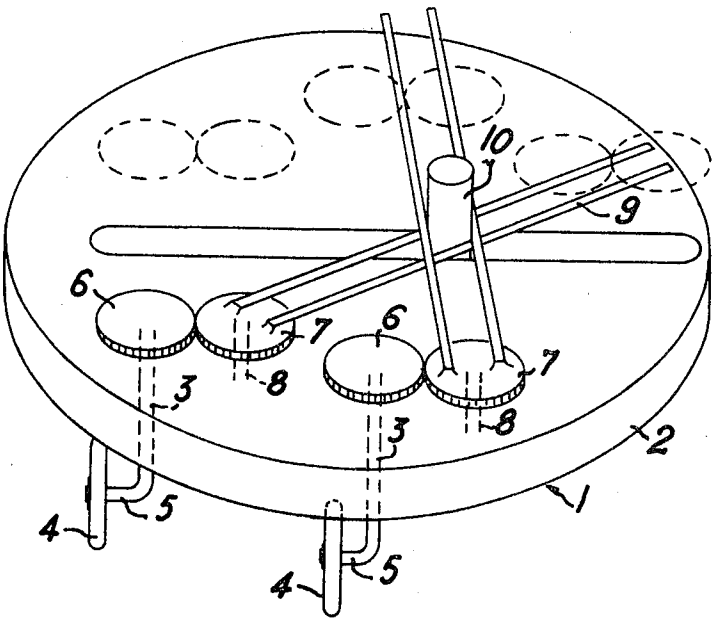


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[31] **147,453**

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[54] **SYSTEM FOR CONTROLLING THE STEERING OF VEHICLE WHEELS**
12 Claims, 9 Drawing Figs.
[52] **U.S. Cl.**..... **180/79.1,**
280/96
[51] **Int. Cl.**..... **B62d 5/04**
[50] **Field of Search**..... **180/79.1;**
280/91, 96

ABSTRACT: In a steering control system for vehicle wheels in which rotational axis of the wheels are disposed in a plane at the vertices of a polygon which can be inscribed within a circle referred to as a base circle, the direction of the axes of rotation of the wheels is caused to converge continuously towards a common point referred to as the center of rotation of the vehicle and the circle which circumscribes the base polygon in the base plane corresponds by means of a geometrical transformation to a reference circle in a reference plane, said center of rotation being related alternately its transformed point in said reference plane and to the harmonic conjugate of said point with respect to said reference circle.



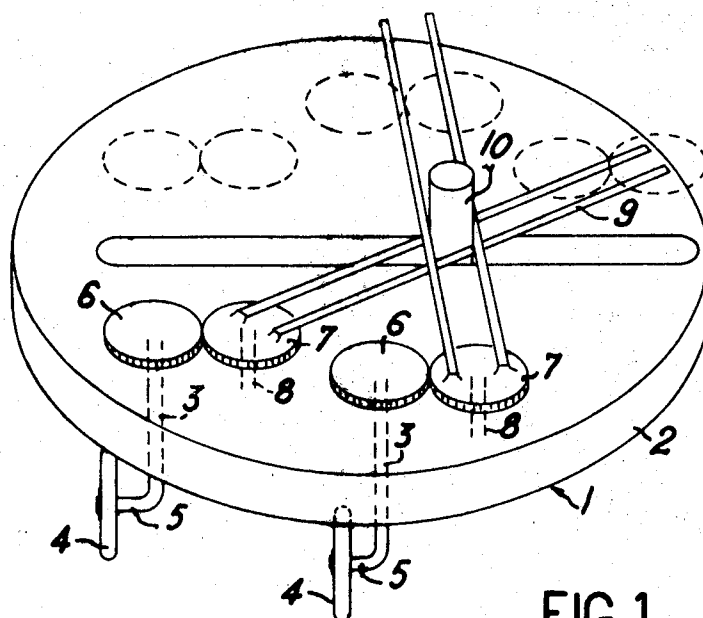
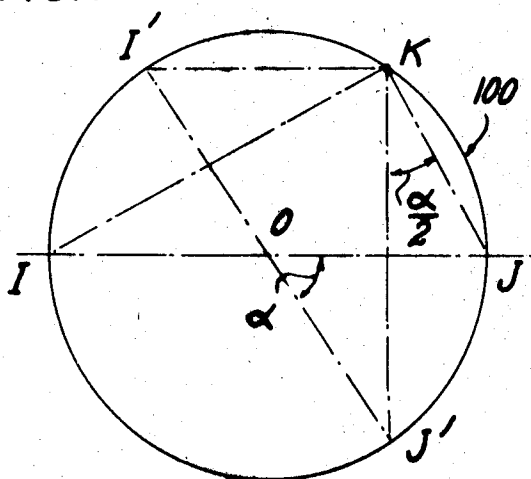
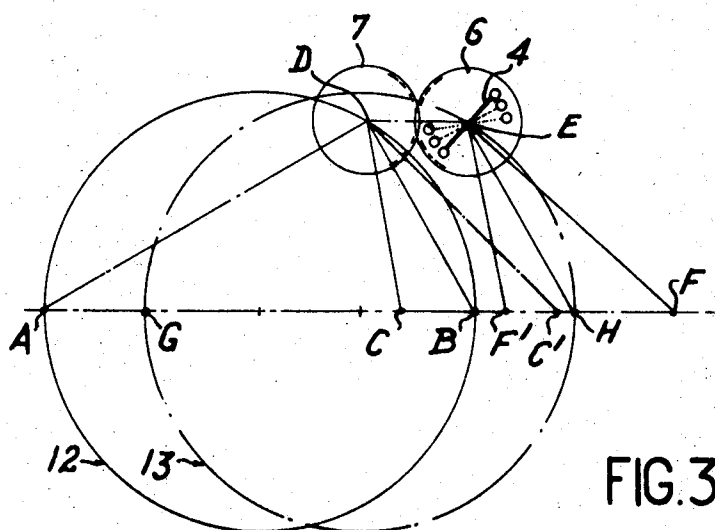
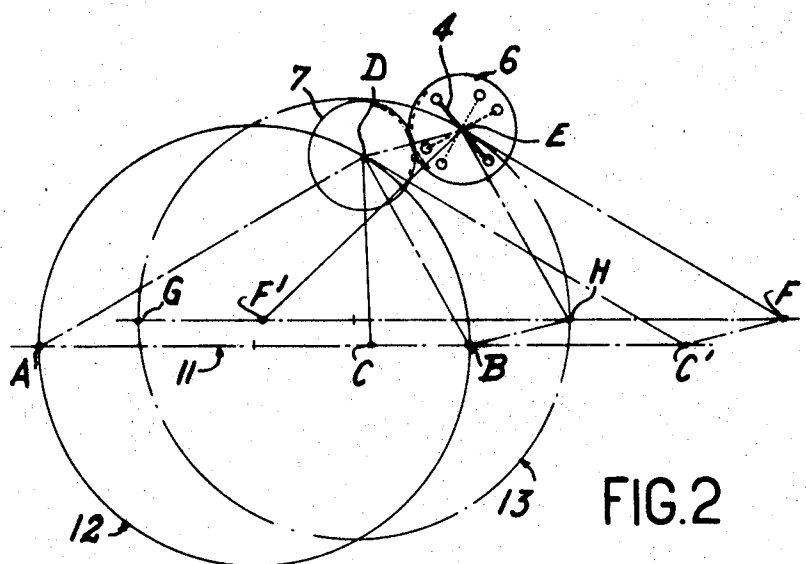


FIG. 1





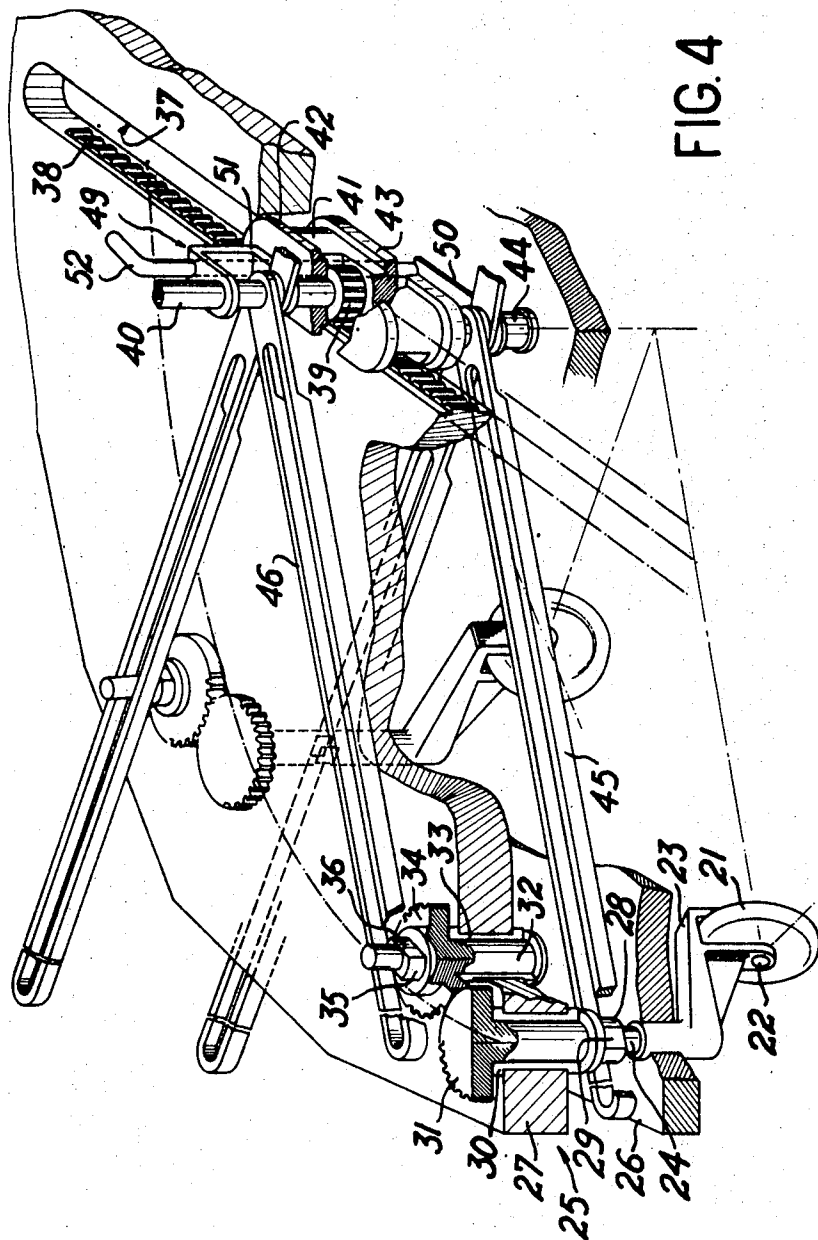
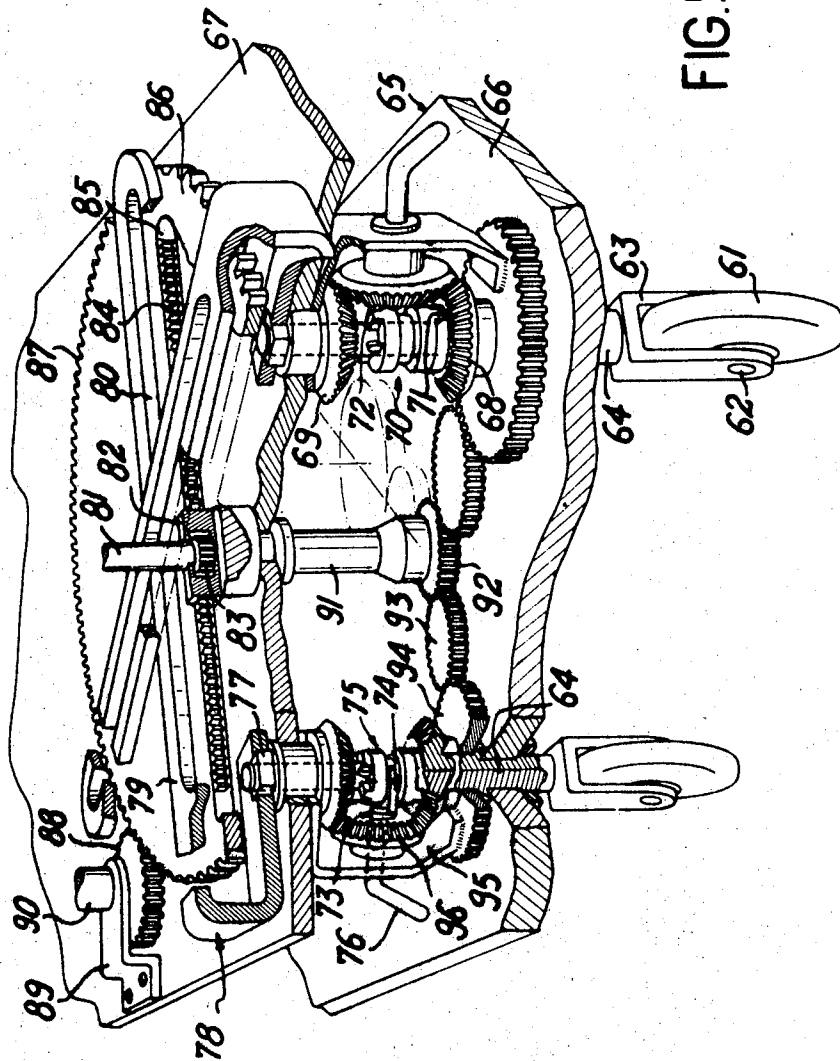
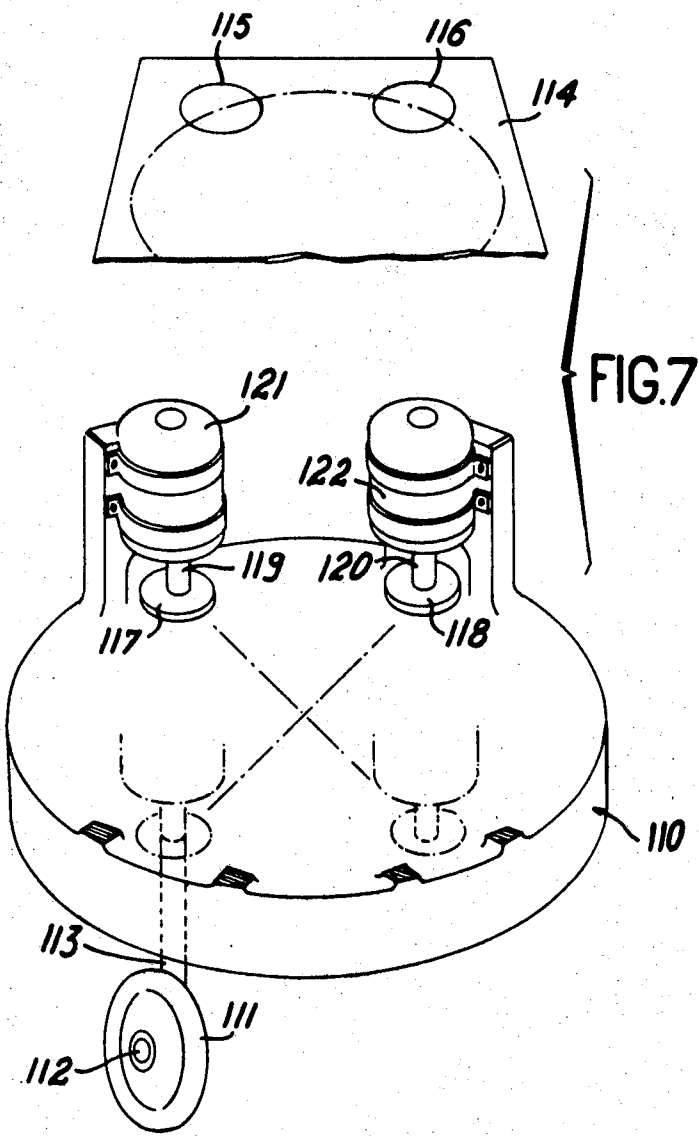
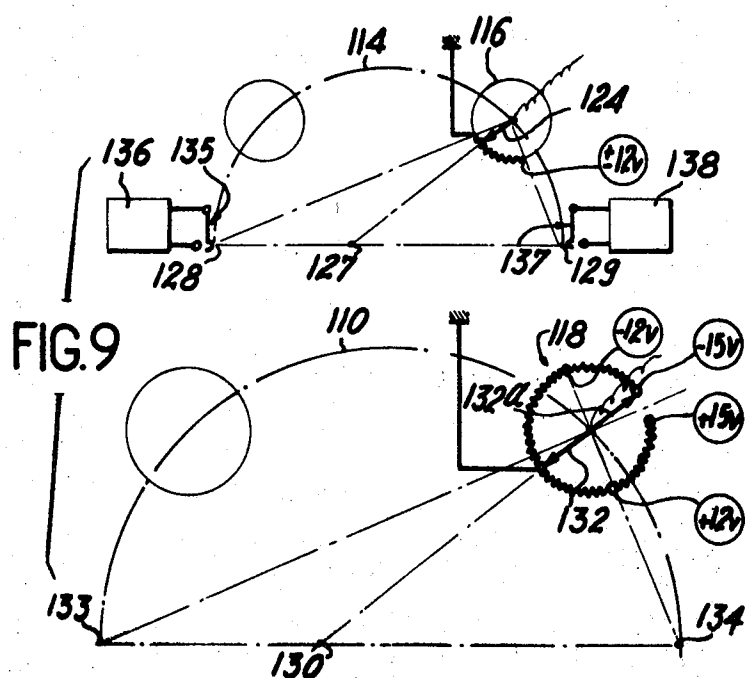
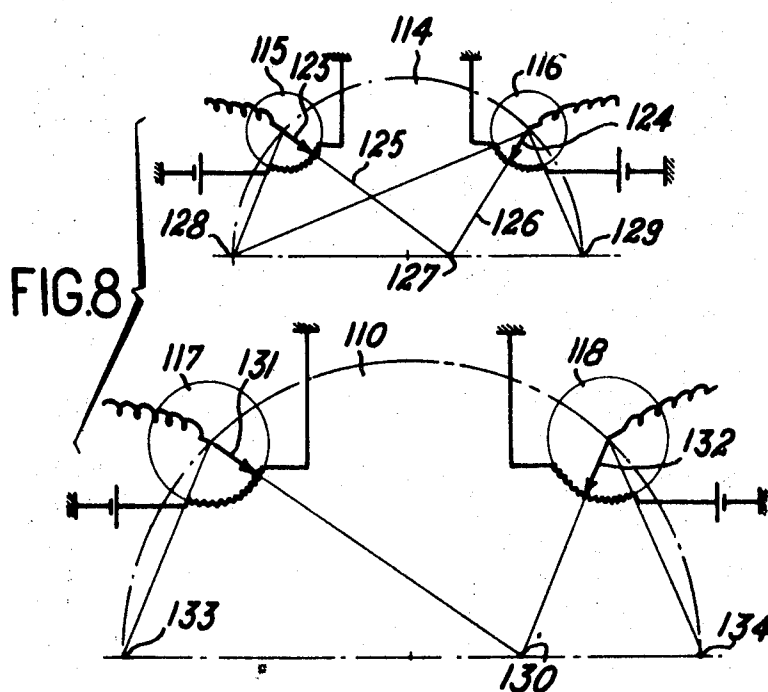


FIG. 4







SYSTEM FOR CONTROLLING THE STEERING OF VEHICLE WHEELS

This invention is concerned with improvements to systems for controlling the steering of the wheels of a vehicle, whereby the wheel-turning radius can be varied between a value at which the center of rotation is projected to infinity in the case in which the wheels are parallel and a zero value at which the center of rotation is located at the center of the vehicle which accordingly rotates about this point. A further aim of the invention is to permit the displacement of the center of rotation in the plane which passes through the axes of rotation of all the wheels irrespective of the value of the turning radius, thereby endowing the vehicle with the most general plane on plane motion.

Steering control systems which are already known suffer from a first limitation in that the center of rotation must necessarily remain on a straight line which is related to the vehicle and usually materialized by the rear axle centerline located at right angles to the longitudinal axis of the vehicle. In the simplest case of a three-wheeled vehicle in which a single wheel has both a driving and steering function and in which the axis of pivotal motion of the wheel is located in the plane at right angles to the common direction of the axle of the other two wheels, it is possible to displace the center of rotation to any point of the straight line of the rear axle; however, a vehicle of this type evidently lacks stability and is suitable only for limited applications. In the derived case in which the wheels of a vehicle are disposed in a lozenge configuration corresponding to the juxtaposed assembly of two three-wheeled vehicles on a common axis, the degree of stability achieved is still not perfect. In addition, only two wheels can have both a driving and a steering function at the same time.

In the most common case of four-wheeled vehicles, a further limitation has to be taken into consideration, namely the fact that the center of rotation can be displaced along the straight line of the rear axle only between given limits. In fact, the front wheels are usually mounted on kingpins which define their respective pivotal axes and are controlled by steering tie rods, the compensated displacements of which are related to the operation of the steering wheel by means of a toothed rack. During this pivotal motion of the wheels, the center of rotation is displaced between infinity, in which case all wheels are parallel, and an ultimate or limiting point which is close to the vehicle but located outside the rectangle of the four wheels; this limiting point defines the minimum turning radius.

The aim of the present invention is to provide a remedy for these disadvantages by permitting any desired displacement of the center of rotation in the plane which contains the axes of rotation of all the wheels and any desired number of wheels. Moreover, all the wheels can be endowed either simultaneously or separately with either a driving or steering function or both at the same time. The invention applies generally to a vehicle in which the pivot axes of the wheels intersect a base plane at the vertices of a base polygon which can be inscribed in a base circle. As a preferable feature, the plane of the base polygon is perpendicular to the pivotal axes of said wheels which are all parallel. However, the invention would also be applicable to the case in which the pivotal axes of the wheels are not necessarily normal to the plane of the base polygon; these wheels can also have particular angles of inclination to this plane, as is the case with conventional motor vehicles in which the support polygon defined by the points of contact of the wheels with the ground is not directly similar to the base polygon and is not deduced from this latter simply by orthogonal projection on the plane of the ground.

To this end, the system under consideration is characterized in that, inasmuch as the direction of the axes of rotation of the wheels is caused to converge continuously towards a common point known as the center of rotation of the vehicle, the circle which circumscribes the base polygon in the base plane corresponds by means of a geometrical transformation to a reference circle in a reference plane, said center of rotation being related alternately to its transformed point in said

reference plane and to the harmonic conjugate of said point with respect to said reference circle.

Preferably, said geometrical transformation is a similitude which constitutes a translation in an extreme case.

In a simplified embodiment of the invention, said transformed point is caused either mechanically or electrically to carry out a displacement along a straight line of the reference plane. In a more general arrangement, said straight line is capable of carrying out a pivotal motion about a point in said reference plane, the combination of the displacement of said point on said straight line and the pivotal motion of this latter being such that said point is permitted to take up any position in said plane.

By virtue of the foregoing arrangements, two possible positions of the center of rotation correspond to each position of the transformed point in the reference plane within the reference circle. The first possible position in which the transformed point is directly related to the center of rotation places this latter inside the base circle which is deduced from the reference circle as a result of the reverse transformation; the second possible position in which the harmonic conjugate of the transformed point which is related to the center of rotation conversely places said center outside the base circle. The center of rotation can thus take up any position either inside or outside said circle corresponding to the homologous, continuous and unlimited displacements of the transformed point within the reference circle.

In a first mode of execution of the invention, the position of the transformed point with respect to the reference circle is determined by means of forks which are pivotally mounted at the vertices of the reference polygon and the ends of which are adapted to cooperate with a control pin, said pin being operated within a guide slot which materializes a straight line of the reference plane. In accordance with the invention, the angular displacements of the forks determine in the case of the vehicle wheels which are associated with the vertices of the base polygon either equal or opposite displacements according as the center of rotation is located either inside or outside the base circle.

To this end, said system is essentially characterized in that it comprises a control plate in which is formed a guide slot, a first set of forks which are capable of being directly keyed on the pivotal shafts of the wheels and extend parallel to the plane of said control plate so as to come into engagement with a first pin which is engaged in said slot, first pinions which are rigidly fixed to said pivotal shafts and disposed in meshing relation with second pinions having the same diameter which are carried by swivel pins located parallel to the pivotal shafts and fixed on said control plate, a second set of forks which are capable of being directly keyed on said swivel-pins and extend parallel to the plane of said control plate so as to come into engagement with a second pin engaged in a second slot of said control plate, the centers of the second pinions being located on the reference circle of which the second slot constitutes a diameter, said reference circle being deduced by translation of the base circle in the direction which joins the pivotal shafts to the associated swivel-pins and the amplitude of which is equal to the common diameter of the first and second pinions. Preferably, said direction is parallel to the first slot whilst the second slot coincides with the first. As a further preferred feature, the forks of the first and second sets are parallel and disposed respectively on each side of the faces of said control plate.

In another embodiment of the invention, said first and second pinions are capable of being alternately coupled to the pivotal shafts of the wheels by means of keys slidably fitted on said shafts, each pair of pinions having the same diameter being coupled together by means of a planetary pinion whose diameter defines the amplitude of the translation which causes the base circle to correspond to the reference circle, said pivotal shafts being additionally coupled with a set of third identical pinions which are in meshing relation by means of bevel pinions with a fourth or common pinion which is carried

by a shaft located parallel to the pivotal shafts and which is adapted to support the guide slot for the control pins, the diameter of said fourth pinion being equal to the diameter of the bevel pinions and one-half the diameter of the third pinions.

Finally, in another embodiment, said control plate comprises a reference circle which is deduced from the base circle by virtue of a similitude and a set of circular electric potentiometers disposed on said circle at the vertices of the reference polygon and having sliding contacts which are caused to converge towards a common pin constituting the transformed point of the center of rotation, said pin being capable of displacement along a diameter of said reference circle and the pivotal shafts of the wheels being driven by individual motors supplied as a function of the positions of the sliding contacts of the duplicating potentiometers which are each associated with a corresponding potentiometer of said control plate. In addition, said control plate is provided at the extremities of the diameter of the reference circle on which said control pin is capable of displacement with relays for reversing the directions of polarity of the duplicating potentiometers which control the individual motors of the pivotal shafts so as to ensure correspondence between said center of rotation and its transformed point or its harmonic conjugate relative to said reference circle.

The different properties mentioned in the foregoing and considered separately or even in combination will be explained in greater detail in the following description of a number of practical examples corresponding to the different modes of execution set forth hereinabove. It will be readily understood that said examples are given solely by way of indication and not in any limiting sense and that any alternative forms which utilize the same properties must be considered as remaining within the scope of the present invention.

In the accompanying drawings:

FIG. 1 is a diagrammatic view of a portion of a vehicle which is equipped with a steering control system in accordance with the invention;

FIGS. 2 and 3 are diagrams relating to the embodiment of FIG. 1 and serving to explain its operation;

FIG. 4 is a perspective view of an embodiment which is derived from that of FIG. 1;

FIG. 5 is another perspective view of another embodiment of more highly improved design;

FIG. 6 is an explanatory diagram of the embodiment of FIG. 5;

FIG. 7 illustrates another alternative embodiment;

FIGS. 8 and 9 are explanatory diagrams of operation of the alternative embodiment shown in FIG. 7.

There is shown diagrammatically in FIG. 1 a vehicle 1 comprising only a part of the steering control system as constructed in accordance with the invention and serving to gain a clearer conception of its general structure as shown by way of example in the perspective view of FIG. 4.

The vehicle 1 shown in FIG. 1 has a frame 2 in the form of a flat plate on which are mounted a series of pivots 3 each associated with a wheel 4 by means of a stub axle or axle-pin 5. Said pivots 3 are in parallel relation and oriented at right angles to the plane of the plate 2; in the example under consideration, the pivots are also spaced on a circle which defines the base circle mentioned earlier and the extremities of the pivots constitute on said circle the vertices of the base polygon. There is mounted at the extremity of each pivot 3 a pinion 6 which is secured to the shaft of the corresponding pivot by suitable means. Said pinion 6 is adapted to cooperate with a second pinion 7 having the same diameter and mounted at the end of a swivel-pin 8 which is parallel to the axis of the corresponding pivot. All the pairs of pinions 6, 7 which are associated with the wheels 4 are identical by design, the straight-line segments which join the centers of these pinions being parallel to each other and having the same length from one pair to the next. In consequence, the centers of the pinions 7 which correspond to the swivel-pins 8 are disposed on a circle

having the same diameter as the circle relating to the pinions 6. This second circle or so-called reference circle is deduced from the first base circle by means of a geometrical transformation which is in this case a translation in the direction of said straight-line segments and equal in amplitude to the diameter of any one of said pinions. There is fixed on each pinion 7 a fork 9 adapted to engage with a pin 10 which is parallel to the pivots 3, said pin 10 being intended to produce the convergence of all the forks which are associated with all the pinions 7. Moreover, said pin 10 is caused by any known means to carry out a movement of displacement within a slot 11 which is formed in the example illustrated in the drawings through the thickness of the plate 2. Said slot extends along a diameter of the reference circle which passes through the centers of the pinions 7. The displacements of the pin 10 from one end of the slot 11 to the other accordingly make it possible by means of the pinions 6 and 7 to control the orientation of the wheels 4 about their respective pivots 3 and consequently to determine the resultant displacement of the center of rotation of the vehicle. In the case which is illustrated in FIG. 1, this displacement of the center of rotation is carried out from infinity when the pin 10 is located at the center of the slot 11, that is to say at the center of the reference circle up to a point which forms part of the base circle when the pin 10 is located at either of the two ends of said slot 11, that is to say when the pin reaches the extremities of the diameter of the reference circle which is materialized by said slot.

The operation which is explained in the foregoing will be more readily understood with reference to FIG. 2. There is shown in this FIG. the reference circle 12 which circumscribes the axes of the pinions 7 and the base circle 13 which circumscribes the axes of the pivots 3, that is to say which passes through the axes of the pinions 6. For the sake of enhanced clarity, there has been shown in FIG. 2 only a single pair of pinions 6, 7, it being understood that the demonstration given hereinafter applies at the same time to all the other pairs which, as stated earlier, are disposed on the circles 12 and 13 respectively. The points A and B on the circle 12 delimit a diameter corresponding to the slot 11 in which is displaced the pin 10, the axis of which is represented at C. The point D on the circle 12 represents schematically the axis of the pinion 7 as outlined whilst the point E on the circle 13 materializes the axis of the associated pinion 6. The circles 12 and 13 are deduced from each other by means of a translation which takes place in the direction of the segment DE and the amplitude of which is equal to the length of said segment, that is to say to the diameter of the pinion 6 which is made equal by design to the diameter of the pinion 7.

If, on the line of extension of the diameter AB, the point C' designates the conjugate of the point C relative to the reference circle 12, the angle $\widehat{ADB}$ being a right angle, the result thereby achieved is that the angles $\widehat{CDB}$ on the one hand and $\widehat{BDC'}$ on the other hand are equal whilst the straight line DB bisects the angle $\widehat{CDC'}$ in accordance with a known property of harmonic beams. Moreover, the pinion 6 rotates continuously through an angle which is opposite to that which is described by the pinion 7 when this latter is driven about its axis D as a result of the motion of its fork caused by the displacement of the point C representing the control pin 10 within the slot 11. In point of fact, said pinion 6 is coupled by means of its pivot 3 to one of the wheels 4 of the vehicle whose rotational axis is defined by the straight line EF which is parallel to the straight line DC'. The result thereby achieved is that the point F which corresponds to the center of rotation of the vehicle is deduced from the point C' by means of the same translation which causes the reference circle 12 to correspond to the base circle 13. Under these conditions, when the point C carries out a displacement along the diameter AB inside the reference circle, the point F is displaced along the diameter GH of the base circle but outside this latter between infinity and the extremities G and H. When F is at infinity, that is to say when the point C is located at the center of the reference circle 12, the corresponding wheel 4 is perpendicular to the

straight line GH. On the other hand, when the point C arrives at B, for example, the point F comes to H at the limits of the diameter GH which corresponds to the base circle.

The foregoing demonstration as applied to all the wheels of the vehicle therefore clearly shows that the arrangement contemplated herein carries out in respect of a displacement of the control pin 10 within its slot 11 inside the reference circle a displacement of the center of rotation F of the vehicle between infinity and the limits of the base circle as deduced from the reference circle by means of a given geometrical transformation.

Consideration will now be given to an extreme case in which the control pin 10 reaches the end of its slot 11, that is to say when, in FIG. 2, the point C reaches one extremity of the diameter of the reference circle at B, for example. As has already been mentioned, the point F which is the center of rotation of the vehicle and which defines the orientation of the wheels arrives at H, EH being parallel at this instant to DB. Under these conditions, the axis EH of the wheel 4 and the corresponding fork as materialized by the straight line DB are deduced from each other as a result of the same translation as that which causes the base circle 13 to correspond to the reference circle 12. Consequently, if the keying of the wheels is modified in this position so that the pinions 7 are freed and rotate freely on their swivel pins 8 whilst a second set of forks is associated with the pivotal axes of the wheels or in other words with the pivots 3 and directly couples said pivots and corresponding pinions 6 to a second control pin which is capable of displacement within the base circle along the diameter GH, it is therefore apparent that the vehicles wheels are directly driven by means of said second control pin by ensuring the convergence of all the rotational axes towards the center of rotation which, in this case, is located inside the base circle 13. The point F' illustrates in FIG. 2 the corresponding position of the center of rotation.

FIG. 3 illustrates an alternative construction which is derived directly from the construction of FIG. 2 in which the translation which causes the base circle 13 to correspond to the reference circle 12 is carried out in a direction parallel to the diameter AB of the reference circle. Under these conditions, the diameter GH of the base circle coincides with AB, which means that the slot 11 is common to the two control pins which produce the pivotal motion of the wheels according as the center of rotation is located either inside or outside the base circle or in other words is directly related to its transformed point within the reference circle or to the conjugate of this point with respect to said circle.

It should nevertheless be noted that, in these two alternative forms, the geometrical transformation which produces a transition from the base circle to the reference circle is a translation; it will be apparent that, generally speaking, another transformation and especially a similitude could be contemplated.

FIG. 4 illustrates a construction which is directly deduced from the general variant illustrated in FIG. 3. There is again shown in this FIG. a vehicle equipped with a steering control system in accordance with the invention and comprising any desired number of wheels, the axes of which are in parallel relation and disposed on a given circle or base circle. There are shown in the drawing only two wheels mounted on axle-pins 22 carried by bearing-brackets 23 each having a vertical shaft 24 which constitutes the pivotal axis of the associated wheel 21 and the angular position of which is controlled by the system in accordance with the invention. The pivotal shafts 24 of the wheels are supported by the frame 25 of the vehicle which comprises two parallel and suitably braced plates 26 and 27. Each pivotal shaft 24 is provided in the portion located between said two plates with a member 28 which forms a tenon and has two flat faces 29 which are oriented parallel to the plane defined by the pivotal shaft 24 and the axle-pin 22 of the corresponding wheel 21. At the two portion thereof, the pivotal shaft 24 passes through the plate 27 within the bore of a bushing 30 and terminates in a pinion 31. The

same arrangement as that described above is adopted in the case of all the other wheels of the vehicle. Swivel-pins 32 which are associated with each pivotal shaft 24 and parallel thereto are mounted in the upper plate 27 of the frame 25 and traverse the plate 27 through support bushings 33. These members are provided at the upper extremities thereof with pinions 34 disposed in meshing relation with the corresponding pinions 31; the pinions 31 and 34 are of identical diameter in order to produce in respect of a rotation of one pinion through any given angle in equal rotation of the other pinion but in the opposite direction. Furthermore, each swivel-pin 32 has an extension above the pinion 14 in the form of a member 35 which forms a tenon, said tenon being similar to the member 28 and having flat faces 36 oriented in a direction perpendicular to the faces 29 of said member 28. The swivel-pins 32 can be located on the plate 27 in any desired position with respect to the pivotal shafts 24 provided that said position remains the same in each pair of pinions which are associated with the different wheels 21 of the vehicle. This position is established by design and, in the example under consideration, is parallel to the position of a slot 37 which is formed through the plate 27 and provides a communication between the top and bottom faces of this latter. Provision is made within the slot 37 for a rack 38 in meshing engagement with a drive pinion 39 carried by a pin 40 which is located at right angles to the plate 27 and extends upwards, said pinion 39 being mounted within a support 41 which is guided in its movement of displacement along the slot 37 by means of flanges 42 and 43 formed at each end. Moreover, the support 41 is provided with a second pin 44 which is parallel to the pin 40 but displaced with respect to this latter in the direction of the slot 37 by a distance equal to that which exists between the axes of the pinions 31 and 34 in any given pair, that is to say to the diameter of one of these pinions. Said second pin 44 extends downwards in the opposite direction to the pin 40.

In accordance with the invention, the system comprises two sets of forks which cause the axes of rotation of the wheels to converge towards the center of rotation according as this latter is located either inside or outside the base circle as explained with reference to FIGS. 2 and 3. Depending on whether they are disposed parallel to the plane of the plate 27 within the space formed between said plate and the bottom plate 26 or above the plate 27, said forks are designated by the reference numeral 45 or 46. The forks 45 are provided with internal faces 47 which are adapted to cooperate with the faces 29 of the member 28 whilst the forks 46 are provided with internal faces 48 which are adapted to guide the faces 36 of the corresponding members 35. All the lower forks 45 are joined at one end to the pin 44. Similarly, all the upper forks 46 are coupled at the common extremity thereof to the pin 40. Finally, the forks 45 on the one hand and 46 on the other hand can be displaced simultaneously in a vertical movement by means of a clamping bracket 49 which is guided along the pins 40 and 44 and is provided with two shouldered extensions 50 and 51 for lifting the forks under the action of a tractive force exerted on an operating lever 52.

The operation of the system as thus constructed can readily be deduced from the indications which have already been given in the foregoing. When the circle of rotation is to be brought inside the base circle, that is to say the circle which passes through the pivot-pins 24 of the wheels 21, the lower forks 45 accordingly produce action by cooperating with the flat faces 29 of the members 28; all the axle-pins 22 converge towards the pin 44 which materializes the center of rotation in the plane of said axle-pins. In this case, the upper forks 46 are freed from the members 35 and do not produce any action on the pinions 34 which are only caused to follow the angular displacements of the pinions 31. On the other hand, when the center of rotation is to be brought outside the base circle, the operation is as follows: when the support 41 has been brought to one of the ends of the slot 37 or in other words to one of the extremities of the diameter of the reference circle, the clamping bracket 49 is operated in such a manner as to lower both

sets of forks at the same time. The lower forks 45 move away from the members 28 whilst the upper forks 46 engage the members 35. When the pin 40 carried by the support 41 again travels along the slot 37, the angular displacements of the pinions 34 are transmitted to the wheels 21 by means of the pinions 31, that is to say with reversal of the direction of rotation. There thus corresponds to each position of the pin 40 one position of the center of rotation or point of convergence of the axle-pins 22 of the wheels 21 which is located outside the base circle. The center of rotation therefore undergoes a displacement which is controlled at will over the full length of the straight line represented by the diameter of the reference circle as defined by the slot 37.

FIG. 5 illustrates a more highly improved alternative form of the steering control system according to the invention whereby, in addition to a displacement of the transformed point of the center of rotation or of its harmonic conjugate within a slot extending along a diameter of the reference circle, said slot can be pivoted in its plane so that the transformed point can thus be moved to any desired position within said circle.

There is again shown in this FIG. a vehicle which is equipped with a given number of wheels 61, each wheel being mounted on an axle-pin 62 supported by a bracket 63 secured to a shaft 64 which constitutes the pivotal axis of the wheel considered. By definition, all the pivotal shafts 64 of the wheels 61 are parallel and disposed in a circle which defines the base circle of the vehicle. Said pivotal shafts 64 are mounted in a frame 65 made up of two parallel spaced plates 66 and 67 which are suitably braced. In the portion located between the two plates 66 and 67, each pivotal shaft 64 is associated with two identical bevel pinions 68 and 69 which are mounted on said shaft and capable of being alternately coupled for rotation with this latter by means of a dog-coupling ring 70 which is slidably mounted but rotationally keyed on the shaft 64. Said sliding ring is provided with projections or dogs 71 which are adapted to engage in recesses having corresponding dimensions and formed in the opposite faces of the pinions 68 and 69. Positioning of the dog-coupling ring 70 along the shaft 64 in order to couple said ring to either of the two pinions considered is controlled by means of a key 73 provided with a lug 74 which is adapted to engage in a groove 75 of the dog-coupling ring 70. Said key has an extension in the form of a handle 76 so that, in certain positions of the pinions which will be defined below, the dogs 71 or 72 of said coupling ring are permitted to engage in their respective recesses of the pinions 68 or 69. Each pinion 69 is rigidly fixed at its upper extremity by means of a nut 77 to a fork-shaped member 78 having a U-shaped transverse cross section and the upper arm 79 of which is provided with a longitudinal slot 80. All the forks 78 which are thus associated by means of the pinion 68 or 69 which the pivotal shafts 64 corresponding to the different wheels of the vehicle are connected at a common point materialized by a control pin 81 which is normal to the plane of the top plate 67 of the frame 65. Said control pin 81 is mounted in a support 82 and provided at the lower end with a pinion 83 disposed in meshing relation with a rack 84 machined in a diametral slot 85 of a rotary disc 86 which is disposed parallel to the plane of the plate 67 and engaged within the interior of the U of all the forks 78. The rotary disc 86 is provided in the outer surface thereof with gear-teeth 87 meshing with an outer pinion 88 carried by a member 89 which is rigidly fixed to the frame 65 and provided with a driving pin 90 for causing the rotary disc to carry out a pivotal motion about its shaft 91. The disc shaft extends substantially to the center of the frame 65 at right angles to the plane of the plates 66 and 67 and is provided at the lower end with a spur-tooth pinion 92. Said pinion 92 is in mesh with a set of identical pinions 93 having the same diameter as the pinion 92 and mounted to rotate freely on shafts (not shown in the drawings) which are carried by the plate 66 and are equal in number to the pivotal shafts 64 and consequently to the wheels 61. Each pinion 93 is in turn adapted to mesh with a pinion 94 which is

coupled for rotation with the pivotal shaft 64 of the corresponding wheel, the diameter of said pinion 94 being double that of the pinion 92. Finally, each pinion 94 is rigidly fixed to a bracket 95 which is adapted to carry a differential planetary pinion 96. Said planetary pinion is mounted to rotate freely on its shaft and adapted to engage simultaneously with both of the pinions 68 and 69 which are associated with the corresponding pivotal shaft 64. Advantageously, the key 73 which controls the position of the dog-coupling ring 70 on the pivotal shaft 64 passes axially through the planetary pinion 96.

The operation of the system which is illustrated in FIG. 5 can be directly deduced from the operation which was explained earlier with reference to FIGS. 1 to 4. The operation involves two main steps, depending on whether the center of rotation of the vehicle is to be brought either inside or outside the base circle. In the structure which is illustrated in this FIG., it is observed that the reference circle which is materialized by the axes of the pinions 69 is deduced directly from the base circle materialized by the pinions 68 by means of a simple translation parallel to the common direction of the pivotal shafts 64, these two circles being therefore equal by design.

In the first step in which the center of rotation of the vehicle is intended to be located inside the base circle, the dog-coupling rings 70 are in the top position on their shafts 64, the dogs 72 of said rings being engaged in the corresponding recesses of the pinions 69. Under these conditions, the shafts 64 are coupled for rotation with said pinions 69 and these latter are in turn driven directly by the forks 78 which converge towards the control pin 81. At each moment, the direction of any axle-pin 62 of a wheel 61 is therefore parallel to that of the corresponding fork 78; the center of rotation thus coincides on the shaft 91 with its transformed point in the translation which causes the base circle to correspond to the reference circle. As in the example described earlier, the displacement of the control pin 81 within the slot 85 by means of the pinion 83 and the rack 84 determines under these conditions the displacement of the center of rotation along a diameter of the base circle.

In the second step, when the center of rotation is intended to correspond not to its transformed point in the reference circle but to the harmonic conjugate of said point relative to said circle, the system is controlled in the following manner: in the case of a limiting point of the operation in the first step, that is to say when the control pin 81 is located at one extremity of the diameter of the reference circle defined by the slot 85, the keys 76 are operated so as to ensure that the dog-coupling rings 70 are released from the pinions 69 and coupled to the pinions 68 by means of their projections or dogs 71 which are accordingly designed to be located opposite to the corresponding recesses. Under these conditions, the pinions 69 are released on the shafts 64 whilst these latter are accordingly coupled for rotation with the pinions 68. In consequence, the pivotal shafts 64 carry out an equal angular displacement but in the opposite direction to that of the pinions 69 which corresponds to a displacement of the control pin 81. In fact, the angular displacement of the forks 78 resulting from the displacement of the control pin 81 results in the case of each associated pinion 69 in an equal angular displacement inasmuch as the fork 78 is coupled to said pinion 69 by means of the nut 77. The rotation of said pinion 69 is then transmitted by means of the planetary pinion 96 which is positionally fixed to the pinion 68 by reversing the direction of angular displacement. As a result, the displacements of the control pin 81 within the slot 85, that is to say inside the reference circle, determine in the case of the center of rotation of the vehicle corresponding displacements outside the base circle between infinity and the limits of said circle as defined by the extremities of the corresponding diameter of the slot 85.

This mode of operation is therefore identical with the operation which was explained in connection with the first embodiment, the only difference being a mechanical variant in the method of keying the pivotal shafts and the pinions which control their angular displacements. However, the al-

ternative form which is illustrated in FIG. 5 also makes it possible to vary the position of the slot 85 or in other words, on the reference circle, to modify the orientation of the diameter along which the transformed point of the center of rotation effects a displacement.

In point of fact, it has been noted that in the case of a position of the control pin 81 at one of the limits of its slot 85, the corresponding orientation of the axle-pins 62 of the wheels is such that said axle-pins are parallel to the associated forks 78. Under these conditions, the rotary disc 86 in which is formed the slot 85 can be caused to pivot about its shaft 91 in particular by means of the pinion 88 and driving pin 90 without modifying this orientation, that is to say without subjecting the drive pinions 68 and 69 to a relative movement with respect to their pivotal shaft 64. To this end, the pinions 92, 93 and 94 are so designed that they retain a parallel relation between the axle-pins 62 and the forks 78 during the rotation of the disc 86 irrespective of the orientation of the slot 85. This means that, in the case of a rotation of the slot about its axis through any angle α , the planetary pinions 96 which are each associated with the pivotal shafts 64 rotate about their own axes through an angle equal to $\alpha/2$. This is readily apparent if reference is made to FIG. 6 in which the circle 100 designates the reference circle, the straight line I J designates the diameter of said circle corresponding to the slot 85 and K designates the position of any one pivotal shaft 64; KJ represents in the case of a limiting position of the fork-control pin the direction of the axis of the associated wheel. When the diameter IJ pivots about the center O of the circle through any angle α so as to come to I' J', it is apparent that, in order that the wheel should retain its orientation, KJ must move to K'J'. In point of fact, this makes it necessary for $\angle JKJ'$ to be equal to $\alpha/2$, which is in fact realized on the circle 100.

Referring again to FIG. 5, it is seen that the rotation of the slot 85 results in a rotational movement of the pinion 92 through the angle α which corresponds to an angular displacement of the pinion 93 which is equal but of opposite direction and in an angular displacement in the same direction but through a half-angle in the case of the pinion 94 which is secured to the pivotal shaft 64. This movement of rotation of the pinion 94 is transmitted to the planetary pinion 96 which performs a pivotal movement about the pinions 68 and 69 without thereby causing any relative motion of these latter. In consequence, the operation of the assembly as a whole is retained without any modification in the position of said pinions. It will naturally be understood that the demonstration described above and contemplated in the particular case in which the control pin 81 is located at one end of its slot 85 could be repeated in the same manner in any position of said control pin.

FIG. 7 illustrates another alternative construction of the invention which is similar to the embodiment of FIG. 1 but in which the transmission of the angular displacements of the forks for producing the convergence of the pivotal axes of the wheel towards the transformed point of the circle of rotation or towards the harmonic conjugate thereof relative to the reference circle is no longer obtained by means of a mechanical coupling system of the pinion type but is carried out by means of a potentiometer control system. This arrangement according to the invention is more especially, although not solely, applicable to the case in which the forces to be developed in order to turn the wheels cannot be obtained by means of simple forks, the mechanical strength of which might prove inadequate. The arrangement referred to also makes it possible to coordinate the orientation of the wheels from a distance, the position of each pivotal shaft associated with any wheel being controlled by means of an independent electric motor which is directly coupled to said shaft. In this FIG., the frame 110 which is illustrated comprises a plurality of wheels 111 (four in number in the example) which are assumed to be driving and steerable wheels and mounted on axle-pins 112, said axle-pins being in turn supported by pivots 113 about which the wheel orientation control is effected. The frame 110

is associated with a coordination plate 114 which can be completely separate from said frame and placed in particular at a distance from this latter, circular control potentiometers which are associated with the wheels of the vehicle being mounted on said plate 114. Only two of these potentiometers 115 and 116 have been shown in the drawings for the sake of greater simplicity, it being understood that the plate 114 in fact supports a number of potentiometers corresponding to the number of wheels, each pivot 113 being additionally associated on the frame 110 with a potentiometer for duplicating the control potentiometer of the coordination plate. In this FIG., the potentiometers 115 and 116 thus correspond respectively to two potentiometers 117 and 118 mounted on the shafts 119 and 120 of two motors 121 and 122 which are directly coupled with the pivots 113 of the corresponding wheels 111.

The diagram of FIG. 8 which again shows side by side the frame 110 of the vehicle and the control plate 114 with the control potentiometers 115 and 116 on the one hand and 117 and 118 on the other hand serves to explain the operation of the device in the embodiment under consideration, this operation being naturally based on the same general arrangements which were explained in connection with the alternative mechanical control systems described earlier.

By definition, the axes of the pivots 113 of the vehicle wheels are all parallel and disposed at intervals in a circle which defines the base circle of the vehicle. Similarly, the control potentiometers on the plate 114 are uniformly spaced in a circle which constitutes the reference circle as deduced from the base circle by means of any perfectly defined geometrical transformation. The sliding contacts 123 and 124 of the control potentiometers 115 and 116 are connected by forks or any like means 125 and 126 to a control pin 127 which is displaceable along a diameter 128, 129 of the reference circle. Said potentiometers are supplied with a direct-current voltage having polarities which are suitably distributed at the terminals of said potentiometers, the voltage collected at the sliding contacts being returned to the associated duplicating potentiometers, that is to say towards the potentiometers 117 and 118 in the case considered. If said potentiometers are connected in such a manner as to conform to the polarities of the control potentiometers, it is apparent that the displacement of the control pin 127 on the plate 114 within the limits of the diameter 128 and 129 carries out by means of followup control a similar displacement of the point 130 towards which the sliding contacts 131 and 132 of the duplicating potentiometers converge on the diameter 133, 134 of the base circle in parallel relation to the sliding contacts 123 and 124. In respect of a displacement of the center of rotation inside the base circle, its transformed point 127 inside the reference circle is thus caused to correspond to said center of rotation in a manner which is exactly similar to that contemplated in the proceeding variants.

Finally, FIG. 9 shows the manner in which electric switching is carried out in this case at the limits of the reference circle so as to cause the center of rotation within the base circle to correspond not to its transformed point within the reference circle but to its harmonic conjugate with respect to said circle.

In order to pass beyond the limiting points of the reference circle, use is made of duplicating potentiometer 118 having two diametrically opposite sliding contacts 132 and 132a. Only one of the two sliding contacts will be employed, namely the particular contact which is located within the useful zone of said potentiometer, that is to say at an angular distance of 90° on each side of the zero voltage point.

Under these conditions, the manner in which the center of rotation oversteps first the limiting point 133, then the limiting point 134 will now be usefully considered. When the control pin 127 coincides with the limiting point 128, the sliding contact 124 of the potentiometer 116 produces action on the contact 135 which accordingly energizes the relay 136. This relay then reverses the voltage at the terminal of the potentiometer 116 opposite to the point 129, for example +12 V to -12 V. In

consequence, when the control pin 127 again passes along the diameter 128—129 but in the opposite direction, the sliding contact 132 of the duplicating potentiometer oversteps the limiting point which corresponds to the extremity 133 of the diameter of the base circle and continues to travel in the same direction while displacing the center of rotation 130 outside the base circle and no longer inside this latter.

Similarly, when the center of rotation passes beyond the point 134, the control pin 127 coincides with the point 129 and produces action on the contact 137 which accordingly energizes a relay 138. This relay 138 has the effect on the one hand of causing the supply voltage at the terminal of the potentiometer 116 located opposite to the point 129 to change over from ± 12 V to -12 V and on the other hand of replacing the sliding contact 132 of the potentiometer 118 by a sliding contact 132a which is diametrically opposite to the same potentiometer 118. When the control pin 127 moves again in the opposite direction, the sliding contact 132—132a of the duplicating potentiometer oversteps the limiting point which corresponds to the extremity 134 of the diameter of the base circle. The geometrical transformation which is thus carried out permits of continuous and unlimited displacement of the center of rotation.

It will be readily understood that the invention is not limited solely to the examples herein described with reference to the accompanying drawings but extends to all alternative forms. In particular, in the case of the embodiment last considered, it is possible to set the diameter of the reference circle on which the control pin is displaced in a number of different positions and especially in two perpendicular directions. In this case, the duplicating potentiometers can be associated alternately with two sets of control potentiometers which are respectively located with respect to these directions. Moreover, it has been assumed in all cases that the pivotal shafts of the wheels were all parallel to each other; it would also be possible to contemplate the more general case of nonparallel shafts which would in that case be coupled by means of universal joint transmission systems or the like to intermediate shafts which would have the function of maintaining the necessary parallel relation.

We claim:

1. Method for controlling the steering of the wheels of a vehicle in which the pivot axes of the wheels intersect a base plane at the vertices of a base polygon inscribed within a base circle, the base plane being parallel to a plane passing through the axes of rotation of the wheels and corresponding to a reference circle in a reference plane by a geometrical transformation, the steps of continuously converging the rotational axes of the wheels towards a common point and center of rotation of the vehicle lying on the axis of rotation of the vehicle, and maintaining the axis of rotation of the vehicle to intersect the base plane at a base point, related selectively to a transformed point in the reference circle related thereto by said geometrical transformation and to the conjugate of the transformed point with reference to the reference circle.

2. Method in accordance with claim 1, wherein said transformed point is displaceable along a straight line in the reference plane.

3. Method in accordance with claim 2, wherein said straight line is pivotable about a point in said reference plane for continuously varying the position of the transformed point in the reference plane.

4. Apparatus for controlling the steering of the wheels of a vehicle in which the pivot axes of the wheels intersect a base plane at the vertices of a base polygon inscribed within a base circle, the base plane being parallel to a plane passing through the axes of rotation of the wheels and corresponding to a reference circle in a reference plane by a geometrical transformation, comprising means for causing the rotational axes of the wheels to continuously converge towards a common point and center of rotation of the vehicle lying on the axis of rotation of the vehicle, the axis of rotation of the vehicle intersecting the base plane at a base point related alternatively to a

transformed point in the reference circle related thereto by said geometrical transformation or to the conjugate of the transformed point with reference to said reference circle, said means including a first set of bifurcated members pivotally mounted at the vertices of a reference polygon corresponding by said geometrical transformation to said base polygon, said members engaging a control pin, said pin intersecting said reference plane at said transformed point and being movable along a first linear guide slot in said reference plane.

5. Apparatus in accordance with claim 4, including a second set of bifurcated members pivotally mounted at the vertices of said base polygon, engaging a second control pin intersecting said base plane at said base point and movable along a second linear guide slot in said base plane.

6. Apparatus in accordance with claim 5, including a control plate, said first and second guide slots being formed in said plate, first pinions, swivel pins for said first pinions extending parallel to the pivot axes of the wheels mounted on said control plate and positioned with their center at the vertices of said base polygon, said first set of bifurcated members engaging said swivel pins and extending parallel to the plane of said control plate, second pinions having the same diameter as said first pinions rigidly fixed to pivotal shafts for the wheels of the vehicle positioned with their centers at the vertices of said reference polygon and connected with said first pinions, said second set of bifurcated members engaging said pivotal shafts, said reference circle being deduced by translation of said base circle in the direction of a line joining said pivotal shafts to the axes of the associated swivel pins and the amplitude of the translation being equal to the distance between the centers of associated ones of said first and said second pinions.

7. Apparatus in accordance with claim 6, wherein said reference plane is in the plane of said base plane and associated ones of said first and said second pinions are in meshing relation.

8. Apparatus in accordance with claim 6, wherein the said line is parallel to said first slot and said first slot coincides with said second slot.

9. Apparatus in accordance with claim 6, said bifurcated members of said first and said second sets being parallel and disposed, respectively, on each side of said control plate.

10. Apparatus in accordance with claim 4, including a control plate, said first guide slot being formed in said plate, first and second pinions carried by pivotal shafts for the vehicle wheels, said shafts being positioned with their centers at the vertices of said reference and said base polygons respectively and alternatively engageable with said pivotal shafts, said first set of bifurcated members being mounted on said first pinions, a planetary pinion coupling associated ones of said first and said second pinions the diameter of said planetary pinion defining the amplitude of translation in the direction of said pivotal shafts, a set of third identical pinions coupled with said pivotal shafts and in meshing relation through bevel pinions with a fourth pinion, a shaft for said fourth pinion parallel to said pivotal shafts and supporting said control plate, the diameter of said fourth pinion being equal to the diameter of said bevel pinions and to one-half the diameter of said third pinions.

11. Apparatus for controlling the steering of the wheels of a vehicle in which the pivot axes of the wheels intersect a base plane at the vertices of a base polygon inscribed within a base circle, the base plane being parallel to a plane passing through the axes of rotation of the wheels and corresponding to a reference circle in a reference plane by a geometrical transformation, comprising means for causing the rotational axes of the wheels to continuously converge towards a common point and center of rotation of the vehicle lying on the axis of rotation of the vehicle, the axis of rotation of the vehicle intersecting the base plane at a base point related alternatively to a transformed point in said reference circle related thereto by said geometrical transformation or to the conjugate of the transformed point with reference to said reference circle, said means including a control plate, a set of circular electric

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potentiometers on said plate disposed on said reference circle at the vertices of a reference polygon corresponding respectively to said base circle and said base polygon by a similitude, sliding contacts for said potentiometers, radially extending members carrying said contacts converging towards a common control pin, said pin being movable along a diameter of said reference circle, pivotal shafts for the wheels, individual motors rotating said shafts, duplicating potentiometers associated with said potentiometers on said control plate, sliding contacts for said duplicating potentiometers and circuit means supplying said motors as a function of the positions of said

last-named sliding contacts.

12. Apparatus in accordance with claim 11, including relays on said control plate at the extremities of the diameter of said reference circle along which said control pin is movable for reversing the directions of polarity of said duplicating potentiometers and for providing alternative correspondence between said center of rotation and its transformed point and the conjugate of the transformed point relative to said reference circle.

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