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B62D 5/04

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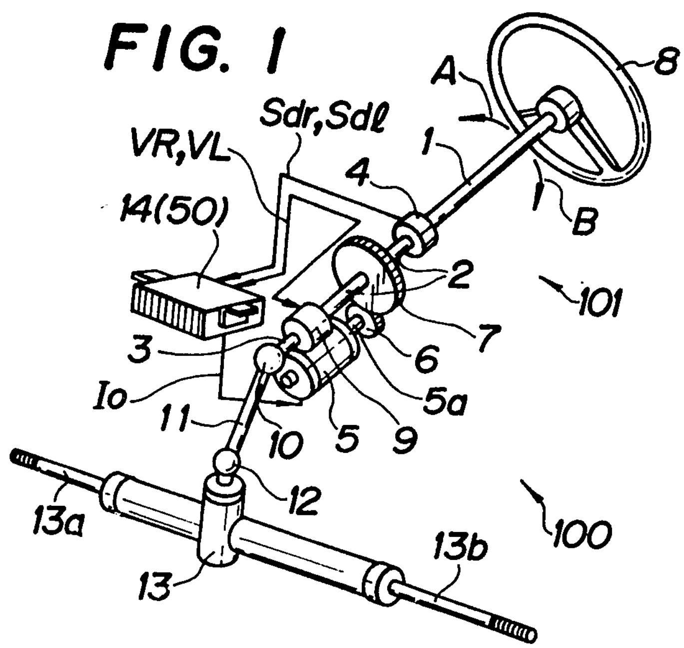
US 2754465

(58) Field of search
B7H

(54) Electric power steering system for vehicles

(57) In an electric power steering system for a vehicle, the steering shaft (101) comprises a first shaft (1) connected to the steering wheel (8), a second shaft (2) interconnected, *via* a torsion bar, with the first shaft (1), and a third shaft (3) as the output shaft (3) interconnected, *via* another torsion bar, with the second shaft (2), and the torque detecting mechanism (4, 9) comprises a torque direction detecting mechanism (4) interposed between the first shaft (1) and the second shaft (2), and a torque magnitude detecting mechanism (9) interposed between the second shaft (2) and the third shaft (3). The signals from the detecting mechanisms (4, 9) are supplied to a control circuit (50) controlling energisation of an electric power assistance motor (5) drivingly coupled to the shaft (2). As alternatives, the motor (5) may be drivingly coupled to the third shaft (3) or an intermediate shaft (11).

FIG. 1



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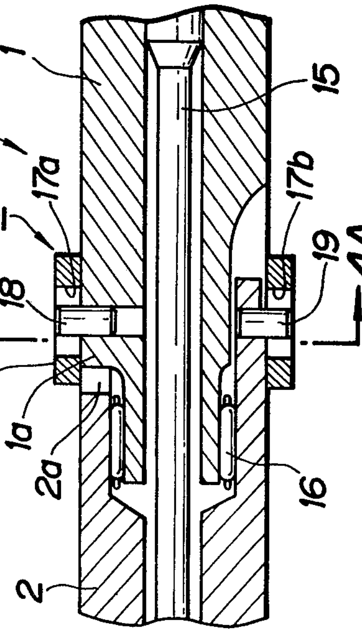


FIG. 3

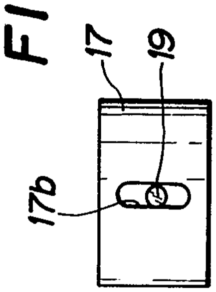


FIG. 4B

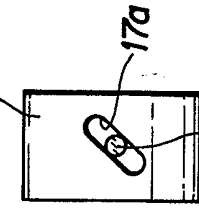


FIG. 4C

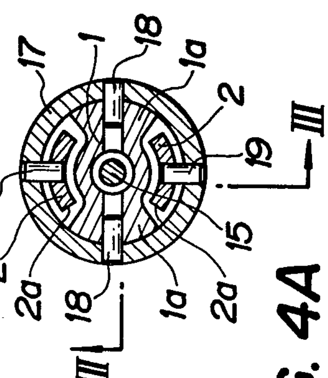


FIG. 4A

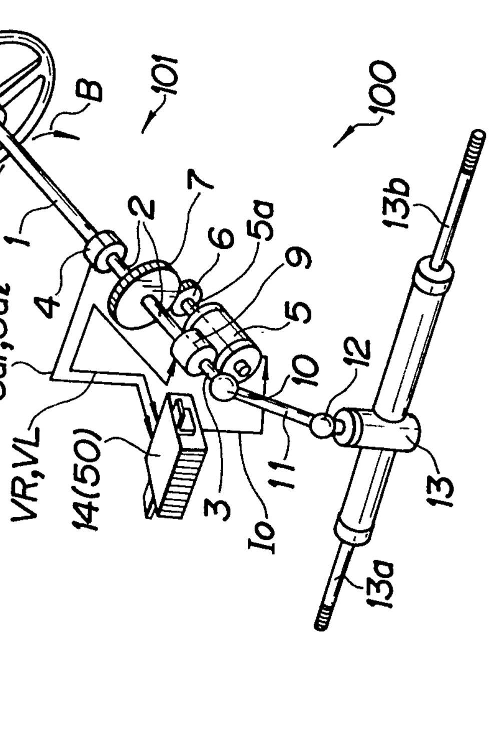


FIG. 1

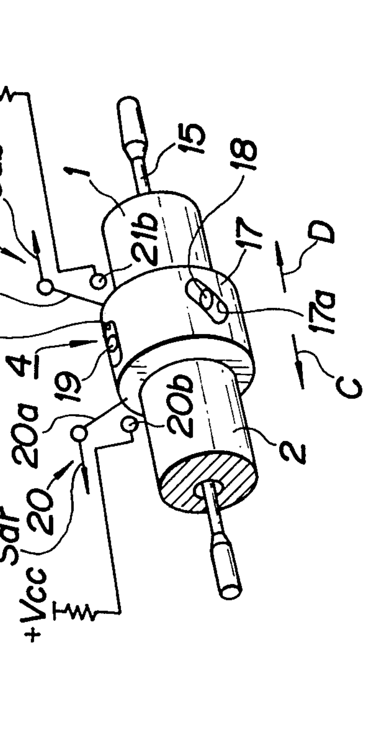
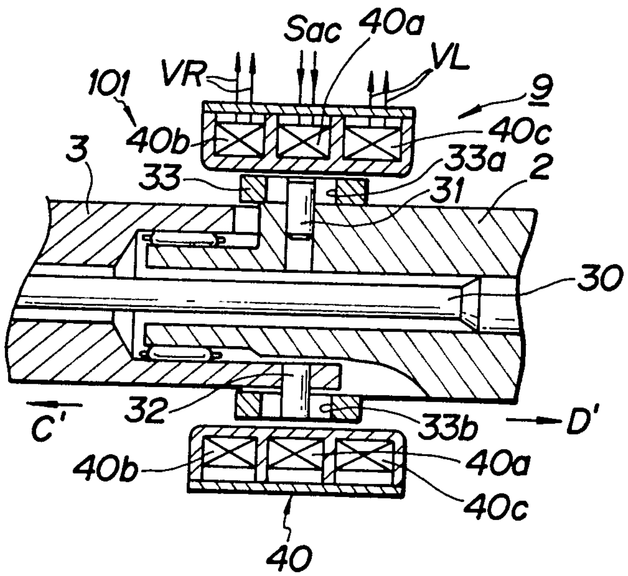


FIG. 2

FIG. 5



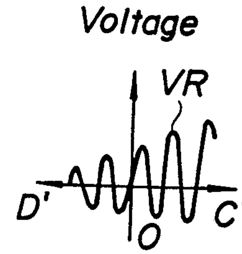


FIG. 7A-1

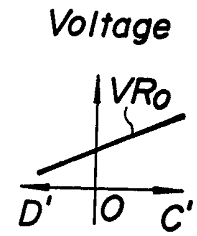


FIG. 7A-2

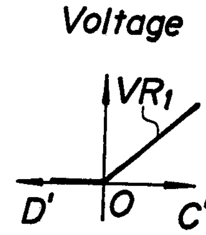


FIG. 7A-3

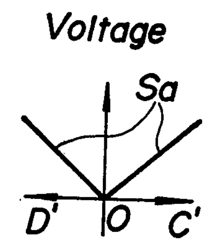


FIG. 7A-4

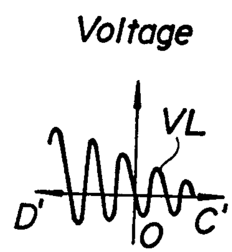


FIG. 7B-1

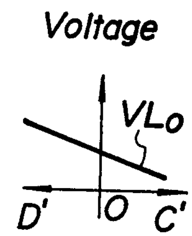


FIG. 7B-2

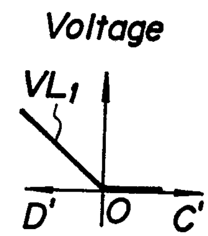


FIG. 7B-3

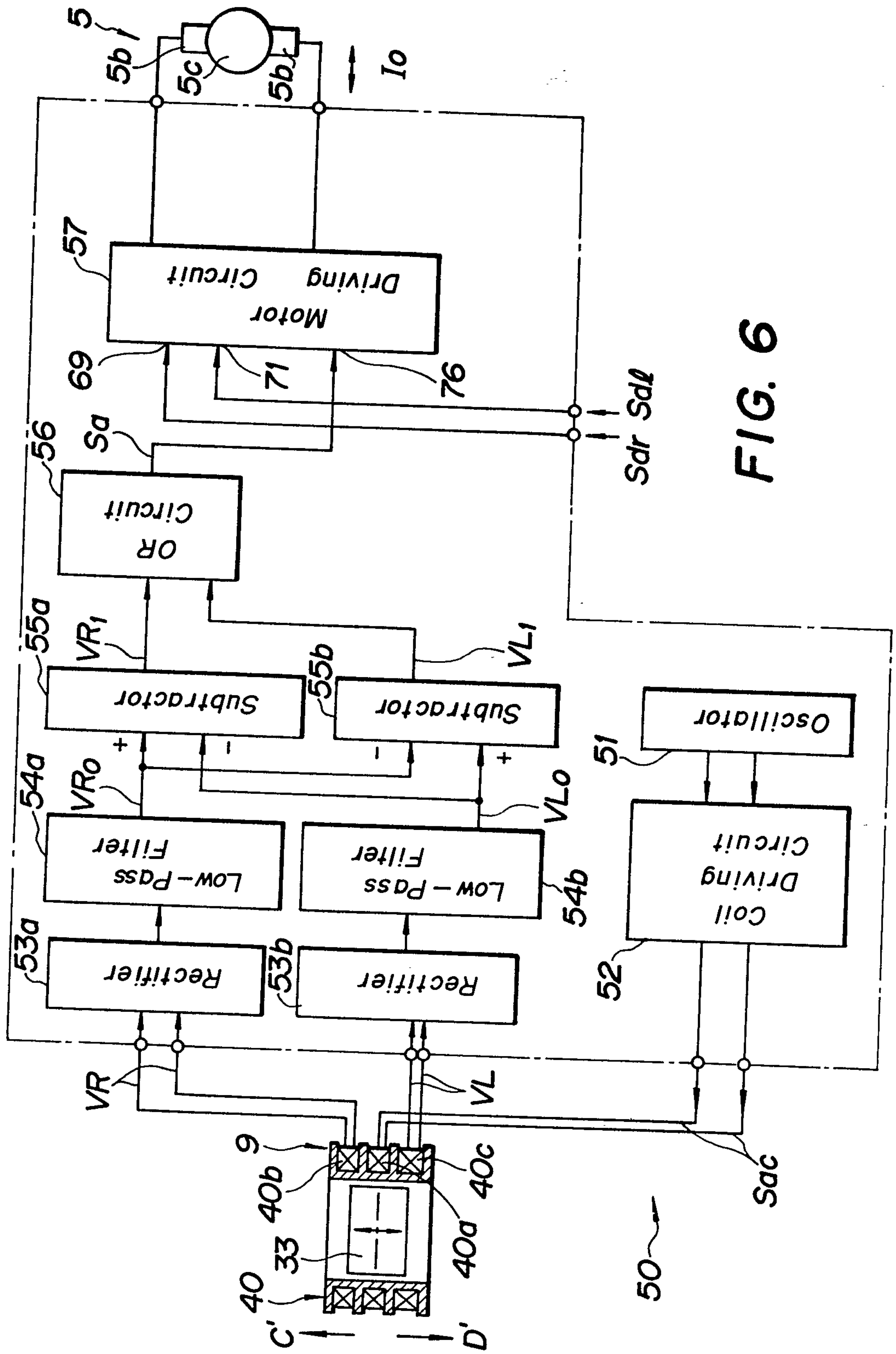
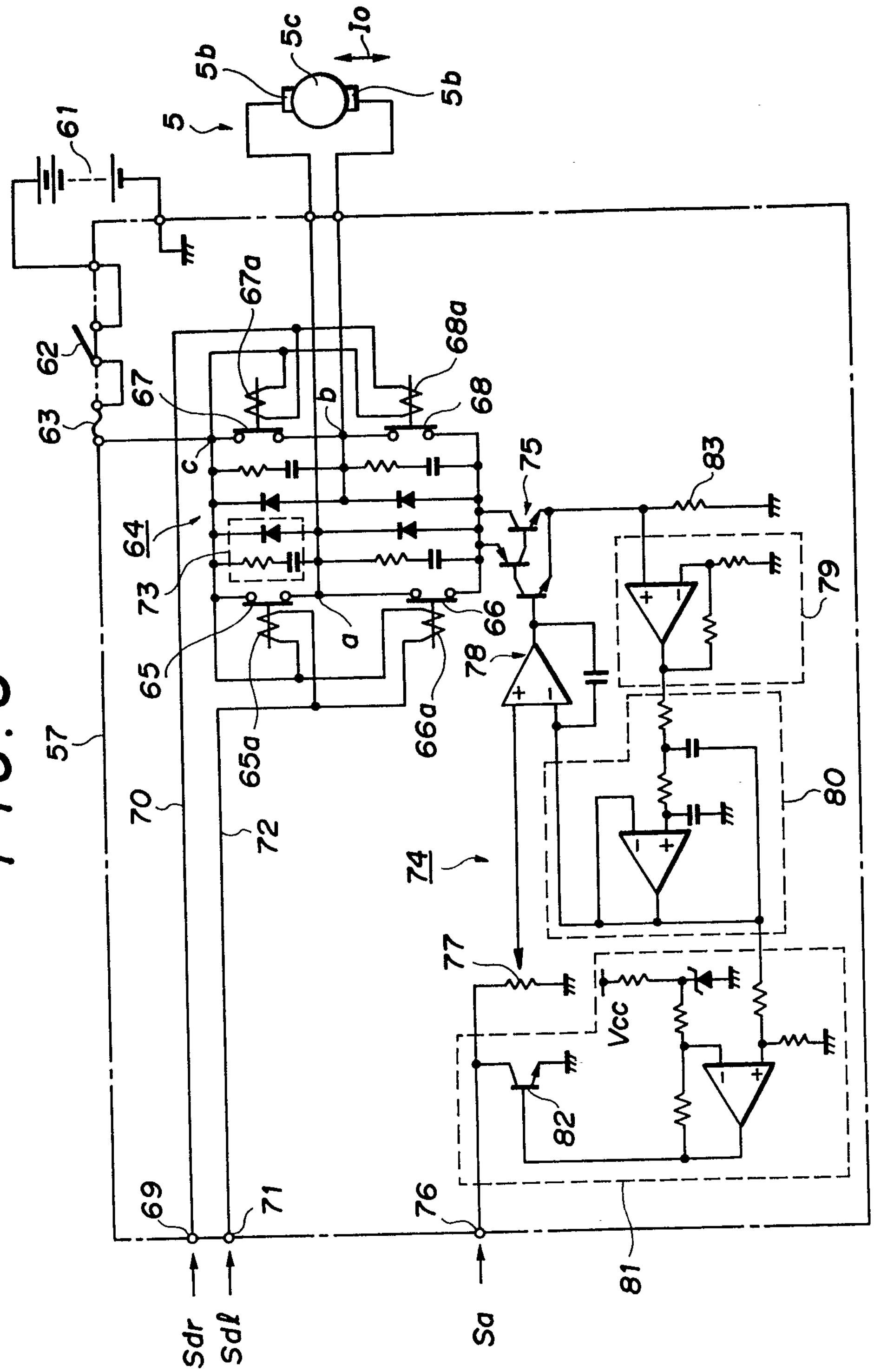

Motor Driving Circuit
OR Circuit
Subtractor
Subtractor
Oscillator
Low-Pass Filter
Low-Pass Filter
Coil Driving Circuit
Rectifier
Rectifier
Io
Sa
Sdr
Sdℓ
VR₁
VL₁
VRo
VLo
VR
VL
Sac
5
5b
5c
9
33
40
40a
40b
40c
50
51
52
53a
53b
54a
54b
55a
55b
56
57
69
71
76
C'
D'

FIG. 6

FIG. 8


5c
5b
5b
Io
5
61
62
63
67
67a
68
68a
b
c
64
73
a
65
65a
66
66a
75
83
79
78
80
74
77
Vcc
82
81
57
70
72
69
71
76
Sdr
Sdl
Sa

SPECIFICATION

Electric power steering system for vehicles

The present invention generally relates to a steering system for vehicles. More particularly, the invention relates to an electric power steering system for vehicles.

In view of problems in hydraulic type power steering systems for vehicles, such as that the structure thereof was complicated, in recent years a variety of electric type power steering systems for vehicles have been proposed.

Those electric type power steering systems were all of a type including an input shaft as a steering shaft connected to a steering wheel, an output shaft interconnected with the input shaft and, through a steering gear mechanism of a desired type, with a tie rod of a road wheel to be steered, an electric motor for supplying the output shaft with auxiliary torque, a torque detection mechanism for detecting the magnitude as well as the direction of steering torque acting on the input shaft, and a driving control circuit for feeding the electric motor with an armature current of such a magnitude and in such a direction as necessary in accordance with a detection signal from the torque detection mechanism.

In the power steering systems of such type, when the steering wheel was operated for steering, the output shaft was supplied with adequate auxiliary torque, thereby facilitating the steering operation.

As examples of such electric power steering systems for vehicles, there was one disclosed by Japanese Patent Application Lay-Open Print No. 59-70257 (laid open on April 20, 1984), and another by Japanese Patent Application Lay-Open print No. 59-227560 (laid open on December 20, 1984).

In the electric power steering system according to the former Lay-Open Print, the steering gear mechanism was of a rack and pinion type and the torque detection mechanism was constituted with a strain gauge sensor disposed on the input shaft. This power steering system produced, based on an output signal from the strain gauge sensor, a torque direction signal and a torque magnitude signal representing the direction in which the steering torque was acting on the input shaft and the magnitude of this steering torque, respectively, and sent, in accordance with these torque representative signals, the armature current of the required magnitude and in the required direction to the electric motor to thereby supply the output shaft with adequate auxiliary torque.

In the electric power steering system according to the latter Lay-Open Print, the steering gear mechanism was of a worm shaft and ball nut type. The input shaft was interconnected through a torsion bar with the output shaft, while the torque detection mechanism was constituted with a sliding resistance member secured to the input shaft and a contact piece secured to the output shaft, the contact piece being put in slidable contact with the sliding resistance member. Also this power steering system produced, based on an output signal from the sliding-resistance type torque detection mechanism, a torque direction signal and a torque magnitude signal, and sent, in accordance with these torque representative signals, the armature current to the electric motor, like the steering system according to the former Lay-Open Print.

In this respect, in both examples according to the aforesaid Japanese Patent Application Lay-Open Prints, the torque direction signal and the torque magnitude signal were produced to be based on the output signal from the torque detection mechanism, that is, a pair of torque representative signals were generated in accordance with a detection signal from a single signal source.

Incidentally, in general, in a vehicle having typically in the front part thereof a ground wheel to be steered, when changing the direction of travel while the vehicle is travelling in a straight line, the front wheel is turned in either direction from a neutral position thereof by operating a steering wheel, thereby entering a turning travel.

In such turning travel, based on wheel alignment of the front wheel as well as self-aligning torque due to deformations of a tyre thereof, righting moment is acting on the front wheel, with a tendency to return the front wheel to the neutral position.

In the case where the steering system of such vehicle is of an ordinary type having no auxiliary torque supplied thereto, therefore, as the strength of steering forces applied to the steering wheel by the driver's hands is gradually reduced substantially to zero while the vehicle is in the turning travel, the front wheel is caused to move with the righting moment so as to gradually approach, finally returning to, the neutral position. Just when the front wheel is righted to the neutral position, the vehicle again enters a straight forward travelling state thereof.

Such transition of travelling state is frequently experienced when turning at corners with a vehicle equipped with an ordinary type steering system.

On the other hand, when assuming that the vehicle be equipped with either of the electric power steering systems according to the aforesaid Japanese Patent Application Lay-Open Prints, there would be found the possibility of experiencing such a problem as described below when returning from a turning state to a straight travel.

Description will now be made of an exemplary case in which this vehicle returns from a rightwardly turning state thereof to straight travel.

In the rightwardly turning state of the vehicle, the steering wheel has steering forces applied thereto through the driver's hands with a tendency to produce clockwise rotation thereof. Under such condition, as the strength of the steering forces is reduced substantially to zero in a relatively short while by gradually releasing or lightly holding the steering wheel, the front wheel tends to return to the neutral position within a relatively short time, by the effect of righting moment acting on the rightwardly turned front wheel, with a tendency to turn same to the left or in the counterclockwise direction when viewed from above, that is, from the side of the driver. Concurrently, however, the output shaft of the power steering system, to which the righting moment is transmitted in the form of counterclockwise torque, is caused to quickly rotate counterclockwise. Such counterclockwise rotation of the output shaft corresponds to a clockwise rotation of the input shaft relative to the output shaft, so that the torque detection mechanism detects false steering torque acting clockwise about the input shaft. Accordingly, to the output shaft is supplied clockwise auxiliary torque of a certain magnitude from the electric motor, thus causing the front wheel to be slightly turned to the right, resulting in a delay of the front wheel as well as of the steering wheel in the returning action to the neutral position.

Such problem results from the constitution of the electric power steering systems according to the aforesaid Japanese Patent Application Lay-Open Prints in which both the torque direction signal and the torque magnitude signal were produced in accordance with the detection signal from one torque detection mechanism.

The present invention has been achieved to effectively solve such problems of conventional electric power steering systems for vehicles.

According to the present invention, there is provided an electric power steering system for a vehicle with a ground wheel to be steered, including a steering wheel, a steering shaft connected to the steering wheel an output shaft operatively interconnected with the ground wheel, an electric motor for operatively supplying the output shaft with auxiliary torque, a torque detecting means for detecting the direction and the magnitude of steering torque acting on the steering shaft, and a driving control circuit for generating a torque direction signal and a torque magnitude signal based on output signals from the torque detecting means, to feed the electric motor with an armature current in such a direction and of such a magnitude as desirous in accordance with both the torque direction signal and the torque magnitude signal, wherein the steering shaft comprises a first shaft connected to the steering wheel, a second shaft operatively interconnected with the first shaft and a third shaft as the output shaft operatively interconnected with the second shaft, and wherein the torque detecting means comprises a torque direction detecting mechanism interposed between the first shaft and the second shaft and adapted to detect the direction of said steering torque as acting on the steering shaft, and a torque magnitude detecting mechanism interposed between the second shaft and the third shaft and adapted to detect the magnitude of the steering torque as acting on the steering shaft.

Accordingly, an object of the present invention is to provide an electric power steering system for a vehicle with a steered ground wheel that may well be a front wheel thereof, which system permits, while the vehicle returns from a turning state to straight travel thereof, the ground wheel as well as a steering wheel in the system to return to the neutral position in a smooth and rapid manner even when the strength of steering forces, as they are applied to the steering wheel, is reduced substantially to zero in a relatively short while by or sometimes without releasing the steering wheel.

The above and further features, objects and advantages of the present invention will more fully appear from the following detailed description of a preferred embodiment of the invention when the same is read in conjunction with the accompanying drawings.

In the drawings:

Fig. 1 is a perspective view of an electric power steering system for vehicles according to a preferred embodiment of the present invention;

Fig. 2 is an enlarged perspective view of a torque direction detecting mechanism in the power steering system of Fig. 1;

Fig. 3 is an enlarged partial view of a quarter cutaway longitudinal section, about the axis of a steering shaft, of the torque direction detecting mechanism of Fig. 2;

Fig. 4A is a sectional view of an essential part of the torque direction detecting mechanism, taken along line 4A -4A of Fig. 3;

Figs. 4B and 4C are plan and side views of a torque direction detecting tubular member in the detecting mechanism of Fig. 4A, respectively;

Fig. 5 is an enlarged view of a quarter-cutaway longitudinal section, about the axis of the steering shaft, of a torque magnitude detecting mechanism in the power steering system of Fig. 1;

Fig. 6 is a block diagram of a driving control circuit in the power steering system of Fig. 1; Figs. 7A-1 to 7A-4 as well as Figs. 7B-1 to 7B-3 are graphs showing output characteristic curves of various circuitries of the driving control circuit of Fig. 6; and

Fig. 8 is a circuit diagram of an electric motor driving circuit in the driving control circuit of Fig. 6.

With reference to Fig. 1, designated at reference numeral 100 is the entirety of an electric power steering system according to a preferred embodiment of the present invention, as it is applied to a vehicle having a pair of ground wheels as left and right front wheels thereof to be steered.

The power steering system 100 includes a steering shaft 101, which comprises a first shaft 1 provided with a steering wheel 8 fixed to the upper end thereof, a second shaft 2 interconnected through a later-described torsion bar with the lower end of the first shaft 1, and a third shaft 3 interconnected with the second shaft 2 through another torsion bar described later. Between the first shaft 1 and the second shaft 2 is interposed a direction detecting mechanism 4 for detecting the direction of steering torque as acting on the steering shaft 101, and between the second shaft 2 and the third shaft 3, a magnitude detecting mechanism 9 for detecting the magnitude of the steering torque.

The second shaft 2 has fixed on the intermediate part thereof a large-diameter gear 7 meshing with a smalldiameter gear 6 which is fixed on a rotating output shaft 5a of an electric motor 5 controlled of the driving thereof in a later described manner. When the motor 5 is energized to start rotation, electromagnetic torque thereby developed is transmitted, while being reduced in the speed of rotation, as assist power through the gears 6, 7 to the second shaft 2, that is, corresponding auxiliary torque is supplied to the steering shaft 101.

The third shaft 3 is further interconnected, by means of a universal joint 10, with an intermediate shaft 11, which in turn is connected through another universal joint 12 to a pinion (not shown) assembled in a steering gearbox 13 of a rack and pinion type. The steering gearbox 13 has transversely projected therefrom left and right output portions 13a, 13b of the rack interconnected through a tie rod to a pair of knuckle arms (not shown) provided for the left and right front wheels, respectively.

In Fig. 1, designated at reference numeral 14 is a control circuit box for accommodating therein a later-described driving control circuit 50, which is fed with detection signals Sdr, Sdl and VR, VL output from the direction detecting mechanism 4 and the magnitude detecting mechanism 9 of the steering torque acting on the input shaft 101, respectively. The detection signals Sdr, Sdl and VR, VL are processed in the control circuit 50 in a later-described manner to obtain an armature current Io to be sent as a driving control signal to the electric motor 5.

Fig. 2 is an enlarged perspective view of the torque direction detecting mechanism 4, including the torsion bar coaxially interconnecting the first and the second shafts 1, 2 with each other, the torsion bar being designated by reference numeral 15. Further, as shown in Fig. 3, which is a longitudinal sectional view of an essential part of the mechanism 4, the first and the second shafts 1, 2 rotatably supported at respective vehicle body sides thereof are fitted in, to be coupled with, each other in such a manner that the first shaft 1 has, in the lower end part thereof, an axially projected end portion rotatably fitted through a needle bearing 16 in an axial opening in the opposed end face of the second shaft 2, while the circumferential part of this opening is formed with a pair of radially cut portions 2a, 2a having projected therein a pair of radially outwardly stepped arm-like portions 1a, 1a of the lower end part of the first shaft 1. Around such mutually fitted parts of the first and the second shafts 1, 2 is fitted an axially slidable tubular member 17 made of an electrically nonconductive material. The tubular member 17 has a pair of sets of elongate holes 17a, 17b radially cut therethrough to be symmetrical to each other with respect to the axis of the steering shaft 101, as shown in Figs. 4A to 4C, one set of elongate holes 17a being formed at the left and right sides of the shaft 101 and inclined in the side view relative to the axis thereof, the other set of elongate holes 17b being formed at the top and bottom sides of the shaft 101 so as to be parallel with the axis thereof. In each of the inclined holes 17a is inserted one of a pair of radial pins 18, 18 fixed to the first shaft 1, and in each of the parallel holes 17b, one of a pair of radial pins 19, 19 fixed to the second shaft 2.

According to the foregoing arrangement, when the first shaft 1 is forced, with steering torque applied to the steering wheel 8, to rotate in the clockwise direction A or counterclockwise direction B in Fig. 1, the steering torque is transmitted through the torsion bar 15 to the second shaft 2. Concurrently, however, due to load imposed on the second shaft 2 from the side of the steering gear box 13, there is developed a phase difference or relative angular displacement between the first and the second shafts 1, 2, causing the tubular member 17, which is engaged at the elongate holes 17a, 17b thereof with the radial pins 18, 19 as described, to move in the axial direction of the steering shaft 101. In other words, as the first shaft 1 is forced to rotate clockwise or counterclockwise relative to the second shaft 2, developing a relative angular displacement therebetween, the tubular member 17 is caused to axially move in the direction C or D in Fig. 2.

In this respect, under the condition that no steering torque is applied to the first shaft 1, the tubular member 17 is set to be held at an original position thereof, that is, at a predetermined axial position on the steering shaft 101, while the radial pins 18, 19 are located at the longitudinally central parts of the elongate holes 17a, 17b of the member 17, respectively.

At both axial ends of the tubular member 17, there are provided a pair of limit switches 20, 21 having a pair of switch-operating elements 20a, 21a adapted to be actuated in accordance with axial movements of the member 17 in such a manner that, when the member 17 is caused to move in the direction C or D till it exceeds an axial limit thereof at a predetermined distance from the original position, the switch 20 or 21 is operated to become closed, whereby the direction of the steering torque acting on the first shaft 1 is detected.

The aforementioned detection signals Sdr, Sdl are given in accordance with open-close actions of the switches 20, 21, to be fed to the driving control circuit 50. More particularly, of the detection signals Sdr, Sdl, one Sdr that is responsible for the detection of clockwise torque is output from the switch 20 and has a signal state thereof determined to be alternatively "on" or "off", such that, when the first shaft 1 has relative to the second shaft 2 an angular displacement developed larger than a predetermined phase difference with clockwise steering torque applied to the steering wheel 8, thereby causing the tubular member 17 to move beyond the axial limit in the direction C, then the torque direction signal Sdr becomes "on", while otherwise this signal Sdr remains "off". Likewise, the other Sdl, that is responsible for the detection of counterclockwise torque and output from the switch 21, has a signal state thereof determined to be alternatively "on" or "off", such that, contrary to the above signal Sdr, when the tubular member 17 is caused to move beyond the axial limit in the direction D, then the torque direction signal Sdl becomes "on", while otherwise this signal Sdl remains "off".

Description will now be made of the constitution of the torque magnitude detecting mechanism 9 interposed between the second and the third shafts 2, 3, with reference to Fig. 5 which is a longitudinal sectional view of the mechanism 9.

The second shaft 2 and the third shaft 3 are coaxially interconnected with each other by the aforementioned torsion bar, which is designated by reference numeral 30, while they are fitted in, to be coupled with, each other by means of a mutual engagement structure similar to that shown in Figs. 4A to 4C and employed between the first and the second shafts 1, 2. Moreover, also around respective mutually fitted parts of the second and the third shafts 2, 3 is fitted an axially slidable tubular member 33 analogous to the aforesaid tubular member 17, which member 33 has formed at both lateral sides thereof a pair of inclined elongate holes 33a engaging with a pair of radial pins 31 secured to the second shaft 2 and at the top and bottom sides thereof a pair of parallel elongate holes engaging with a pair of radial pins secured to the third shaft 3.

According to the foregoing arrangement, like the tubular member 17 in the torque direction detecting mechanism 4, when the second shaft 2 is caused to clockwise rotate relative to the third shaft 3, thereby developping a phase difference or relative angular displacement therebetween, the tubular member 33 of the torque magnitude detecting mechanism 9 is then forced to axially move in the direction C′ in Fig. 5 to a position at a distance from an original position thereof in correspondence to the relative angular displacement. To the contrary, when the second shaft 2 is rotated counterclockwise, then the tubular member 33 is forced to likewise move in the direction D′ in Fig. 5.

In this respect, under the condition that no steering torque is transmitted from the steering wheel 8 to the second shaft 2, the tubular member 33 is set to be held at the original position which is a predetermined axial position on the steering shaft 101.

Incidentally, different from the tubular member 17 as an insulating element, the tubular member 33 is made of a magnetic material.

Further, around the tubular member 33 is disposed a differential transformer 40 of a cylindrical configuration, which transformer 40 is secured to a body (not shown) of the vehicle. In the differential transformer 12, there are installed a single primary winding 40a and a pair of secondary windings 40b, 40c. The primary winding 40a is fed with an alternating-current signal Sac from the driving control circuit 50 or, more particularly, from an oscillator 51 through a primary coil driving circuit 52 (see Fig. 6). From the secondary windings 40b, 40c are output the aforementioned detection signals VR, VL to be fed to the driving control circuit 50 or, more particularly, to be input to a pair of rectifiers 53a, 53b, respectively (see Fig. 6).

In the foregoing arrangement, under the condition that, without torque applied to the second shaft 2, no phase difference is developed between the second and the third shafts 2, 3, the tubular member 33 is set to be held at an axially central position of the differential transformer 40.

With reference to Fig. 6, there will be described below the constitution as well as the function of the driving control circuit 50 which is adapted to feed the armature current Io to the electric motor 5 in accordance with the respective detection signals Sdr, Sdl and VR, VL from the torque direction detecting mechanism 4 and the torque magnitude detecting mechanism 9.

As aforementioned, the control circuit 50 includes the oscillator 51 cooperating with the coil driving circuit 52 to feed the primary winding 40a of the differential transformer 40 with the alternating-current signal Sac. With the primary winding 40a excited, the secondary windings 40b, 40c of the transformer 40 are energized to output the detection signals VR, VL as a pair of alternating-current signals of a predetermined frequency. The output signals VR, VL are set to be of an even amplitude while the magnetic tubular member 33 is held at the original position. As this member 33 is forced to move in the direction C′ or D′, the output signals VR, VL from the secondary windings 40b, 40c have, at the side towards which the member 33 is moving, an increasing amplitude and, at the opposite side from which it is going away, a decreasing amplitude.

Incidentally, in each of Figs. 7A-1 to 7A-4 as well as 7B-1 to 7B-3, the axis of abscissa represents the axial displacement of the tubular member 33, while the origin 0 corresponds to the original or neutral position thereof, positive abscissa to movements thereof in the direction C′ in Fig. 5, that is, clockwise steering torque, and negative abscissa to movements thereof in the direction D′ in Fig. 5, that is, counterclockwise steering torque.

The described characteristics of the secondary windings 40b, 40c of the differential transformer 40 are illustrated in Figs. 7A-1, 7B-1. Shown in Fig. 7A-1 is an exemplary characteristic curve of the output signal VR from the secondary winding 40b, and 2B-1 is an exemplary characteristic curve of the output signal VL from the secondary winding 40c.

The output signals VR, VL from the secondary windings 40b, 40c are first rectified through the rectifiers 53a, 53b and then deprived of ripples by a pair of lowpass filters 54a, 54b to output a pair of smoothed signals VRo, VLo, respectively. The output signal VRo from the low-pass filter 54a and the output signal VLo from the low-pass filter 54b, which have characteristic curves thereof exemplarily shown in Figs. 7A-2 and 7B-2, respectively, are input to a pair of subtractors 55a, 55b, where they are processed through a pair of subtractive operations such that, at the subtractor 55a, VR_1 = VRo—VLo provided that VR1 becomes nearly equal to zero when VRo $\leq$ VLo and, at the subtractor 55b, VL_1 = VLo -VRo provided that VL_1 becomes nearly equal to zero when VLo $\leq$ VRo. As a result, the subtractors 55a, 55b have such characteristic curves of their output signals VRl, VLl that are exemplarily shown in Figs. 7A-3, 7B-3, respectively.

In this respect, the differential transformer 40 is connected such that, as the tubular member 33 is displaced from the original position in the direction C′ in Fig. 6, that is, toward the secondary winding 40b, the magnitude of the signal VR_1 straight-linearly increases from zero in proportion to the displacement of the member 33 and that, as the member 33 is displaced from the original position in the direction D′ in Fig. 6, that is, toward the secondary winding 40c, the magnitude of the signal VL_1 straight-linearly increases from zero in proportion to the displacement of the member 33.

Incidentally, the driving control circuit 50 has as the power source no more than a single power supply (not shown) of positive polarity, except for power sources of the oscillator 51 and the primary coil driving circuit 52. For such reasons, each of the subtractors 55a, 55b has its output signal set to be substantially zero volts at the positive voltage side, when its positive input terminal is fed with an input signal of a voltage not larger than that of an input signal fed to its negative input terminal.

Further, with reference to Fig. 6, the output signals VR_1, VL_1 of the subtractors 55a, 55b are both input to an analogue OR circuit 56, where they are synthesized to obtain a signal Sa to be output therefrom. The signal Sa, of which the characteristic curve is such as exemplarily shown in Fig. 7A-4, is employed as a torque magnitude signal for controlling the magnitude of the armature current Io to be fed to the electric motor 5, so that the magnitude of the current Io is directly proportional to that of the signal Sa, as will be described later.

The output signal Sa from the OR circuit 56 is input to an electric motor driving circuit 57, whereto also the output signals Sdr, Sdl from the torque direction detecting mechanism 4 are input as torque direction signals. In the motor driving circuit 57, the signals Sa and Sdr, Sdl are processed in a later described manner to produce the armature current Io to be sent to the electric motor 5.

Incidentally, in Fig. 6, designated at reference characters 5b, 5b are commutating brushes of the electric motor 5, and 5c is a rotor as an armature of the motor 5.

Referring now to Fig. 8, which is a circuit diagram of the electric motor driving circuit 57, the circuit 57 will be described below of the control actions that it takes to the electric motor 5 in accordance with the torque magnitude signal Sa and the torque direction signals Sdr, Sdl.

First, the control of the rotating direction of the rotor 5a of the motor 5 will be described.

As shown in Fig. 8, the motor driving circuit 57 is provided with a direct-current power source 61 as a power supply for supplying a direct current to be utilized as the armature current Io, which direct current is supplied through a power switch 62 and a fuse 63 to a direction control circuit 64 adapted to determine the direction of conduction of the armature current Io. The direction control circuit 64 comprises four relay switches 65, 66, 67, 68 controlled for on-off actions thereof with four exciting coils 65a, 66a, 67a, 68a, the relay switches 65, 66, 67, 68 being interconnected into a bridge having output terminals *a*, *b* thereof connected to the brushes 5b of the electric motor 5. The exciting coils 65a, 66a, 67a, 68a of the relay switches 65, 66, 67, 68 are connected to a line 70 provided with an input terminal 69, whereto the torque direction signal Sdr is input, and to another line 72 provided with another input terminal 71, whereto the torque direction signal Sdl is input. The connection of the coils 65a, 68a to the lines 70, 72 is made the same in the direction of conduction, while that of the coils 66a, 67a to the lines 70, 72 is reversed, so that, when the direction signal Sdr input to the terminal 69 is turned to "on", the switches 66, 67 open and concurrently the switches 65, 68 close and, to the contrary, when the direction signal Sdl input to the terminal 71 is turned to "on", the switches 65, 68 open and concurrently the switches 66, 67 close.

As a result, the direction of the armature current Io is selected to be either from the terminal *a* to terminal *b* or from the terminal *b* to terminal *a*. More particularly, when the direction signal Sdr is "on", only the relay switches 65, 68 are closed, so that the direct current from the power source 61 is sent through the bridge terminal *c*, the switch 65, and the terminal *a* to the electric motor 5 and then returned from the motor 5, through the terminal *b* to the switch 68. To the contrary, when the direction signal Sdl is "on", only the relay switches 66, 67 are closed, so that the direct current from the power source 61 is sent through the terminal *c*, the switch 67, and the terminal *b* to the electric motor 5 and then returned from the motor 5 through the terminal *a* to the switch 66. Incidentally, to each of the relay switches 65, 66, 67, 68, there is connected in parallel a protection circuit 73 consisting of a diode, a resistor, and a condenser, to thereby prevent the dicharge of sparks attendant the onoff actions of the switches 65 to 68.

The motor driving circuit 57 further includes a magnitude control circuit 74 for controlling the magnitude of the armature current Io. The control circuit 74 has a below described signal input therefrom to a transistor circuit 75 consisting of a triple of high-power transistors connected in series, at which circuit 75 the magnitude of the current Io is controlled in proportion to the signal input thereto.

In the magnitude control circuit 74, which is provided with a terminal 76 for receiving the torque magnitude signal Sa, this signal Sa is divided by a resistor 77 into a necessary voltage and then input to an amplifier 78, where it is amplified to obtain the aforesaid signal input to the transistor circuit 75. Therefore, the armature current Io to be fed to the electric motor 18 has a magnitude proportional to the voltage of the torque magnitude signal Sa, so that the second shaft 2 is applied with auxiliary torque of a magnitude proportional to the magnitude signal Sa.

The magnitude control circuit 74 further includes a non-inverting amplifier 79, a low-pass filter 80, and an overcurrent prevention circuit 81. The magnitude of the armature current Io is detected, by means of a resistance 83, in the form of a voltage signal, which signal is fed back through the non-inverting amplifier 79 and the lowpass filter 80 to the amplifier 78, as well as to a transistor 82 in the overcurrent prevention circuit 81, the transistor 82 being connected in parallel to the resistor 77. In such circuit arrangement, when the armature current Io is brought into an overcurrent state, the transistor 82 becomes on, interrupting the supply of the magnitude signal Sa to the resistor 77, so that the current Io is prevented from being sent with excessive amperage to the electric motor 5.

As will be understood from the foregoing description, in the motor driving circuit 57, the armature current Io to be fed to the electric motor 5 is controlled in magnitude with the torque magnitude signal Sa input from the OR circuit 56, and in direction of conduction with the torque direction signals Sdr, Sdl input from the torque direction detecting mechanism 4.

It will also be understood that, in the foregoing arrangement, when either the limit switch 20 or 21 of the torque direction detecting mechanism 4 is operated to be closed, the armature current Io to be fed to the electric motor 5 has the direction of conduction determined in the driving control circuit 50, while the amperage of the armature current Io is determined in accordance with the detection signals VR, VL fed from the differential transformer 40 in correspondence to the magnitude of torque in concern.

Incidentally, in this embodiment, the torsion bar 15 interconnecting the first and the second shafts 1, 2 with each other has a smaller spring rate in the twisting direction than the torsion bar 30 interconnecting the second and the third shafts 2, 3 with each other. Therefore, under such a condition that, in the way of the driver's increasing from zero the strength of steering forces applied to the steering wheel 8 with a tendency to produce either clockwise or counterclockwise rotation thereof, so that neither the limit switch 20 nor 21 is operated to be closed, thus leaving the electric motor 5 deenergized, the relative angular displacement between the first and the second shafts 1, 2 is made larger than that between the second and the third shafts 2, 3.

Hereinbelow, there will be described the function of the electric power steering system 100.

In this respect, any time when the steering wheel 8 is operated in an ordinary manner, the driving control circuit 50 is functioning, cooperating with the torque direction detecting mechanism 4 and the torque magnitude detecting mechanism 9, to send to the electric motor 5 the armature current Io with an adequate magnitude and in an adequate direction of conduction, so that adequate auxiliary torque is supplied to the second shaft 2, that is, to the steering shaft 101, and thus transmitted also to the intermediate shaft 11, thereby facilitating the steering operation of the driver.

For easy comprehension, the function of the power steering system 100 will be described first of a stage that the vehicle equipped with this system 100 is to experience when entering from a straight-forward travel into a rightwardly turning state, and then of a subsequent stage in which the vehicle returns again to the straight-forward travel.

In the straight-forward travel, the steering wheel 8 is held at a neutral position thereof, without relative angular displacements developed between the first and the second shafts 1, 2 nor the second and the third shafts 2, 3, thus leaving both the tubular members 17, 33 of the torque direction and magnitude detecting mechanisms 4, 9 located at the original positions thereof, so that the electric motor 5 is not operated at all.

From such condition, when steering forces are applied to rotate the steering wheel 8 in the clockwise direction, it so follows that the first and the second shafts 1, 2 have a relative angular displacemet D_{12} developed therebetween, causing the tubular member 17 to move in the direction C, and just when this member 17 has exceeded the preset axial limit the limit switch 20 is operated to become on. At this time, between the second and the third shafts 2, 3 is given a relative angular displacement D_{23} smaller than the angular displacement D_{12}, while the torque magnitude signal Sa has a voltage corresponding to the angular displacement D_{23}.

In this respect, not limiting to such case, the torque magnitude signal Sa has a signal value proportional to the steering torque acting on the steering shaft 101.

Because of the limit switch 20 being turned on, the torque direction signal Sdr output therefrom is now made "on". Thus, hereafter, the driving control circuit 50 feeds the electric motor 5 with the armature current Io controlled to be of an amperage proportional to the signal value of the torque magnitude signal Sa and in a direction of conduction corresponding to clockwise rotation of the motor 5. At the motor 5 is thus developed corresponding electromgnetic torque to be transmitted as clockwise auxiliary torque through the reduction gearing consisting of the small-diamter gear 6 and the large-diameter gear 7 to the second shaft 2. The resulting rotation of the steering shaft 101 is transmitted in the form of torque through the intermediate shaft 11 into the steering gearbox 13, whereby the front wheels are rightwardly steered, turning the vehicle to the right.

In such rightwardly turning state, when the strength of steering forces applied to the steering wheel is reduced substantially to zero in a relatively short while by or without releasing the steering wheel 8, the torsion bars 15, 30 positively function to return within a relatively short time the first, the second, and the third shafts 1, 2, 3 to the original positions thereof, where they have no relative angular displacements developed therebetween.

In this respect, by the function of the torsion bar 15, the relative angular displacement between the first and the second shafts 1, 2 is permitted be relatively easily reduced to zero, thus turning "off" the torque direction signal Sdr, whereby the armature current Io is made zero, deenergizing to stop the electric motor 5.

On the other hand, due to the righting moment described, each of the front wheels tends to return to a neutral position thereof within a relatively short time. Such righting moment is transmitted to the third shaft 3, which is thus forced to quickly turn to the left, that is, in the counterclockwise direction when viewed from the side of the first and the second shafts 1, 2.

Such left turn of the third shaft 3 corresponds to a right turn of the second shaft 2 relative to the third shaft 3 and hence torque magnitude detecting mechanism 9 has detected a false steering torque clockwise acting about the second shaft 2, giving a certain value above zero to the torque magnitude signal Sa.

At the same time, the rapid leftward rotation of the third shaft 3 is transmitted through the torsion bar 30 to the second shaft 2, while tending to be further transmitted through the torsion bar 15 also to the first shaft 1.

In this respect, since the steering wheel 8 is substantially left free from steering forces thereto, the load to be now borne by the torsion bar 15 is based on no more than very small moment of intertia due to the weights of the steering wheel 8 and the first shaft 1. Accordingly, in the case where the second shaft 2 is rotated counterclockwise when viewed from the side of the first shaft 1, also the first shaft 1 is caused to counterclockwise rotate substantially integrally with the second shaft 2.

More specifically, the first shaft Ishould rotate slightly to the left relative to the second shaft 2. However, with such slight relative rightward rotation of the first shaft 1, the tubular member 17 of the torque direction detecting mechanism 4 will not be moved in the direction C so far that the limit switch 20 again becomes on. Thus, the torque direction signal Sdr is kept "off".

Accordingly, even when, in the driving control circuit 50, the signal VRI based on the output signal VR from the torque magnitude detecting mechanism 9 has a certain value above zero, thus giving a certain value above zero to the torque magnitude signal Sa, the torque direction signal Sdr left "off" as described and keeps the armature current Io at a zero level thereof, so that the electric motor 5 will not rotate again to the right.

As a result, each of the front wheels as well as the steering wheel 8 is righted to the neutral position in a smooth and rapid manner.

For the vehicle equipped with the electric power steering system 100, similar results will be achieved also when the strength of steering forces applied to the steering wheel 8 is reduced substantially to zero in a relatively short while by or without releasing the steering wheel 8 to thereby return the vehicle from a leftwardly turning state to the straight-forward travel.

As will be easily understood, in this embodiment, when the relative angular displacement between the first and the second shafts 1, 2 is developed to have a value exceeding a predetermined phase difference, the arm-like portions la of the first shaft 1 are brought into abutment with the cut portions 2a of the second shaft 2, whereby the first and the second shafts 1, 2 are caused to rotate integrally with each other. Such concept facilitates the provision of a fail-safe design in the power steering system 100. Similar facilitation is achieved also at the mutually fitted region between the second and the third shafts 2, 3.

Incidentally, in this embodiment, electromagnetic torque developed at the electric motor 5 is supplied as auxiliary torque to the second shaft 2. In this respect, such auxiliary torque may alternatively be applied to the third shaft 3 or to the intermediate shaft 11.

Further, in this embodiment, the steering gear mechanism in the steering gearbox 13 is of a rack and pinion type. However, in a preferred modification, a voluntary type of steering gear mechanism may be employed, provided that righting moment of steered front ground wheel is mechanically transmitted at the side of a steering shaft.

Furthermore, in this embodiment, the spring rate of the torsion bar 15 is set smaller than that of the torsion bar 30. Such relation of the spring rate may advantageously be modified in a voluntary manner by adequately changing the distance from the original position of the tubular member 17 to the axial limit thereof at which the limit switch 20 or 21 is operated to be closed.

Although there has been described what is at present considered to be the preferred embodiment of the invention, it will be understood that the present invention may be embodied in other specific forms without departing from the essential characteristics thereof. The present embodiment is therefore to be considered in all respects as illustrative and not restrictive. The scope of the invention is indicated by the appended claims rather than by the foregoing description.

CLAIMS

1. An electric power steering system for a vehicle with a ground wheel to be steered, including a steering wheel, a steering shaft connected to said steering wheel, an output shaft operatively interconnected with the ground wheel, an electric motor for operatively supplying said output shaft with auxiliary torque, torque detecting means for detecting the direction and the magnitude of steering torque acting on said steering shaft, and a driving control circuit for generating a torque direction signal and a torque magnitude signal based on output signals from said torque detecting means, to feed said electric motor with an armature current in such a direction and of such a magnitude as desirous in accordance with both said torque direction signal and said torque magnitude signal, wherein said steering shaft comprises a first shaft connected to said steering wheel a second shaft operatively interconnected with said first shaft, and a third shaft as said output shaft operatively interconnected with said second shaft, and wherein said torque detecting means comprises a torque direction detecting mechanism interposed between said first shaft and said second shaft and adapted to detect the direction of said steering torque as acting on said steering shaft, and a torque magnitude detecting mechanism interposed between said second shaft and said third shaft and adapted to detect the magnitude of said steering torque as acting on said steering shaft.

2. An electric power steering system according to claim 1, wherein said auxiliary torque from said electric motor is applied to said second shaft.

3. An electric power steering system according to claim 1 or 2, wherein said first shaft and said second shaft are interconnected with each other through a first elastic member said second shaft and said third shaft are interconnected with each other through a second elastic member and said first elastic member has a smaller spring rate than said second elastic member.

4. An electric power steering system according to claim 1, 2 or 3 wherein said output shaft is interconnected with the ground wheel through a rack and pinion type gear mechanism.

5. An electric power steering system substantially as hereinbefore described with reference to the accompanying drawings.

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