuator
	11	Sliding rod
	12	Direction of the linear motion of the sliding rod
5	2	Connecting rod
	21	First end of the connecting rod
	211	Direction of the rotary motion of the first end of the connecting rod
	22	Second end of the connecting rod
	3	Transfer lever
10	31	First end of the transfer lever
	321	Direction of the rotary motion of the second end of the transfer lever
	4	Auxiliary arm
	41	First end of the auxiliary arm
	42	Second end of the auxiliary arm
15	5	Wheel hub carrier
	51	Rotary motion of the wheel hub carrier
	6	Wheel steering pin
	7	Vehicle frame
	8	Rotatable connecting element
20	8a	Rotatable connecting element for connecting the transfer lever to the frame
	8b	Rotatable connecting element for connecting the transfer lever to the sliding rod
	8c	Rotatable connecting element for connecting the transfer lever to the sliding rod
25	8d	Rotatable connecting element for connecting the auxiliary arm to the sliding rod
	8e	Rotatable connecting element for connecting the connecting rod to the hub carrier kola
30	8f	Rotatable connecting element for connecting the transfer lever to the auxiliary arm
	a	Length of the auxiliary arm
	b	Length of the transfer lever
	c	Length of the arm of the transfer lever
35	d	Perpendicular distance of the rotatable connection of the transfer lever with the connecting rod from the straight connecting line between the rotatable connections of the ends of the transfer lever
	S	Straight line connecting the rotatable connections of the ends of the transfer lever
40		

PATENT CLAIMS

1. A vehicle wheel steering mechanism which comprises a linear actuator (1) which is provided with a sliding rod (11) which is coupled by a connecting rod (2) to a wheel hub carrier (5) of a vehicle wheel, wherein between the sliding rod (11) and the connecting rod (2) is inserted a transfer lever (3) which is rotatably mounted in a frame (7) of the vehicle, **characterized in that** the transfer lever (3) is rotatably mounted in the vehicle frame (7) by one end (31), wherein by its second end (32) it is rotatably coupled to the end of the sliding rod (11) of the linear steering actuator (1) and the transfer lever (3) is between both its ends (31, 32) rotatably connected to the connecting rod (2).

2. The vehicle wheel steering mechanism according to claim 1, **characterized in that** the rotatable connection of the transfer lever (3) to the connecting rod (2) is situated at a distance (d) from the straight connecting line (S) between the rotatable connections of both ends (31, 32) of the transfer lever (3) and the frame (7) and the end of the sliding rod (11).

3. The vehicle wheel steering mechanism according to claim 1 or 2, **characterized in that** the rotatable connection of the transfer lever (3) to the vehicle frame (7) is implemented by a rotatable connecting element (8a) with at least one degree of freedom of rotary motion, wherein the rotatable connection of the transfer lever (3) to the end of the sliding rod (11) is implemented by a rotatable connecting element (8b) with at least three degrees of freedom of rotary motion and the rotatable connection of the transfer lever (3) to the connecting rod (2) is implemented by a rotatable connecting element (8c) with at least three degrees of freedom of rotary motion.

4. The vehicle wheel steering mechanism according to claim 1 or 2, **characterized in that** a second end (32) of the transfer lever (3) is rotatably connected to a first end (41) of the auxiliary arm (4), which is by its second end (42) rotatably connected to the sliding rod (11) of the linear actuator (1).

5

5. The vehicle wheel steering mechanism according to claim 4, **characterized in that** the rotatable connection of the transfer lever (3) to the vehicle frame (7) is implemented by the rotatable connecting element (8a) with at least one degree of freedom of rotary motion, the rotatable connection of the transfer lever (3) to the auxiliary arm (4) is implemented by a rotatable connecting element (8f) with at least one degree of freedom of rotary motion, the rotatable connection of the transfer lever (3) to the connecting rod (2) is implemented by the rotatable connecting element (8c) with at least three degrees of freedom of rotary motion and the rotatable connection of the auxiliary arm (4) to the sliding rod (11) is implemented by a rotatable connection (8d) with at least three degrees of freedom of rotary motion.

6. The vehicle wheel steering mechanism according to any of the preceding claims, **characterized in that** the transfer lever (3) comprises at least two parallel plates which are spaced apart from each other and between which rotatable connections and rotatable mountings are arranged for coupling the transfer lever (3) to the other elements of the mechanism.

7. A method of optimizing the vehicle wheel steering mechanism according to any of the preceding claims, **characterized in that** for predefined vehicle parameters, the lengths of the individual elements of the mechanism and the distances of the rotatable mountings and connections of the individual elements of the mechanism are determined, whereupon the outer wheel steering angles for different inner wheel steering angles of the same axle are successively determined

and the degree of compliance of the vehicle steering with the Ackermann steering condition for different inner wheel steering angles of the axle is evaluated.

AMENDED CLAIMS

received by the International Bureau on 30 December 2022

1. A vehicle wheel steering mechanism which comprises a linear actuator (1) which contains a sliding rod (11) which is provided with two opposite ends, wherein
5 the sliding rod (11) is connected at each end to one transfer lever (3) and each transfer lever (3) being connected to a connecting rod (2), which is connected with a wheel hub carrier (5) of a respective wheel of the vehicle, wherein both transfer levers (3) are rotatably mounted in a frame (7) of the vehicle, **characterized in that**
10 the transfer levers (3) each are rotatably mounted in the vehicle frame (7) by one end (31), wherein the transfer levers (3) each are by second end (32) rotatably coupled to the respective end of the sliding rod (11) of the linear steering actuator (1) and the transfer levers (3) are between both its ends (31, 32) rotatably connected to the respective connecting rod (2).

15 2. The vehicle wheel steering mechanism according to claim 1, **characterized in that** the rotatable connection of the transfer lever (3) to the connecting rod (2) is situated at a distance (d) from the straight connecting line (S) between the rotatable connections of both ends (31, 32) of the transfer lever (3) and the frame (7) and the end of the sliding rod (11).

20

3. The vehicle wheel steering mechanism according to claim 1 or 2, **characterized in that** the rotatable connection of the transfer lever (3) to the vehicle frame (7) is implemented by a rotatable connecting element (8a) with at least one degree of freedom of rotary motion, wherein the rotatable connection of the transfer
25 lever (3) to the end of the sliding rod (11) is implemented by a rotatable connecting element (8b) with at least three degrees of freedom of rotary motion and the rotatable connection of the transfer lever (3) to the connecting rod (2) is implemented by a rotatable connecting element (8c) with at least three degrees of freedom of rotary motion.

4. The vehicle wheel steering mechanism according to claim 1 or 2,
characterized in that a second end (32) of the transfer lever (3) is rotatably
connected to a first end (41) of the auxiliary arm (4), which is by its second end (42)
5 rotatably connected to the sliding rod (11) of the linear actuator (1).

5. The vehicle wheel steering mechanism according to claim 4, **characterized**
in that the rotatable connection of the transfer lever (3) to the vehicle frame (7) is
implemented by the rotatable connecting element (8a) with at least one degree of
10 freedom of rotary motion, the rotatable connection of the transfer lever (3) to the
auxiliary arm (4) is implemented by a rotatable connecting element (8f) with at least
one degree of freedom of rotary motion, the rotatable connection of the transfer lever
(3) to the connecting rod (2) is implemented by the rotatable connecting element (8c)
with at least three degrees of freedom of rotary motion and the rotatable connection
15 of the auxiliary arm (4) to the sliding rod (11) is implemented by a rotatable
connection (8d) with at least three degrees of freedom of rotary motion.

6. The vehicle wheel steering mechanism according to any of the preceding
claims, **characterized in that** the transfer lever (3) comprises at least two parallel
20 plates which are spaced apart from each other and between which rotatable
connections and rotatable mountings are arranged for coupling the transfer lever (3)
to the other elements of the mechanism.

7. A method of optimizing the vehicle wheel steering mechanism according to
25 any of the preceding claims, **characterized in that** for predefined vehicle
parameters, the lengths of the individual elements of the mechanism and the
distances of the rotatable mountings and connections of the individual elements of
the mechanism are determined, whereupon the outer wheel steering angles for
different inner wheel steering angles of the same axle are successively determined

and the degree of compliance of the vehicle steering with the Ackermann steering condition for different inner wheel steering angles of the axle is evaluated.

Statement under Article 19 PCT

Based on the International Search Report and Written Opinion of the International Searching Authority we have amended claim 1. To the amended claim we provide the following statement.

The present invention according to amended claim 1 is a wheel control mechanism comprising a transfer lever 3 for transferring the movement of the end of the sliding rod 11 to the connecting rod 2 (20, 26), wherein the transfer lever 3 is connected to the sliding rod 11 at one end of the steering control to the wheels of the vehicle, including rack-and-pinion drive, i.e. approaching the ideal Ackermann steering condition, in a large range of wheel rotation angles, up to 25 °. The wheel steering mechanism includes a linear drive 1 provided with a sliding rod 11, which is coupled to a connecting rod 2 via a transmission lever 3, which is rotatably mounted in the frame at one end and is rotatably connected to the sliding rod 11 at the other end and between its first and second ends is rotatably connected to the connecting rod 2. The connecting rod 2 is a steering tie rod of the wheel and is not used to suspend the wheel. The transmission lever 3 according to the present invention does not therefore serve to damp the vertical forces of the wheel suspension, but only to transmit the movement of the end of the sliding rod 11 of the linear drive 1 to the connecting rod 2.

The present invention makes it possible to optimize the ratios of the individual parts of the transfer lever 3 according to the parameters of the selected vehicle and according to the parameters of other components of the vehicle steering mechanism so that the steering mechanism achieves the greatest possible degree of compliance with the Ackermann condition when transferring movement from the steering control to the wheels of the vehicle, up to the angle of rotation of the wheel 25° . In addition, the wheel steering mechanism according to our invention not only enables the use of the Ackermann principle, but because it is not connected to other lever mechanisms, the size, location, rotation, etc. of its components is not limited, which can therefore be optimized for different axle kinematics, or optionally other parameters/types of vehicles and thereby achieve an unprecedentedly high compliance of such steering control with the Ackermann principle.

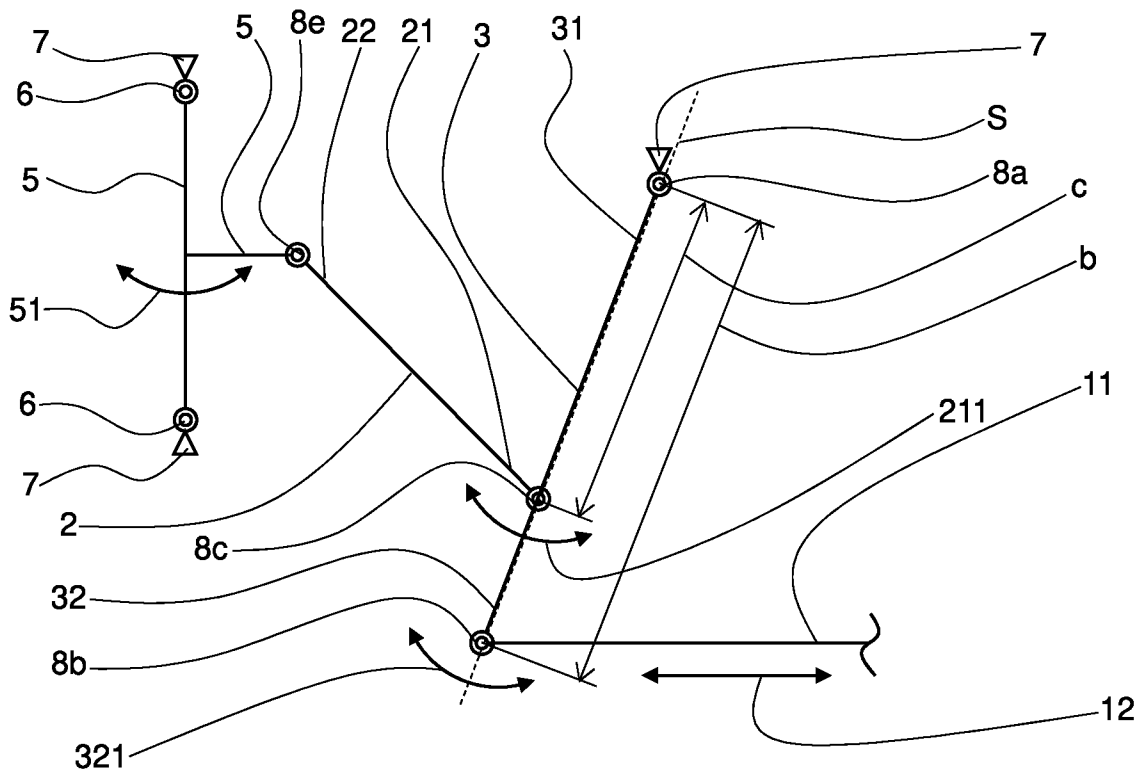


Fig. 1

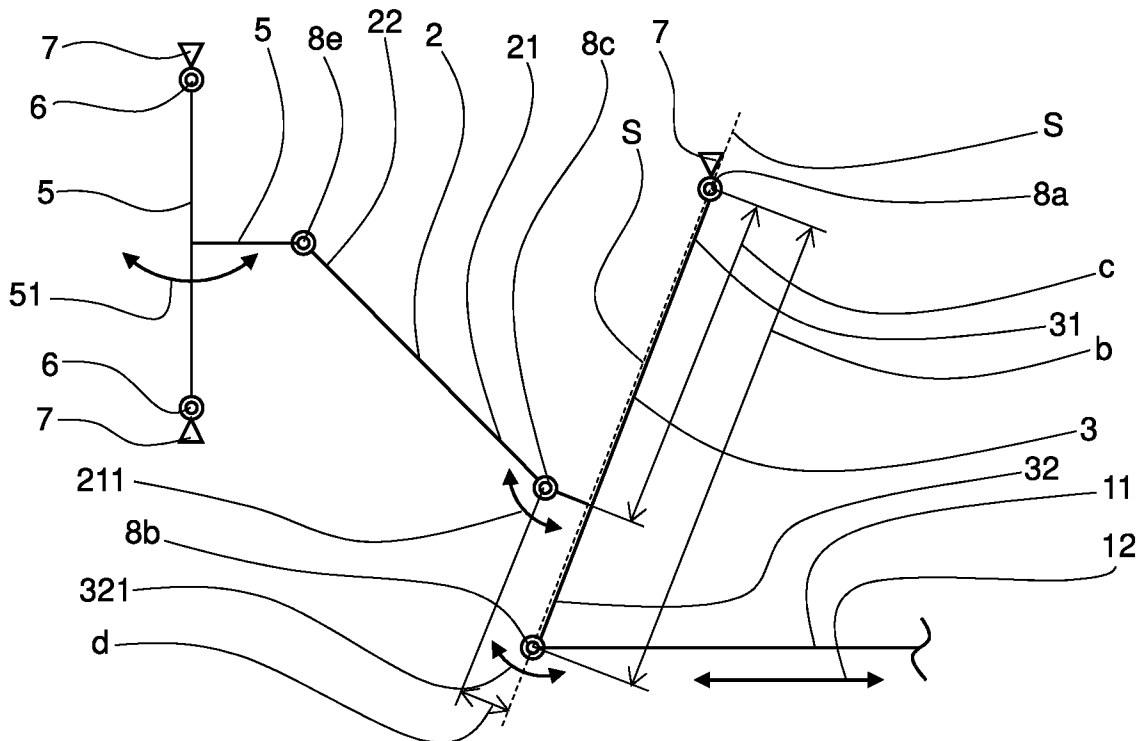


Fig. 2

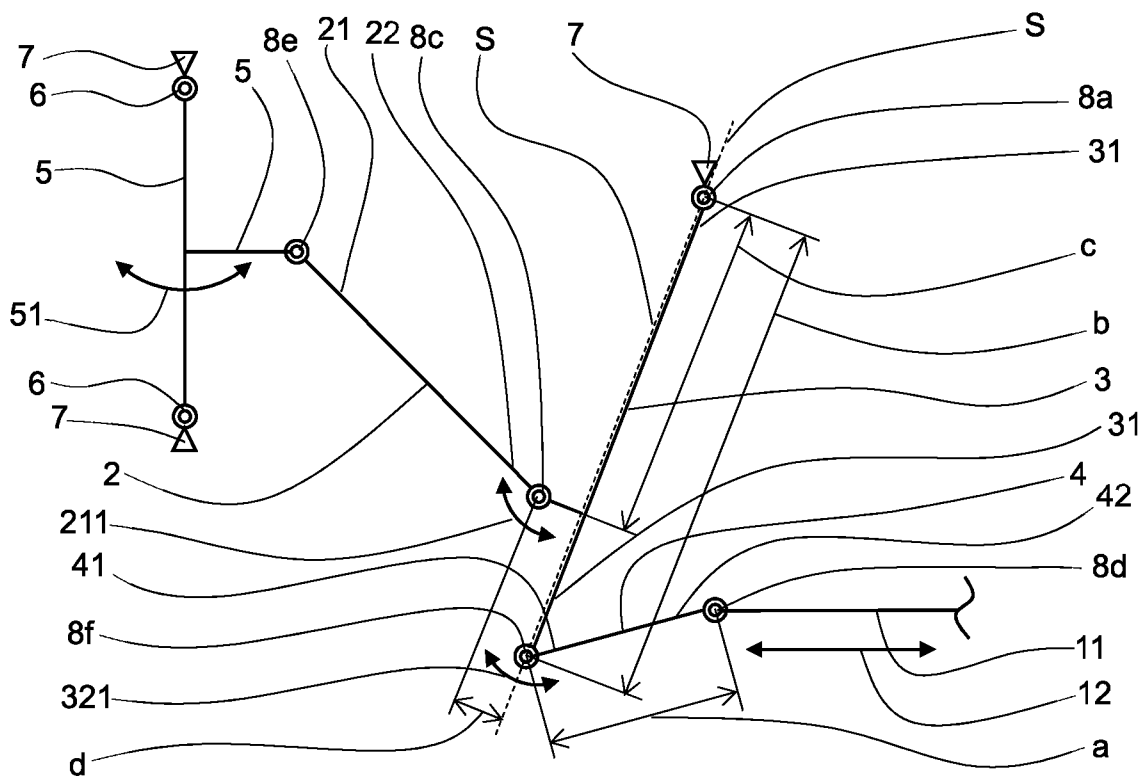


Fig. 3

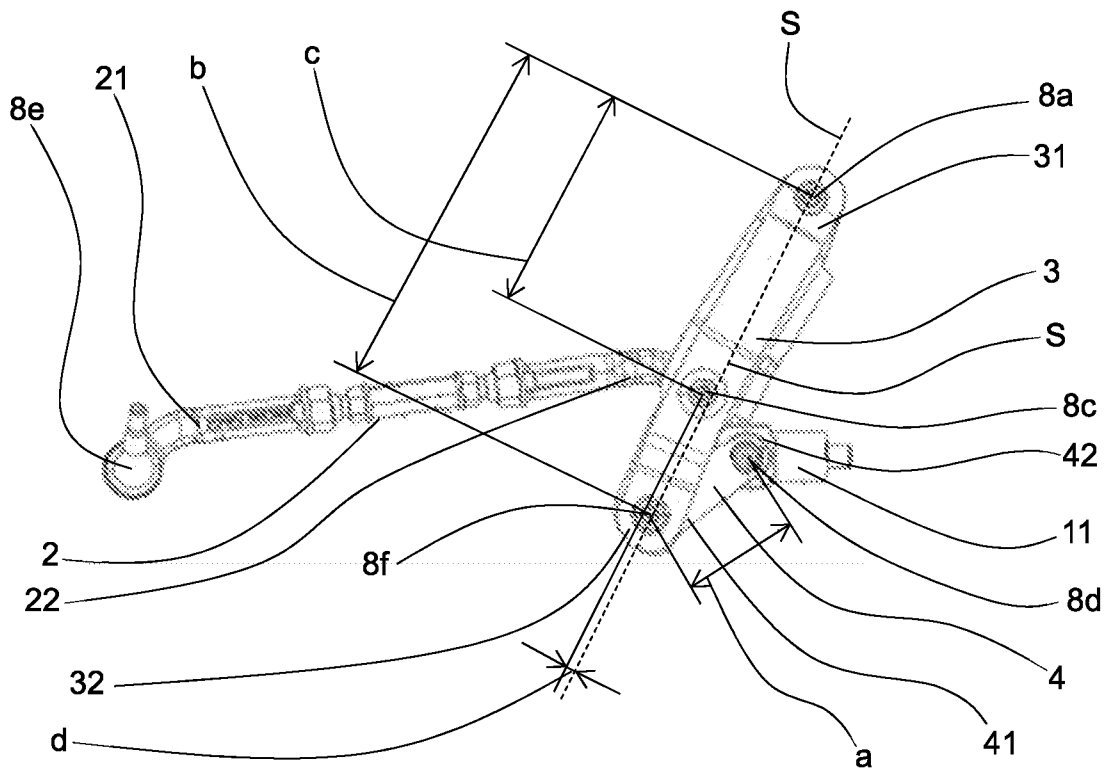


Fig. 4

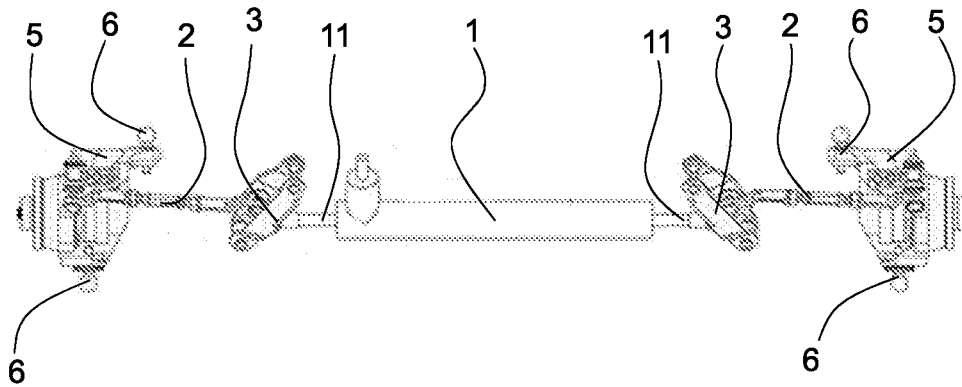


Fig. 5

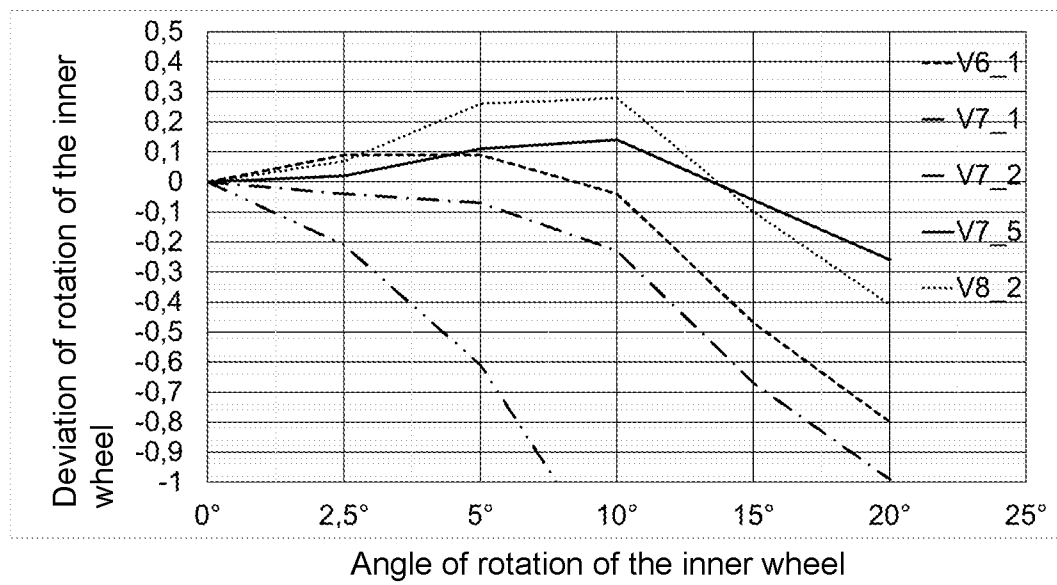


Fig. 6

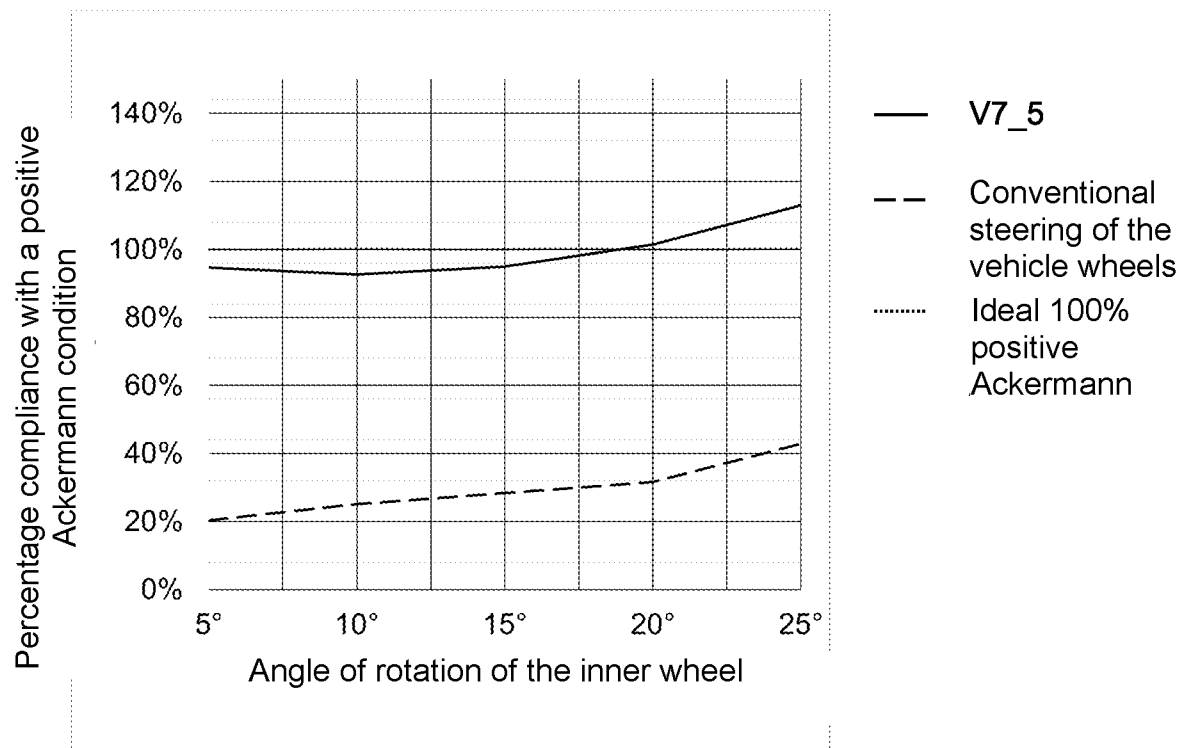


Fig. 7

INTERNATIONAL SEARCH REPORT

International application No
PCT/CZ2021/050094

A. CLASSIFICATION OF SUBJECT MATTER

INV. **B62D17/00 B60G7/00 B62D7/06**
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)

B62D B60G

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, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2018/050725 A1 (PATTOK ERIC D [US] ET AL) 22 February 2018 (2018-02-22) paragraph [0018]; figures 1,2 -----	1, 2, 4, 7
X	EP 0 307 547 A1 (BAYERISCHE MOTOREN WERKE AG [DE]) 22 March 1989 (1989-03-22) column 2, line 49 - column 3, line 9; figure -----	1, 6, 7
X	US 5 094 472 A (OYAMA YASUHARU [JP] ET AL) 10 March 1992 (1992-03-10) figures 7, 6 -----	1, 6, 7
X	US 2005/017472 A1 (KONDO KAZUO [JP] ET AL) 27 January 2005 (2005-01-27) paragraph [0062] ----- -/-	1, 3, 5, 7

☒ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

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"E" earlier application or patent but published on or after the international filing date

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

11 May 2022

Date of mailing of the international search report

20/05/2022

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Areal Calama, A

INTERNATIONAL SEARCH REPORT

International application No

PCT/CZ2021/050094

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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International application No

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