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(51) INT CL⁴
B62D 5/04 6/00

(52) Domestic classification (Edition H):
B7H 101 201 307 311 XG

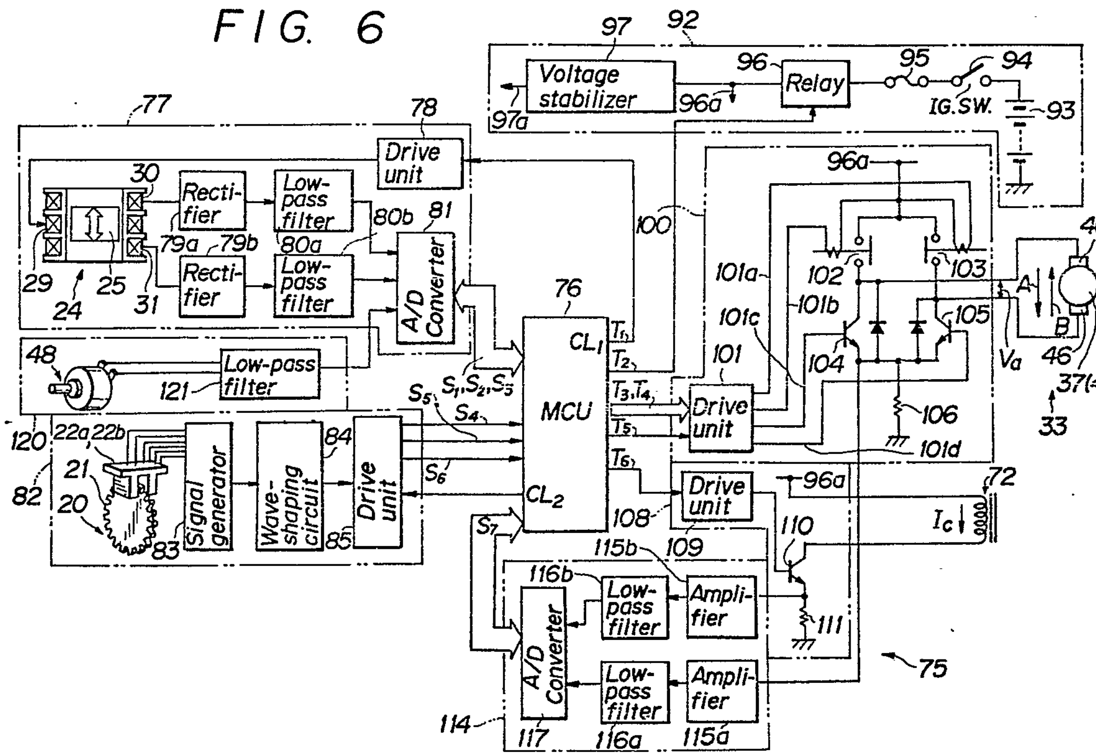
(56) Documents cited
None

(58) Field of search
B7H

(54) Electric power steering system for vehicles

(57) An electric power steering system for a vehicle including a driving control circuit (76, 100, 108) for feeding, in dependence on an output signal (S_1, S_2) from a steering torque detection mechanism (77) for detecting steering torque acting on an input shaft, a drive signal (Va) to an electric motor (33) for producing auxiliary torque to be supplied to an output shaft. In the steering system, the auxiliary torque to be developed at the electric motor (33) is reduced, under the condition that a steering angle of the steering wheel has exceeded a predetermined angle.

FIG. 6



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The drawings originally filed were informal and the print here reproduced is taken from a later filed formal copy.

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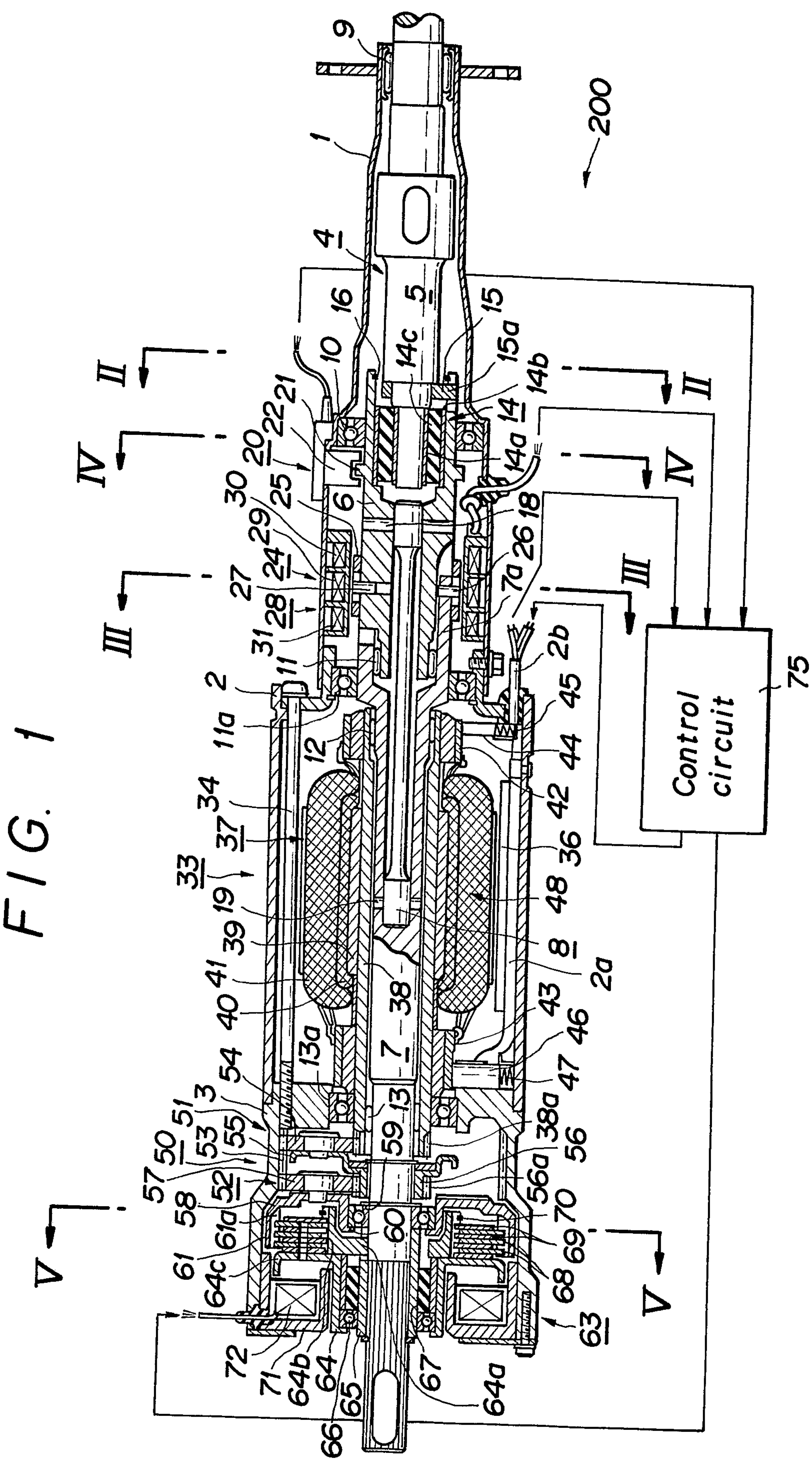


FIG. 1

FIG. 2

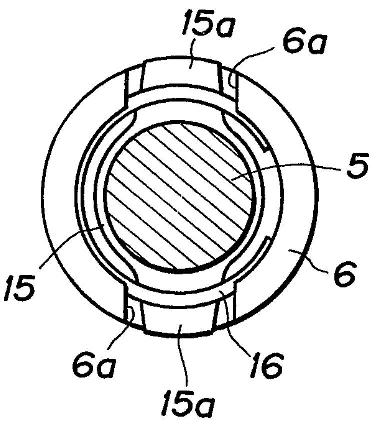
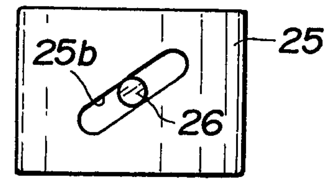


FIG. 3C



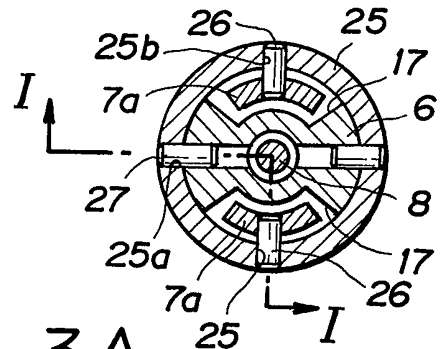


FIG. 3A

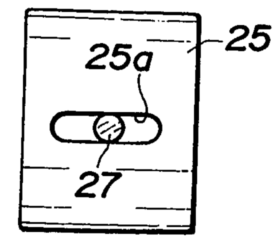


FIG. 3B

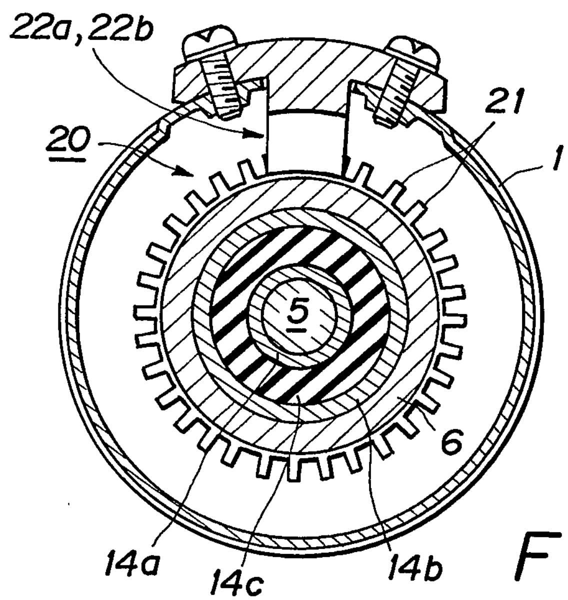


FIG. 4

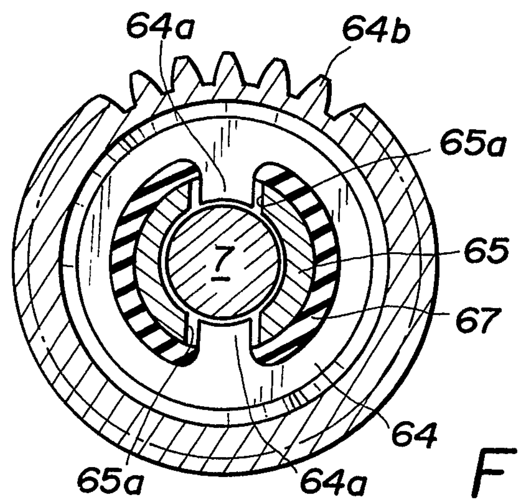


FIG. 5

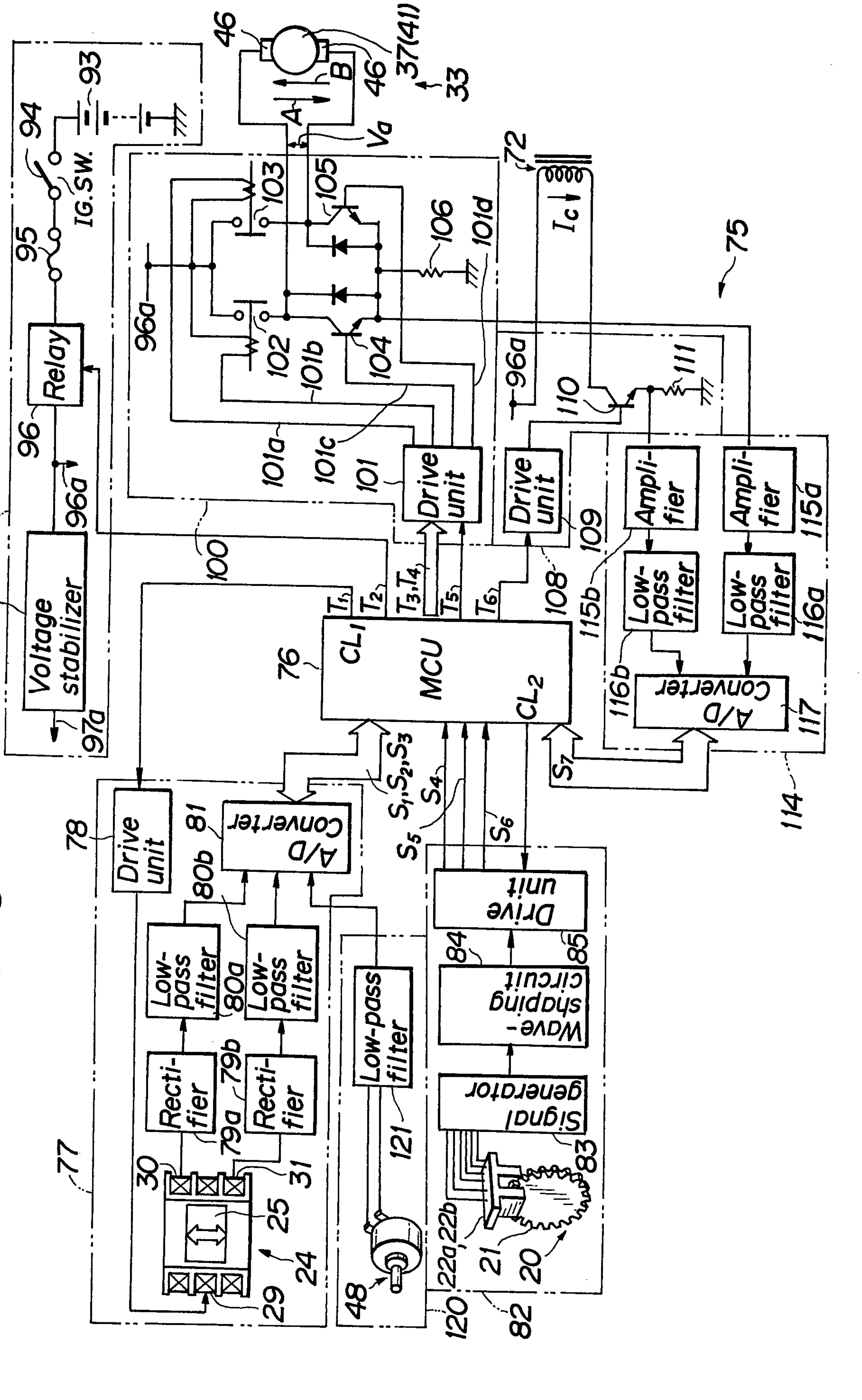

Relay
IG.SW.
Voltage stabilizer
Drive unit
Drive unit
Ampli-fier
Ampli-fier
Low-pass filter
Low-pass filter
MCU
CL_1
CL_2
T_1
T_2
T_3,T_4
T_5
T_6
A/D Converter
S_1,S_2,S_3
S_4
S_5
S_6
S_7
Drive unit
A/D Converter
Low-pass filter
Low-pass filter
Recti-fier
Recti-fier
Low-pass filter
Drive unit
Wave-shaping circuit
Signal generator
I_c
V_a
A
B
92
93
94
95
96
96a
97
97a
100
101
101a
101b
101c
101d
102
103
104
105
106
108
109
110
111
114
115a
115b
116a
116b
117
72
75
76
77
78
79a
79b
80a
80b
81
82
83
84
85
120
121
20
21
22a
22b
24
25
29
30
31
33
37(41)
46
48

FIG. 6

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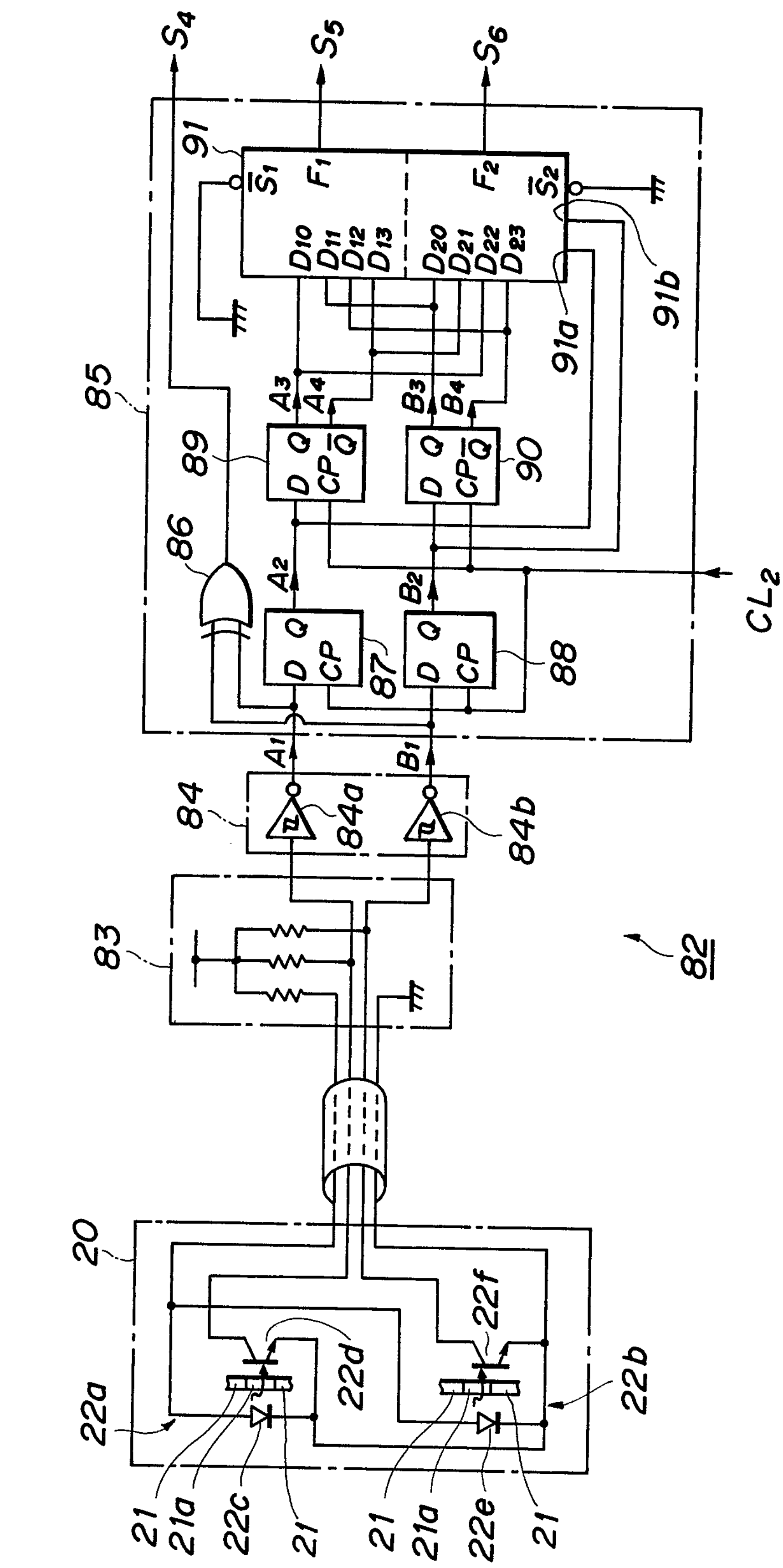


FIG. 7

FIG. 8

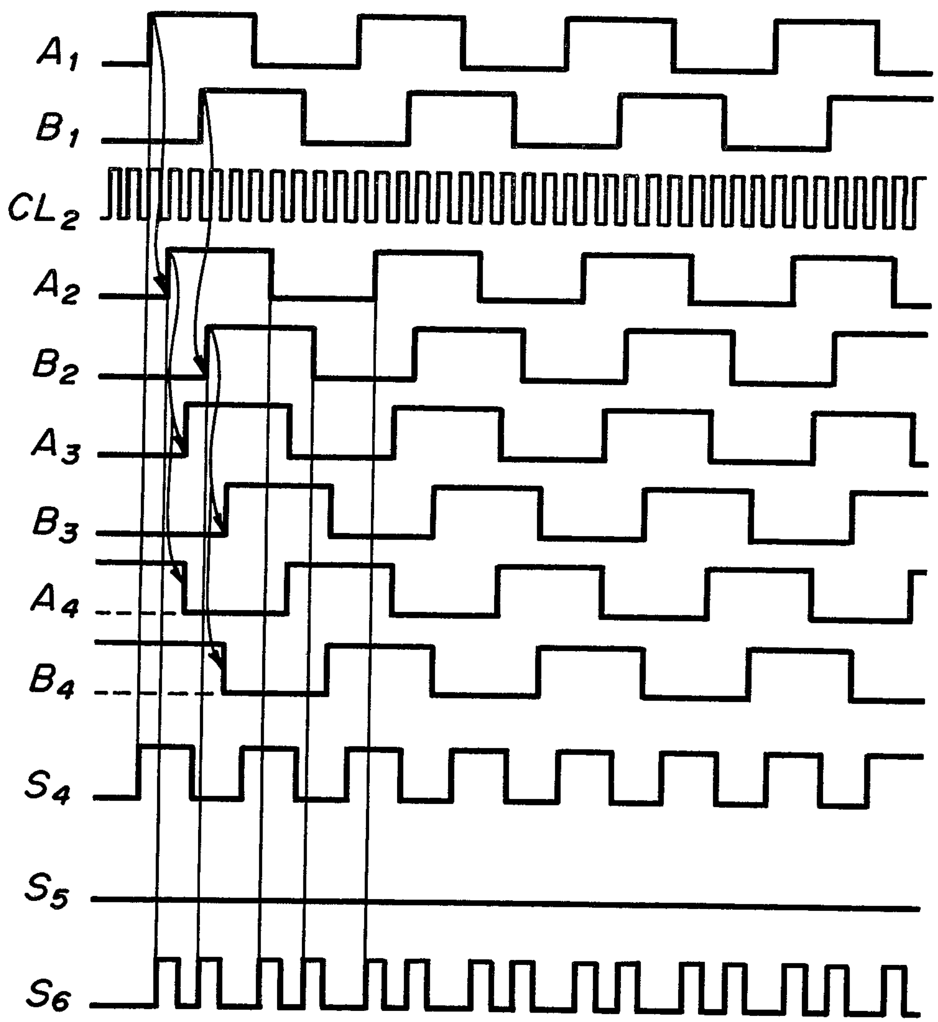
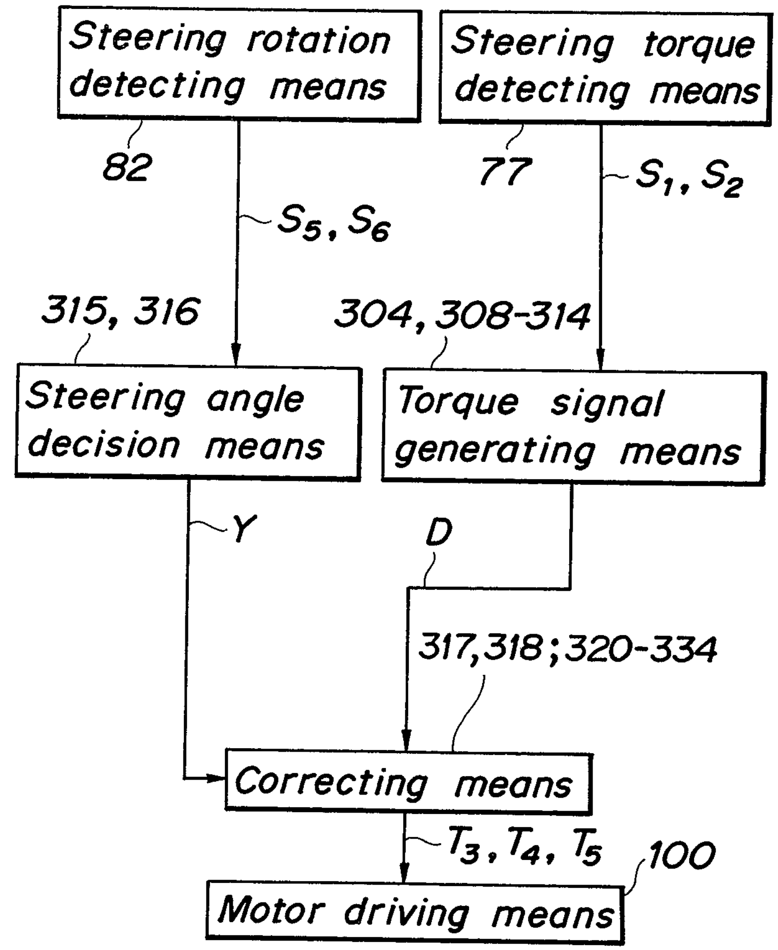
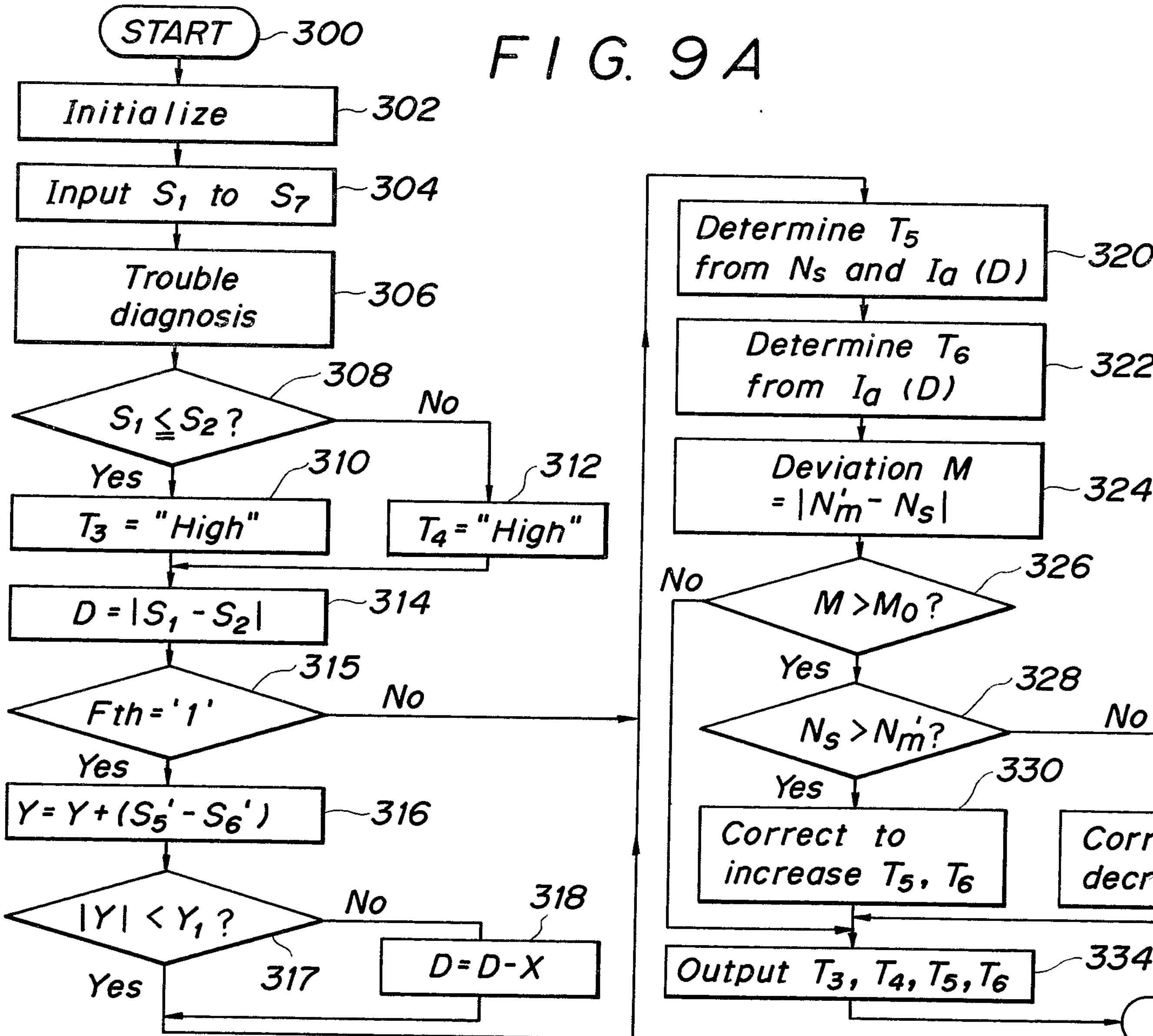

A1
B1
CL2
A2
B2
A3
B3
A4
B4
S4
S5
S6

FIG. 16


Steering rotation detecting means
82
S5, S6
Steering torque detecting means
77
S1, S2
315, 316
Steering angle decision means
304, 308-314
Torque signal generating means
Y
D
317,318;320-334
Correcting means
T3, T4, T5
100
Motor driving means

F I G. 9A


START
300
Initialize
302
Input S_1 to S_7
304
Trouble diagnosis
306
$S_1 \leqq S_2$?
308
No
Yes
T_3 = "High"
310
T_4 = "High"
312
$D = |S_1 - S_2|$
314
Fth = '1'
315
No
Yes
$Y = Y + (S_5' - S_6')$
316
$|Y| < Y_1$?
317
No
Yes
D = D - X
318
Determine T_5 from N_s and I_a (D)
320
Determine T_6 from I_a (D)
322
Deviation M $= |N_m' - N_s|$
324
$M > M_0$?
326
No
Yes
$N_s > N_m'$?
328
No
Yes
Correct to increase T_5, T_6
330
Correct to decrease T_5, T_6
332
Output T_3, T_4, T_5, T_6
334
304

F I G. 9B

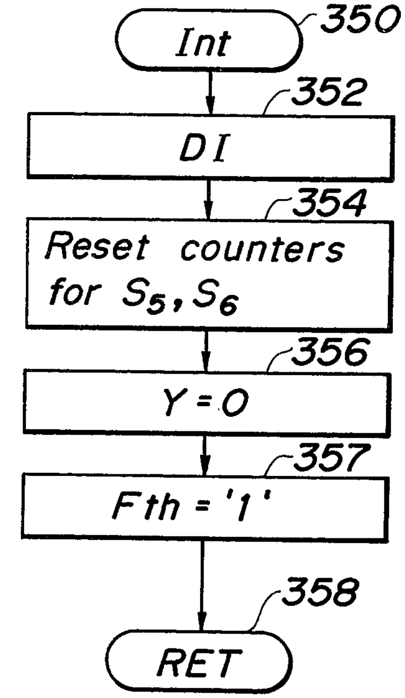

Int
350
DI
352
Reset counters for S_5, S_6
354
Y = 0
356
Fth = '1'
357
RET
358

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FIG. 10

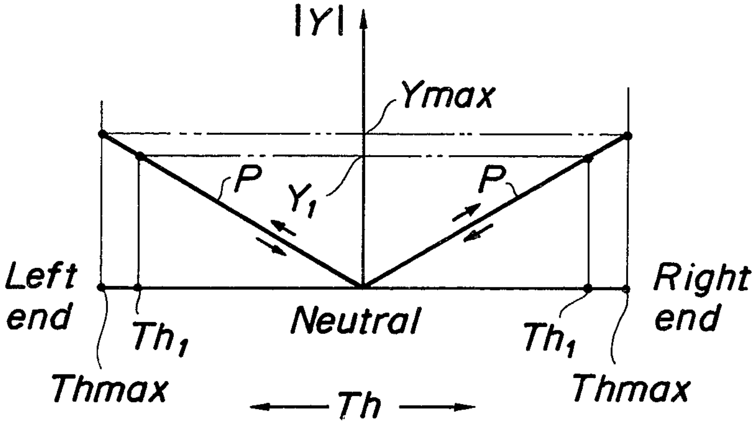


FIG. 11

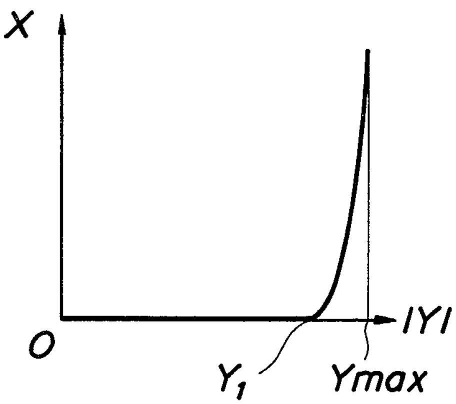


FIG. 12

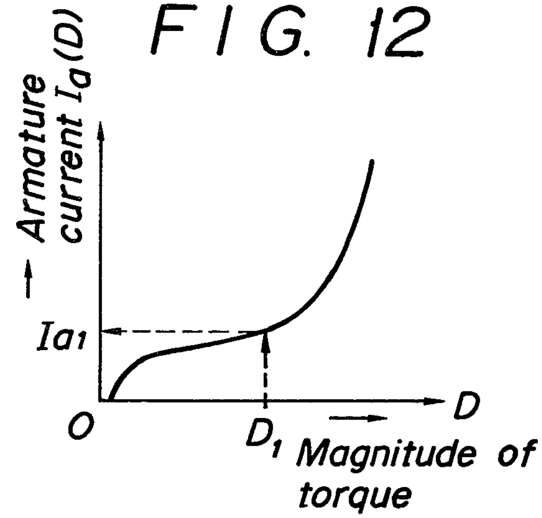


FIG. 13

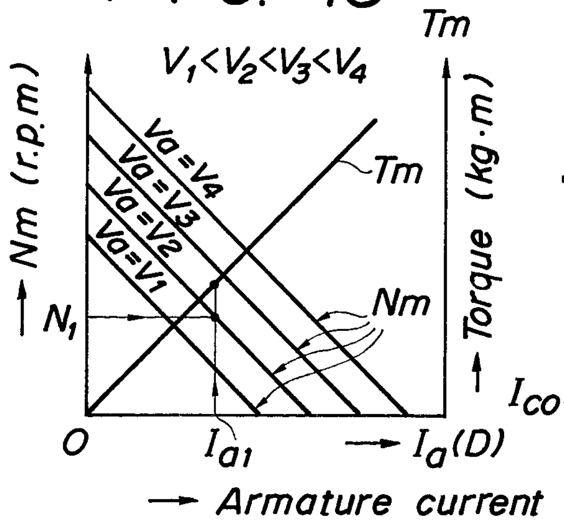


FIG. 14

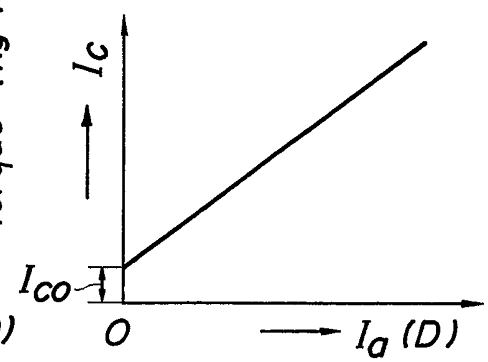
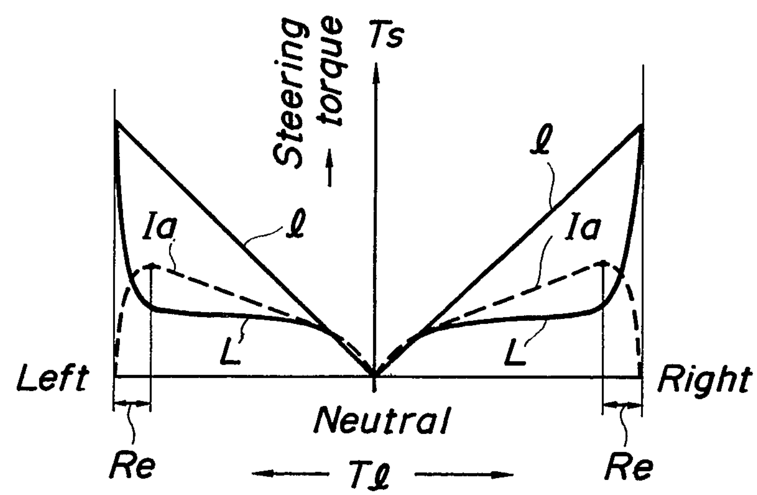


FIG. 15



SPECIFICATION

Electric power steering system for vehicles

The present invention generally relates to a power steering system for vehicles. More particularly, the invention relates to an electric power steering system for vehicles which produces auxiliary torque for steering by means of a steering servo device using an electric motor.

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

Exemplarily, in Japanese Patent Application Lay-Open Print No. 59-70257, laid open on April 20, 1984, there is disclosed an electric power steering system for vehicles.

This electric power steering system for vehicles includes an input shaft as a steering shaft connected to a steering wheel, an output shaft interconnected through a universal joint with the input shaft and through a gear mechanism of a rack and pinion type with a tie rod of a steered wheel, an electric motor for supplying auxiliary torque through a reduction gearing to the output shaft, a torque detection mechanism disposed on the input shaft to detect steering torque acting on the input shaft, and a driving control circuit adapted to produce, based on a detection signal from the torque detection mechanism, a torque magnitude signal and a torque direction signal representing the magnitude and the direction of the steering torque acting on the input shaft, respectively, and to feed the electric motor with an armature current proportional in magnitude to the torque magnitude signal and in a direction of conduction in accordance with the torque direction signal. The torque detection mechanism consists of a strain gauge sensor.

With such arrangement, when the steering wheel is operated, the output shaft is supplied with adequate auxiliary torque from the electric motor, so that the steering operation is facilitated.

In such electric power steering systems as according to the aforementioned Japanese Lay-Open Print, however, like the case of ordinary manual steering systems without assist power, there is employed a steering gear mechanism in which, when a steering wheel is rotated in either direction, clockwise for example, by a predetermined angle from a neutral position thereof, a rack at the output side is moved to be positioned at a corresponding one of the stroke ends thereof, keeping the steering wheel from being further rotated in the same direction. In general, the predetermined angle is approximately 540°, or corresponds to approximately one and half revolutions of the steering wheel.

In electric power steering systems of such a type as according to the aforementioned Japanese Lay-Open Print, therefore, at the stroke ends of an output-side rack, that is, at both steering ends of a steering wheel, it is rather desirous to reduce auxiliary torque or stop producing torque by the electric motor. Such desire arises from the viewpoint that the electric motor itself as well as the entirety of the electric power steering system should have its durability increased and its electric power consumption decreased.

The present invention has been made to successfully achieve such desideratum in conventional electric power steering systems of the type described.

Accordingly, an object of the present invention is to provide an electric power steering system for vehicles in which, under such condition that a steering wheel is rotated close to either of the steering ends thereof, the development of auxiliary torque by an electric motor is at least reduced, whereby the electric motor itself as well as the entirety of the steering system is permitted to have its durability increased and its electric power consumption decreased.

To achieve such object, the present invention provides an electric power steering system for vehicles including an input shaft operatively connected to a steering wheel, an output shaft operatively connected to a steered wheel, an electric motor for operatively supplying auxiliary torque to the output shaft, a means for detecting steering torque acting on the input shaft, and a driving control means for feeding the electric motor with a motor drive signal in dependence on an output signal from the steering torque detecting means, and comprising a means for detecting a steering angle of the steering wheel, and a correction means for operatively correcting to decrease the motor drive signal, to thereby reduce the auxiliary torque to be developed at the electric motor, under the condition that the steering angle of the steering wheel is detected to be exceeding a predetermined angle by the steering angle detecting means.

The above and further features, objects and advantages of the present invention will more fully appear from the following detailed description of an exemplary embodiment of the invention when the same is read in conjunction with the accompanying drawings, in which:-

Figure 1 is a longitudinal quarter-cutaway sectional view of an electromagnetic servo device as an essential part of an electric power steering system for vehicles according to a preferred embodiment of the present invention;

Figure 2 is a cross-sectional view along line II - II of Figure 1;

Figure 3A is a cross-sectional view showing a mobile ferrous member of a steering torque sensor in the electromagnetic servo device, along line III -III of Figure 1;

Figures 3B and *3C* are side and top views of the mobile member of Figure 3A, respectively;

Figure 4 is a cross-sectional view showing a steering rotation sensor in the electromagnetic servo device, along line IV - IV of Figure 1;

Figure 5 is a cross-sectional view along line V - V of Figure 1;

Figure 6 is a detailed diagram of a control circuit of the electromagnetic servo device;

Figure 7 is a further detailed diagram of a steering rotation detecting circuit in the control circuit of Figure 6;

Figure 8 is a time chart of output signals at various parts of the circuit of Figure 7;

Figures 9A and *9B* are schematic flowcharts of main loop processes and interrupt processes, respectively, to be performed at a micro-computer unit in the control circuit of Figure 6;

Figure 10 is a graph showing a relation between an integral value of steering angle representative output pulses from the steering rotation detecting circuit and a steering angle;

Figure 11 is a graph showing a relation between the integral value of the steering angle representative pulses and a correction value for an unloading process;

Figure 12 is a graph showing a basic relation between a steering torque signal and an armature current of an electric motor of the electromagnetic servo device;

Figure 13 is a graph for describing operational characteristics of the electric motor of the electromagnetic servo device, there being shown relations between armature current, revolution number, and load torque of the motor;

Figure 14 is a graph showing a relation between the armature current of the electric motor and a drive current of a magnetic clutch of the electromagnetic servo device;

Figure 15 is a graph showing a relation between load torque imposed on and steering torque acting on the electromagnetic servo device; and

Figure 16 is a schematic functional block diagram of the control circuit of Figure 6.

Referring first to Figure 1, designated at reference numeral 200 is the entirety of an electromagnetic servo device as an essential part of an electric power steering system for vehicles according to a preferred embodiment of the present invention, as it is equipped in a vehicle (not shown). The servo device 200 includes an input shaft 4 connected at the right end thereof in Figure 1 to a steering wheel (not shown) of the steering system, a steering column 1 adapted to accommodate therein the input shaft 4, the steering column 1 being fixed to a body (not shown) of the vehicle, an output shaft 7 connected at the left end thereof in Figure 1 to a steering gearbox (not shown) for steered wheels (not shown) of the vehicle, the output shaft 7 being coaxially arranged relative to the input shaft 4, a casing 3 for accommodating therein the output shaft 7, and a stator 2 of a later-detailed electric motor 33, the stator 2 being integrally joined to the column 1 and the casing 3.

The input shaft 4 is loose-fitted at the axially innermost part thereof in the axially innermost part of the output shaft 7, while those innermost parts of the shafts 4, 7 are interconnected with each other through a torsion bar 8 arranged coaxial with the shafts 4, 7. The input and the output shafts 4, 7 are rotatably held in position by means of a pair of bearings 9, 10 and a triple of bearings 11, 12, 13, respectively.

The electromagnetic servo device 200 comprises a steering rotation sensor 20 arranged around the input shaft 4, a steering torque sensor 24 arranged around the loose-fitted innermost parts of the input and the output shafts 4, 7, the electric motor 33 of a direct-current type coaxially arranged around the output shaft 7 and adapted to supply auxiliary torque to the shaft 7 as will be described later, a reduction gearing 50, an electromagnetic clutch 63, and a control device in the form of a control circuit 75 for driving to control the electric motor 33 and the electromagnetic clutch 63 in accordance with respective detection signals output from the steering rotation sensor 20 and the steering torque sensor 24.

More particularly, the input shaft 4 is separated into a first shaft 5 and a tubular second shaft 6. The first shaft 5 has at the axially outer end thereof, that is, at the right end thereof in Figure 1, the steering wheel secured thereto, as described, and is connected at the axially inner end thereof to the tubular second shaft 6 through a rubber bush 14 interposed therebetween for preventing the transmission of vibrations. The rubber bush 14 consists of a radially inner and an outer metallic tubes 14a, 14b and an elastic member 14c interposed therebetween. The inner tube 14a is fixed on the first shaft 5, and the outer tube 14b, in the second shaft 6.

Further, as shown in Figure 2, at the axially inner end part of the first shaft 5 there is fixedly fitted thereon an annular member 15 having a pair of radially outward projections 15a circumferentially spaced apart from each other, which projections 15a are inserted in a pair of slots 6a, with a proper angular gap left, respectively, the slots 6a being formed at the axially outer end of the second shaft 6, that is, at the right end thereof in Figure 1. The first and the second shafts 5, 6, elastically interconnected with each other by the rubber bush 14, are thus permitted, by the gaps, to be angularly displaced relative to each other and adapted, by the annular member 14, to be locked relative to each other after a predetermined relative angular displacement therebetween, so that the elastic member 14c is prevented from being subjected to larger torques than predetermined in the twisting direction thereof. Incidentally, designated at reference numeral 16 is a circle clip for preventing the annular member 15 from coming out of place.

Furthermore, as shown in Figures 3A to 3C, the second shaft 6 has, at the axially opposite end thereof, that is, at the left end thereof in Figure 1, a pair of axially extending grooves 17 formed therein at an angular interval of 180°, while the output shaft 7 has, in the axially innermost part thereof which is enlarged in diameter and supported by the stator 2 through a bearing 11a, a pair of axially extending projections 7a formed at respective positions corresponding to the grooves 17 of the second shaft 6, the projections 7a being inserted in the grooves 17, leaving a predetermined gap, respectively. Moreover, at the same end, the second shaft 6 is reduced, and this reduced part is inserted in, to be supported by, the enlarged innermost part of the output shaft 7.

Still more, in respective axially inner end portions of the second shaft 6 and the output shaft 7, there are formed opposing axial holes coaxial relative to each other to have coaxially disposed therein the torsion bar 8, which is secured at one end thereof (at the right end thereof in Figure 1) by a pin 18 to the second shaft 6 and at the axially opposite end by another pin 19 to the output shaft 7. The axially outer end of the output shaft 7 is interconnected, by means of splines formed thereon, with the steering gearbox as a member at the loading side, as described. Accordingly, steering torque applied from the steering wheel to the input shaft 4 is transmitted through deformation of the torsion bar 8 to the output shaft 7 as well as to members at the loading side. In this respect, the rubber bush 14 interposed between the first and the second shafts 5, 6 of the first shaft 4 is set more rigid or harder to deform than the torsion bar 8 interposed between the second shaft 6 and the output shaft 7.

As shown in Figure 4, the steering rotation sensor 20 comprises a plurality of radially outward projections 21 in the form of teeth equi-angularly spaced apart along the circumference of the second shaft 6, and a pair of photocouplers 22a, 22b fixed to the steering column 1 in such a manner that each of them has its coupled parts at both axial sides of the radial projections 21. In the sensor 20 with such arrangement, therefore, the coupling by light beam at each of the photo-couplers 22a, 22b is alternately interrupted and made, by the projections 21 and gaps 21a therebetween respectively, as the steering wheel is rotated by operation.

In this respect, as shown in Figure 7, the photocouplers 22a, 22b comprise light-emitting elements 22c, 22e consisting of LED's, respectively, and light-receiving elements 22d, 22f consisting of phototransistors.

Respective positions of the photo-couplers 22a, 22b are determined such that the periods in their detection of the projections 21 and the gaps 21a are shifted in phase from each other by a predetermined value, one-fourth of each cycle in this embodiment.

More particularly, the circumferential width of each of the projections 21 and that of each of the gaps 21a are set equal to each other and, letting this be W, the positions of the photo-couplers 22a, 22b are circumferentially spaced apart from each other by a distance of $(n + 1/4)\cdot 2W$, where n is an integer, unity in this embodiment.

Accordingly, as the second shaft 6 is rotated by operation of the steering wheel in either direction, the photo-transistors 22d, 22f output a pair of electric signals shifted in phase from each other by 1/4 cycle.

The steering torque sensor 24 comprises a differential transformer consisting of a mobile tubular ferrous core member 25 axially slidably fitted around the mutually engaged innermost parts of the second shaft 6 of the input shaft 4 and the output shaft 7, and a winding part 28. As shown in Figures 3A to 3C, the mobile core member 25 has formed therethrough a pair of first elongate holes 25a engaged with a pair of pins 26 radially projecting from the axial projections 7a of the output shaft 7 and a pair of second elongate holes 25b engaged with another pair of pins 27 axially projecting from the second shaft 6, these radial pins 27 being each respectively angularly spaced apart at 90° from the radial pins 26. The first elongate holes 25a are formed in the axial direction of the core member 25, and the second elongate holes 25b, inclined at a necessary angle with respect to the axis of the member 25. As a result, in accordance with an angular difference circumferentially developed between the second shaft 6 and the output shaft 7, the inclined elongate holes 25 cooperate with the pins 26 engaged therewith to cause the mobile core member 25 to move in the axial direction, so that the core member 25 is displaced in accordance with steering torque acting on the input shaft 4 or on the second shaft 6 thereof.

More particularly, in the case where, examplarily providing that steering torque is applied to the second shaft 6 in the clockwise direction when viewed at the side of the steering wheel and load torque larger than the steering torque is imposed on the output shaft 7, the second shaft 6 is thus rotated relative to the output shaft 7 in the clockwise direction when viewed at the side of the steering wheel, then the mobile core member 25 is caused to move upwardly in Figure 3C, that is, rightwardly in Figure 3B or leftwardly in Figure 1.

To the contrary, in the case where the second shaft 6 is rotated relative to the output shaft 7 in the counterclockwise direction when viewed at the side of the steering wheel, then the core member 25 is caused to move in the opposite direction to the above.

In either of the foregoing cases, due to the inclined elongate holes 25b of the mobile core member 25 engaged with the radial pins 26 provided at the side of the output shaft 7, which holes 26 are so shaped as to have a straight-linear form when the tubular core member 25 is developed, the core member 25 has an axial displacement in the moving direction from an original middle or neutral position thereof in proportion to the circumferential relative angular displacement between the second shaft 6 as an input side member and the outut shaft 7.

In this respect, the mobile core member 25 is adapted to be located at the middle position under the condition that no steering torque is acting on the input shaft 4 and hence the relative angular displacement between the second shaft 6 and the output shaft 7 is kept zero. In the state shown in Figures 1 and 3A to 3C, the core member 25 is located at such middle position.

Further, in the differential transformer, the winding part 28 arranged around the mobile core member 25 is constituted with a primary winding 29 having a pulse signal input thereto, and a pair of secondary windings 30, 31 coaxially disposed at both sides of the primary winding 29 and adapted to produce an output signal corresponding to the axial displacement of the core member 25. Accordingly, as the relative angular displacement between the second shaft 6 and the output shaft 7 develops with deformation of the torsion bar 8, the axial displacement of the mobile core member 25 is transduced into electric signals to be output.

The electric motor 33 comprises the stator 2 of a cylindrical form integrally joined by means of bolts 34 to both the steering column 1 and the casing 3, the stator 2 having at least one pair of magnets 36 fixed to the inside thereof, and a rotor 37 rotatably arranged around the output shaft 7. The rotor 37 includes a tubular shaft 38 freely-rotatably fitted on the output shaft 7 by means of needle bearings 12, 13 interposed therebetween and likewise supported by the casing 3 through a ball bearing 13a, and an armature assembly integrally fixed on the tubular shaft 38, which assembly consists of a laminated ferrous core 39 having skew slots formed therein for allowing a first multiple winding 40 and a second multiple winding 41 to be laid thereon, with a fine air gap left between the magnets 36 and the second winding 41. Moreover, the tubular shaft 38 has fixed thereon a first commutator 42 connected to the first multiple winding 40 and a second commutator 43 connected to the second multiple winding 41. Further, a set of brushes 44 urged into contact with the first commutator 42 and another set of brushes 46 likewise put in contact with the second commutator 43 are accommodated in brush holders 45, 47 fixed to the stator 2, respectively, while the brushes 44, 46 have leading wires thereof taken out of the stator 2 through non-magnetic pipes 2a, 2b, respectively. In the foregoing arrangement, the magnets 36, the first multiple winding 40, the first commutator 42, and the brushes 44 are cooperating to constitute a direct-current generator 48 as a motor speed sensor for detecting the number of revolutions per unit time of the rotor 37 of the electric motor 33, which generator 48 is thus adapted to be employed for giving an output signal of a direct-current voltage proportional to the revolution number of the rotor 37. On the other hand, as well as the magnets 36, the second multiple winding 41, the second commutator 43, and the brushes 46 cooperate to constitute a proper electrical part of the electric motor 33 for producing auxiliary torque.

The reduction gearing 50 comprises two stages 51, 52 of planetary gear arranged around the output shaft 7. As shown in Figure 1, the primary stage 51 consists of a primary sun gear 38a formed along the outer circumference of the left end part of the tubular shaft 38, the right half of a common ring gear 53 formed along the inner circumference of the casing 3, a triple of primary planet gears 54 interengaged between the sun and the ring gears 38a, 53, and a first carrier member 55 for pivotally supporting the planet gears 54, the carrier member 55 being loose-fitted on the output shaft 7. The secondary stage 52 consists of a secondary sun gear 56a formed along the outer circumference of a tubular member 56 integrally joined with the first carrier member 55, the left half of the common ring gear 53, a triple of secondary planet gears 57 interengaged between the sun and the ring gears 56a, 53, and a second carrier member 58 for pivotably supporting the planet gears 57, which carrier member 58 has integrally formed therewith at the radially inner side thereof an inner tubular portion 60 supported by the output shaft 7 through a bearing 59 and at the radially outer side thereof an outer tubular portion 61 extending along the inner circumference of the casing 3, the outer tubular portion 61 being provided with inner teeth 61a formed along the inner circumference thereof. Therefore, when the rotor 37 of the electric motor 33 rotates, the rotation of the rotor 37 is transmitted through the tubular shaft 38, the primary sun gear 38a, the primary planet gears 54, the first carrier member 55, the secondary sun gear 56a, and the secondary planet gears 57 to the second carrier member 58 and thus to the outer tubular portion 61 thereof, while being reduced in speed.

In the electromagnetic clutch 63, a rotor 64 thereof is rotatably supported through a bearing 66 on a ring member 65 which is spline-fixed on the output shaft 7, while the rotor 64 is elastically connected to the output shaft 7 by means of a ring-like elastic member 67 for absorbing torsional vibrations. The rotor 64 of a tubular form is provided with an axial extension extending so far as to surround the inner tubular portion 60 of the second carrier member 58, which extension has a pair of projections 64a radially inwardly projecting from the inner circumference thereof toward the outer circumference of the output shaft 7. As shown in Figure 5, the radial projections 64a are inserted in a pair of slots 65a formed in the ring member 65, with a necessary circumferential gap left therebetween, respectively, so as to have an angularly engaged relation to the ring member 65. Accordingly, the rotor 64 is adapted to be kept elastically interconnected with the output shaft 7 within a relative angular displacement therebetween corresponding to the circumferential gap or before the projections 64a of the rotor 64 are brought into abutment with the ring member 65. The axial extension of the rotor 64 has along the outer circumference thereof outer teeth 64b formed thereon, and further the rotor 64 has, at a position thereon at the opposite end of the axial extension thereof relative to the second carrier member 58, a disc-like support plate portion 64c projecting in the radial direction. Between the support plate portion 64c of the rotor 64 and the second carrier member 58, there are alternately disposed a plurality of disc-like plates 68 having cut in the outer circumferences thereof grooves meshing with the inner teeth 61a of the outer tubular portion 61 of the carrier member 58 and a plurality of disc-like plates 69 having cut in the inner circumferences thereof grooves meshing with the outer teeth 64b of the axial extension of the rotor 64, thereby constituting a multi-plate clutch mechanism. Incidentally, in Figure 1, designated at reference numeral 70 is a stopper of the plates 69.

Moreover, at the axially outer end of the casing 3 is provided an annulus 71 fixed therein, which has a channel-like cross section. The annulus 71 has accommodated therein an annular excitation coil 72 electrically connected through a leading wire to the control device 75. Thus, with current conduction through the excitation coil 72, there is developed a field of electromagnetic force to thereby attract, through an unshown suitable implement, the aforementioned plates 68, 69 all together toward the coil 72, so that auxiliary torque having been transmitted from the electric motor 33 to the outer tubular portion 61 of the second carrier member 58 in a speed-reducing manner through the reduction gearing 50 can normally be further transmitted through the multi-plate clutch mechanism consisting of the elements 61a, 68, 69, and 64b, the rotor 64, and the elastic member 67 to the output shaft 7.

In this respect, in a state in which the rotor 64 has been rotated relative to the output shaft 7 until the relative angular displacement therebetween reaches a predetermined value, the radial projections 64a from the axial extension of the rotor 64 are put into abutment with corresponding side faces of the slots 65a in the ring member 65, so that the auxiliary torque developed by the electric motor 33 is mechanically transmitted from the rotor 64 to the output shaft 7 in a non-elastic manner.

Description will now be made of the control device 75 as a control circuit of the electromagnetic servo device 200, with reference to Figure 6.

In Figure 6, designated at reference numeral 76 is a micro-computer unit. The micro-computer unit 76 has input thereto respective detection signals S_1 to S_7 output from a steering torque detection circuit 77, a steering rotation detection circuit 82, a motor speed detection circuit 120, and an abnormality detection circuit 114.

The steering torque detection circuit 77 comprises the aforementioned steering torque sensor 24, a drive unit 78 for outputting a reference clock pulse T_1 in the micro-computer unit 76, while dividing same at a number of stages, to the primary winding 29 of the steering torque sensor 24, a pair of rectifiers 79a, 79b for rectifying respective analogue electric signals given from the secondary windings 30, 31 of the torque sensor 24 in accordance with the axial displacement of the mobile core member 25 of the sensor 24, a pair of low-pass filters 80a, 80b for eliminating high-frequency components of those signals as rectified, and an A/D (analogue to digital) converter 81 for converting respective analogue electric signals from the low-pass filters 80a, 80b into a pair of digital signals to be output as steering torque signals S_1, S_2 to the micro-computer unit 76.

The motor speed detection circuit 120 comprises the aforementioned generator 48 as a motor rotation speed sensor, and a low-pass filter 121 for eliminating high-frequency components of an analogue voltage signal output from the generator 48. An analogue voltage signal output from the low-pass filter 121 is input to the A/D converter 81, where it is converted into a digital signal to be output as armature speed signal S_3 representing the rotation speed of the armature 37 corresponding to the number Nm of revolutions per minute thereof. As will be understood later, the motor speed detection circuit 120 is adapted to function as a feedback signal generator.

As shown in Figures 6 and 7, the steering rotation detection circuit 82 comprises a signal generator 83 adapted to apply electric power to the the photo-couplers 22a, 22b of the steering rotation sensor 20 to thereby output the aforementioned electric signals therefrom, a wave-shaping circuit 84 consisting of a pair of Schmitt trigger circuits 84a, 84b for adequately shaping the waveform of the output signals from the signal generator 83, and a drive unit 85 consisting of four D-type flip-flops 87, 88, 89, 90 adapted to function with a clock pulse given from a terminal CL_2 of the micro-computer unit 76, a multiplexer 91 of a double four-channelled-circuit type, and an exclusive-OR circuit 86.

At the steering rotation detection circuit 82 with such arrangement, in the case where, with the steering wheel rotated clockwise for example, the projections 21 as light-shielding parts and the gaps 21a as light-transmitting parts therebetween are rotated in the clockwise direction as viewed at the side of the steering wheel, it so follows that the photo-transistors 22d, 22f cooperating with each other with a differential of ¼ cycle in phase, receive those beams of light which are projected from the LED's 22c, 22e and transmitted from time to time through a corresponding one of the light transmitting parts 21a and the next one thereto, respectively. Therefore, in this case, the aforementioned output signal from the photo-transistor 22f is delayed by ¼ cycle in phase from that of the photo-transistor 22d. As a result, the detection circuit 82 has at various parts thereof such output signals as shown in Figure 8, whereof detailed description will be given later.

Incidentally, the multiplexer 91 is adapted to function in accordance with such a truth table as shown below

Select Terminals			*Outputs*
$\overline{S}_n$	91b	91a	F_n
H	X	X	L
L	L	L	D_{n0}
L	L	H	D_{n1}
L	H	L	D_{n2}
L	H	H	D_{n3}

In the table above, reference character H represents "high" level, and L "low" level. X may be either of H and L, and the suffix n = 1 or 2.

With reference to Figures 7 and 8, description will now be made of various interrelations among output signals A_1 to A_4, B_1 to B_4, and S_1 to S_6 at essential parts of the steering rotation detection circuit 82.

As described, in the detection circuit 82, the drive unit 85 is supplied with the clock pulse from the terminal CL_2 of the micro-computer unit 76, which signal is obtained by dividing the system clock T_1 of the unit 76 at a predetermined number of stages.

When the steering wheel is rotated, exemplarily clockwise as described, the aforementioned electric signals shifted one from the other by ¼ cycle are input from the signal generator 83 to the wave-shaping circuit 84, where the Schmitt trigger circuits 84a, 84b produce rectangular pulse signals A_1, B_1 to be output, respectively, which signals also are different in phase by ¼ cycle from each other. In the exemplary case shown in Figure 8, the signal B_1 output from the circuit 84b is delayed by ¼ cycle from the output signal A_1 of the circuit 84a.

The pulse signals A_1, B_1 are input to D terminals of flip-flops 87, 88, respectively, which are triggered so as to have output signals A_2, B_2 thereof delayed from the signals A_1, B_1, in rise/fall, for a period of one cycle of the clock pulse from the terminal CL_2, at maximum, respectively.

Moreover, the output signal A_2 of the flip-flop 87 is input to the D terminal of the next flip-flop 89, which is triggered to have output signal A_3 at the Q terminal thereof delayed from the signal A_2, in rise/fall, for a period of one cycle of the clock pulse from the terminal CL_2, at maximum, while it concurrently outputs at the $\overline{Q}$ terminal thereof inverted signal A_4 that is reversed in level with respect to the signal A_3.

Likewise, the output signal B_2 of the flip-flop 88 in input to the D terminal of the next flip-flop 90, which is triggered to have output signal B_3 at the Q terminal thereof delayed from the signal B_2, in rise/fall, for a period of one cycle of the clock pulse from the terminal CL_2, at maximum, while it concurrently outputs at the $\overline{Q}$ terminal thereof inverted signal B_4 that is reversed in level with respect to the signal B_3.

Then, the output signals A_3, A_4, B_3, B_4 are sent to input terminals D_{10}, D_{11}, D_{12}, D_{13}, D_{20}, D_{21}, D_{22}, D_{23} of the multiplexer 91 with such connections as shown in Figure 7. Among select terminals 91a, 91b, $\overline{S_1}$, $\overline{S_2}$ of the multiplexer 91, the latter two $\overline{S_1}$, $\overline{S_2}$, are earthed.

The multiplexer 91, of which the logic is as shown in the truth table given before, has at output terminals F_1, F_2 thereof signals S_5, S_6 of such waveforms as shown in Figure 8, respectively. More particularly, in the case shown in Figure 8, the signal S_5 is continuously kept at the "low" level, while the signal S_6 has four rectangular pulses appearing within one cycle of the output signal A_1, or more correctly, within that of the output signal A_2.

Further, in the drive unit 85 of the steering rotation detection circuit 82, the output signals A_1, B_1 of the wave-shaping circuit 84 are input to the exclusive-OR circuit 86, which in turn outputs signal S_4 that has two rectangular pulses appearing within one cycle of the signal A_1, as shown in Figure 8.

It is advised that the time chart of Figure 8 corresponds to the case of clockwise rotation of the steering wheel, as described.

To the contrary, in the case where the steering wheel is rotated counterclockwise, then respective pulses in the signal A_1 are delayed by ¼ cycle from corresponding pulses in the signal B_1 and, depending thereon, other signals A_2 to A_4, B_2 to B_4, and S_4 to S_6 are produced to be output. In this case, therefore, the waveforms of the signals S_5, S_6 as shown in Figure 8 are interchanged therebetween, while that of the signal S_4 is maintained.

Incidentally, it will be easily understood that the duration of those pulses which appear in the signals A_1, B_1 as quasi-original detection signals is in inverse proportion to a steering speed Ns of the steering wheel.

As will be comprehended from the foregoing description, between the output signals S_5 and S_6 of the steering rotation detection circuit 82, only the latter S_6 has pulses appearing therein if the steering wheel is rotated clockwise and the former S_5 does if the rotation of the steering wheel is counterclockwise.

The output signals S_4 to S_6 of the steering rotation detection circuit 82 are input to the micro-computer unit 76, and more particularly, to three unshown counters therein, respectively, while also the clock signal represented by the terminal CL_2 is input to another unshown counter in the unit 76. In the micro-computer unit 76, the input signal S_4 from the detection circuit 82 is employed as a signal for computing the steering speed Ns, and the input signals S_5 and S_6 therefrom, as signals for computing a steering angle Th of the steering wheel.

The micro-computer unit 76 comprises necessary unshown I/O (input and output) ports, memory, processor, and controller.

For driving the micro-computer unit 76 as well as other circuits, there is provided an electric power circuit 92 comprising a normally-closed relay 96 which is installed in a power line led out from a positive terminal of a battery 93 mounted on the vehicle through a key switch 94 of an ignition switch IG.SW. and a fuse 95, and a voltage tabilizer 97 to which electric power is supplied through the relay 96. The relay 96 is provided with an output terminal 96a for applying electric power from the battery 93 to an electric motor drive circuit 100 and an electromagnetic clutch drive circuit 108, and the voltage stabilizer 97, with an output terminal 97a for applying stabilized power to the micro-computer unit 76 and other circuit elements. Therefore, while the key switch 94 is turned on, the micro-computer unit 76 is put in an energized state thereof, where it is permitted to process the respective input signals S_1 to S_7, following a program stored in the memory, to output three control signals T_3, T_4, T_5 to be used for driving the electric motor 33 and a clutch current control signal T_6 to be used for driving the electromagnetic clutch 63 to the motor drive circuit 100 and the clutch drive circuit 108, respectively, to thereby control the driving of the motor 33 and the clutch 63. Among those control signals, T_3 and T_4 are a clockwise rotation representative and a counterclockwise rotation representative signals, respectively, responsible for determining the terminal polarity of an armature voltage Va to be applied to the electric motor 33 in correspondence to the steering direction of the steering wheel, and T_5 is a voltage control signal responsible for determining the armature voltage Va.

The electric motor drive circuit 100 comprises a drive unit 101, and a bridge circuit consisting of a pair of relays 102, 103 and a pair of npn transistors 104, 105. In the bridge circuit, the relays 102, 103 have a common supply terminal thereof connected to the output terminal 96a of the relay 96 of the power circuit 92, and the transistors 104, 105 have the emitters thereof connected through a resistor 106 to the earth as common side, whereas respective excitation coils of the relays 102, 103 and the bases of the transistors 104, 105 are connected to output terminals 101b, 101a and 101c, 101d of the drive unit 101, respectively, and the collectors of the transistors 104, 105 cooperate with each other to provide a potential difference to be applied as the armature voltage Va through the aforementioned brushes 46, 46 across the second multiple winding 41 as an armature winding of the electric motor 33.

The drive unit 101 of the motor drive circuit 100 is adapted for driving the relay 102 or 103 and the transistor 105 or 104 in accordance with the rotation direction representative control signals T_3, T_4 and for outputting a pulse signal, as a series of PWM (pulse duration modulation) waves obtained by modulating the duration of a rectangular-pulse signal of constant frequency in accordance with the voltage control signal T_5, to the base of either of the transistors 104, 105.

Accordingly, in a state in which, being given steering torque representative detection signals S_1, S_2 representing steering torque of a certain magnitude acting clockwise on the input shaft 4, the micro-computer unit 76 has output in a later-described manner the clockwise rotation representative and the counterclockwise rotation representative signals T_3, T_4 as set "high" and "low", respectively, and the voltage control signal T_5 with a signal value corresponding to the steering torque above, then the drive unit 101 is caused to excite the relay 102 through the terminal 101b and concurrently to apply the aforementioned pulse signal, as it is duration-modulated in accordance with the value of the voltage control signal T_5, through the terminal 101d to the base of the transistor 105. Under such condition, the armature voltage Va to be applied across the electric motor 33 is proportional in effective value to the duration of the modulated pulse signal and has such a terminal polarity that an armature current Ia runs in a direction A of conduction forcing the motor 33 to rotate clockwise.

In the above case, the drive unit 101 has no exciting current output through the terminal 101a and no pulse signal output through the terminal 101c, so that the relay 103 remains de-energized and the transistor 104 remains off.

To the contrary, in a state in which steering torque of a certain magnitude acts counterclockwise on the input shaft 4 and thus the micro-computer unit 76 has output the clockwise rotation representative and the counterclockwise rotation representative signals T_3, T_4 as set "low" and "high", respectively, and the voltage control signal T_5 with a signal value corresponding to the steering torque, then there advances a sequence of direction-reversed processes, causing the relay 103 to be excited and concurrently the transistor 104 to be set on, so that the armature current Ia runs through the electric motor 33 in a direction B of conduction forcing the motor 33 to rotate counterclockwise.

In other words, in the electric motor drive circuit 100, there is performed a process for controlling the direction of rotation of the electric motor 33 by selective current conduction to a combination of relay 102 and transistor 105 or an opposite combination of relay 103 and transistor 104, as well as a process for effecting a conduction period control of the transistors 104, 105 by modulating the duration of pulses to be applied to the bases of the transistors 104, 105, while applying across the electric motor 33 the armature voltage Va having an effective value corresponding to the conduction period control, whereby the motor 33 is controlled so as to produce auxiliary torque in correspondence to steering torque applied to the steering wheel.

The electromagnetic clutch drive circuit 108 comprises a drive unit 109 and an npn transistor 110. The transistor 110 is connected at the collector via the excitation coil 72 of the electromagnetic clutch 63 to the aforementioned output terminal 96a of the relay 96 in the power circuit 92, at the emitter through a resistor 111 to the earth as common side, and at the base to an output terminal of the drive unit 109. The drive unit 109 is adapted for outputting to the base of the transistor 110 a pulse signal of which the duration is modulated in accordance with the clutch current control signal T_6 output from the micro-computer unit 76. Accordingly, in the clutch drive circuit 108, there is performed at the drive unit 109 a process for effecting a current conduction control of the transistor 110 in accordance with the clutch current control signal T_6, to thereby control the torque transmission of the electromagnetic clutch 63.

As described, in the present embodiment of the invention, there is employed the abnormality detection circuit 114, which is adapted for detecting abnormalities of the electric motor 33 and the electromagnetic clutch 63. The abnormality detection circuit 114 comprises an amplifier 115a for amplifying a voltage signal taken out from a terminal of the aforementioned resistor 106 in the motor drive circuit 100, another amplifier 115b for amplifying a voltage signal taken out from a terminal of the aforementioned resistor 111 in the clutch drive circuit 108, a pair of low-pass filters 116a, 116b for eliminating high-frequency components of output signals from the amplifiers 115a, 115b, respectively, and an A/D (analogue to digital) converter 117 for converting analogue signals output from the low-pass filters 116a, 116b into a digital detection signal to be output as the aforementioned signal S_7 to the micro-computer unit 76. In this respect, this detection circuit 114 is adapted to detect abnormalities of the electric motor 33 and the electromagnetic clutch 63 by checking respective terminal voltages of the resistors 106, 111. In the case where an abnormality is detected by the circuit 114, the micro-computer unit 76 enters in a later-described manner an abnormality diagnosis process, where it functions so as to output a relay control signal T_2 to the relay 96 of the power circuit 92 to thereby interrupt the power supply to circuit elements.

There will be described below various programmed functions of the micro-computer unit 76.

Figures 9A and 9B are flow charts schematically showing main loop processes and interrupt processes, respectively, in the micro-computer unit 76. In those Figures, designated at reference numerals 300 to 334 and 350 to 358 are associated process stages.

By turning on the ignition key switch 94 at the power circuit 92, the micro-computer 76 as well as other associated circuits is applied with electric power and permitted to exhibit control functions thereof.

First, the control flow goes to an initialization stage 302, where first of all, by masking interrupts, various parameters and factors as well as circuits in the micro-computer unit 76 are initialized. At this moment, the counters to be fed with the output signal S_4 from the steering rotation detection circuit 82 and the clock signal CL_2, respectively, are reset as well, and also a later-described unload control permission flag Fth is reset to "0". Thereafter, an interrupt is enabled.

In this respect, the electromagnetic servo device 200 is provided with a neutral position sensor for applying an interrupt request to the micro-computer unit 76, when the neutral position of the input shaft 4 is thereby detected.

The flow-chart of Figure 9b shows, as a whole, an interrupt handling routine for handling such interrupt.

Promptly after the flow has come to interrupt stage 350, the interrupt is disabled at stage 352. Accordingly, thereafter, that is, after the neutral position of the input shaft 4 has been once detected under the condition that the ignition switch IG.SW. is turned on, the interrupt request from the aforementioned neutral position sensor to the micro-computer unit 76 is not acknowledged by the unit 76.

At subsequent stage 354, the counters to be fed with the output signals S_5, S_6 from the steering rotation detection circuit 82, respectively, are both reset.

Further, at stage 356, the content of a later-described steering angle register Y is cleared to zero.

Thereafter, at stage 357, the unload control permission flag Fth is set to "1".

Upon completion of all necessary processes through the foregoing stages 352 to 357, the flow returns to a main loop shown in Figure 9A, at the next address therein with respect to that address at which the interrupt request in question was raised.

As will be understood, in the present embodiment of the invention, the interrupt handling routine of Figure 9B is programmed so as to execute a sequence of processes for detecting the neutral position of the input shaft 4 and, in consideration of the steering angle Th, for properly setting a flag, resetting counters, and clearing a register to zero.

In this respect, however, there may advantageously be employed a modified example in which, instead of executing such interrupt handling as described above, the neutral position of an input shaft is stored in a micro-computer unit at the time of fabrication of the steering system and, whether an ignition switch is turned on or off, electric power is normally applied to a circuit element adapted for storing variations of steering angle.

In the main loop of Figure 9A, at stage 304, the detection signals S_1 to S_7 from the respective detection circuits 77, 82, 114, 120 are input to be read and stored.

At the next stage 306 as a sub-routine stage, there is made a trouble diagnosis whether the detection signals S_1 to S_7 are proper or not, by checking them for abnormalities. If any abnormality is found, then the relay control signal T_2 is output from the micro-computer unit 76 to the relay 96, thereby interrupting the power supply from the power circuit 92, so that the power assist function of the electric power steering system stops, allowing the steering system to be operated by human strength.

More particularly, the control circuit 75 then stops controlling the electric motor 33. In cases where, under such condition, with steering torque applied to the steering wheel the input shaft 4 is caused to rotate in either direction, the torque transmission from the input shaft 4 to the output shaft 7 initially is effected through the torsion bar 8, giving rise to an increasing torsional deformation thereof. And, if the output shaft 7 has such load torque imposed thereon that is so larger than the steering torque as to cause the relative angular displacement between the input and the output shafts 4, 7 to develop till it reaches a predetermined maximum value, then at this time the aforementioned projections 7a of the axially innermost part of the output shaft 7 are brought into abutment with corresponding side walls of the grooves 17 formed at the inner end of the second shaft 6 of the input shaft 4, there being established an engaged relation therebetween in which the output shaft 7 is mechanically and integrally rotated with the input shaft 4 in a corresponding one direction. Such engagement relation between the projections 7a of the output shaft 7 and the grooves 17 of the second shaft 6 of the input shaft 4 provides a fail-safe function to the electromagnetic servo device 200.

If the detection signals S_1 to S_7 are all normal and proper, then at subsequent stage 308 as a decision stage a comparison of signal value is made between the steering torque representative detection signals S_1, S_2 from the steering torque detection circuit 77 to thereby judge whether the steering direction of the steering torque is clockwise or counterclockwise, whereupon it is decided which of the clockwise rotation representative and the counterclockwise rotation representative signals T_3, T_4 should be set "high".

More particularly, at the stage 308, it is judged whether or not the signal value of the clockwise steering torque representative signal S_2 is larger than that of the counterclockwise steering torque representative signal S_2.Then, there is made such a decision, if the case is so, that the flow should go to stage 310, where the clockwise rotation representative signal T_3 is to be set "high", and if not judged so, that it should go to stage 312, where the counterclockwise rotation representative signal T_4 is to be set "high".

After having made such processes, the flow comes to stage 314, where an operation is performed to determine the magnitude D as absolute value of steering torque from the steering torque representative signals S_1, S_2, such that $D = |S_1 - S_2|$.

Subsequent to the process at the stage 314, there is executed an unloading control process through a group of stages 315 to 318.

More particularly, at the stage 315 as a decision stage, it is judged whether or not the unload control permission flag Fth is set to "1". If the flag Fth is not set "1", the flow goes to stage 320, where the unloading control process is prohibited, as will be described later.

In the case the flag Fth is set "1", the flow goes to the next stage 316, where the content of the (integrated) steering angle register Y is updated, following an arithmetic operation, such that $Y = Y + (S_5' + S_6')$, where S_5', S_6', are count values of the aforementioned counters of the steering angle representative detection signals S_5, S_6 input thereto and hence are always positive. Therefore, if the steering wheel is rotated clockwise from the neutral position, Y has a negative value and, if it is rotated counterclockwise from the neutral position, the value of Y is positive.

In this respect, at the stage 304, as well as the signals S_1 to S_7, the clock signal CL_2 has a count value thereof read to be stored. Moreover, counters of the signals CL_2, S_4, S_5, S_6 are cleared to zero, promptly after their count values have been read.

Incidentally, between the absolute value $|Y|$ of the content of the steering angle register Y and the steering angle Th, there is such a relation as illustrated by straight lines P of Figure 10. In Figure 10, represented by reference character Thmax is the maximum value that the steering angle TH of the steering wheel is permitted to have when the steering wheel is rotated clockwise or counterclockwise, and Th_1 is a predetermined value of the steering angle Th that is smaller than the maximum steering angle Thmax, while lying in the vicinity thereof. The absolute value $|Y|$ of the register Y becomes equal to the predetermined value TH_1 and the maximum value Thmax, when the steering angle Th is developed to the values TH_1 and Thmax, respectively.

At the stage 317 as a decision stage following the stage 316, it is judged whether or not the absolute value $|Y|$ is smaller than the predetermined value Y_1. In the case $|Y|$ is smaller than Y_1, the steering angle Th is naturally smaller than the predetermined value TH_1 and hence the flow goes to subsequent stage 320.

To the contrary, if $|Y|$ is judged to be larger than Y_1 at the stage 317, the flow goes to stage 318, where a correction value X is deducted from the magnitude D of the steering torque as detected. In this respect, between the absolute value $|Y|$ of the register Y and the correction value X of the magnitude D, there is such a relation as shown in Figure 11. If the value of the magnitude D as thus corrected becomes negative, however, the magnitude D is set zero. Further, also in the case where the absolute value $|Y|$ is substantially equal to the maximum steering angle Thmax, the magnitude D is set zero irrespective of the correction value X.

At the stage 320, operations are made first to determine the steering speed Ns from respective count values of the clock signal CL_2 and the steering speed representative output signal S_4 of the steering rotation detection circuit 82 and then to give, by way of a memory address designation based on the steering speed Ns and the torque magnitude D, a value to the voltage control signal T_5 to be used for determining the armature voltage Va, as will be described below.

Incidentally, the count values of the clock signal CL_2 and the detection signal S_4 may preferably be read at the stage 320.

Description will now be directed to how to determine the signal value of the voltage control signal T_5.

As will be easily understood, between the input shaft 4 and the electric motor 33, which is interconnected through the reduction gearing 50 and the electromagnetic clutch 63 with the output shaft 7 that is inherently needed to be rotated substantially at the same rotation speed or angular velocity as the input shaft 4, there should exist such a relation that $Nm_1 = K \cdot Ns_i$, where Nm_i is the rotation speed in terms of the number of revolutions per unit time that the motor 33 is required to have when the input shaft 4 is rotated at a steering speed Ns_i, and K is the gear ratio of the reduction gearing 50 that is given in terms of the ratio of drive side speed to driven side speed. In this respect, it is advised that the electromagnetic clutch 63 fundamentally is adapted to be put in service so as to transmit torque from the reduction gearing 50, as it is, to the output shaft 7, while the excitation current Ic to the clutch 63 is controlled in a later described manner.

The necessary rotation speed Nm of the electric motor 33 is this determined from the steering speed Ns.

Incidentally, in the micro-computer unit 76, the memory has stored in a continuously addressed manner in a certain area thereof a set of numerical data of the armature current Ia as a function Ia(D) of the magnitude D of steering torque, wheareas the current Ia has such a relation to the magnitude D as shown in Figure 12. Accordingly, when given a value of the magnitude D of steering torque, it is permitted to determine the value of necessary armature current Ia(D) as one of the stored data to be identified by simply designating a corresponding address, without performing extra computations.

Moreover, as will be comprehended from Figure 13 showing operating characteristics of the direct-current motor 33, while the armature voltage Va to be applied across the motor 33 is kept constant, in proportion to increase in load torque Tm on the motor 33 the armature current Ia increases and the motor rotation speed Nm decreases. On the other hand, in the case where the load torque Tm is constant, the motor rotation speed Nm increases as the armature voltage Va increases, while the armature current Ia is kept constant.

At this point of description, it is understood that the necessary motor rotation speed Nm is determined from the steering speed Ns, and the necessary armature current Ia(D) is determined by address designation according to the magnitude D of steering torque.

Incidentally, the memory of the micro-computer unit 76 has stored in a matrixingly continuously addressed manner in another area thereof a set of numerical data of the armature voltage Va as a function of both the motor rotation speed Nm and the armature current Ia in correspondence to such relations thereamong as shown in Figure 13. Accordingly, when given respective values of the motor rotation speed Nm and the armature current Ia, it is permitted to determine the value of necessary armature voltage Va as one of the stored data to be identified by simply designating a pair of corresponding addresses. Exemplarily, in a case where the necessary motor rotation speed Nm is determined to be N_1 in Figure 13 and the magnitude D of steering torque is given as a value D_1 in Figure 12 and hence the necessary armature current (Ia(D) is determined to be Ia_1 in Figures 12, 13, there is determined a value V_2 in Figure 13 as the necessary armature voltage Va.

In correspondence to a thus determined value of the necessary armature voltage Va, the voltage control signal T_5 is determined.

Practically, however, numerical data of the armature voltage Va are stored so as to permit the voltage Va to be determined by address designation according to respective values themselves of the steering speed Ns and the armature current Ia(D), without the need of determining the necessary motor rotation speed Nm from the steering speed Ns. The reason why such operation is possible resides in the proportional relation or linearity between the motor speed Nm and the steering speed Ns.

Accordingly, the armature voltage Va is determined by address designation based on the steering torque representative signals S_1, S_2 and the steering speed signal S_4, thus resulting in increased control speed of the micro-computer system 76.

Referring again to the flow chart of Figure 9A, at the stage 322, the clutch current control signal T_6 for the electromagnetic clutch 63 is determined according to the magnitude D of steering torque. In respect of the signal T_6 also, the determination is made by way of address designation. More particularly, first the clutch excitation current Ic is determined by address designation according to the necessary armature current Ia(D) which is determined from the computed magnitude D of steering torque. In this respect, the clutch current Ic has such a relation to the armature current Ia(D) as shown in Figure 14. Then, in correspondence to the thus determined clutch current Ic, the clutch current control signal T_6 is determined. Incidentally, in Figure 14, designated at reference character Ico is a bias current component of the clutch current Ic that is supplied for necessary absorption such as of frictional forces.

Then, at the stage 324, with respect to the steering speed Ns as determined from the steering speed signal S_4 from the steering speed detection circuit 82 and an apparent motor speed Nm′ represented by the motor speed signal S_3 from the motor speed detection circuit 120, there is obtained a deviation M therebetween, such that $M = | Nm' - Ns |$ or in other words the deviation M is determined as the absolute value of the difference between the apparent motor speed Nm′ and the steering speed Ns, whereas such deviation may be otherwise represented, exemplarily in terms of a ratio between the steering speed Ns and the product of the motor rotation speed Nm and the gear ratio K of the reduction gearing 50. In this respect, the generator 48 of the motor speed detection circuit 120 is adapted to have an output characteristic which assures a relation such that $Nm' = nm/k$, where Nm′ and Nm are the apparent and actual motor speeds, respectively, and K is the aforementioned gear ratio. Thus, the apparent motor speed Nm′ is of a nature directly comparable with the steering speed Ns.

Then, at stage 326 as a decision stage, a decision is made of the magnitude of the deviation M, by judging whether $M > M_0$, where M_0 is a predetermined critical value. If the deviation M is found within a permissible range under the value M_0, the flow goes to stage 334 that is an output stage at which the control signals T_3, T_4, T_5, T_6 are output, as they are determined till then, without correcting the armature voltage control signal T_5 and the clutch current control signal T_6.

In the case the deviation M is larger than the value M_0, the flow goes to the next stage 328 as a decision stage, where the apparent motor speed Nm′ and the steering speed Ns are compared with each other by judging whether $Ns > Nm'$.

Then, in the case the steering speed Ns is faster than the apparent motor speed Nm′, the flow goes to stage 330, where an increasing correction of the voltage control signal T_5 is made to increase the armature voltage Va to thereby raise the actual rotation speed Nm in terms of revolution number of the electric motor 33, and in correspondence thereto an increasing correction of the clutch current control signal T_6 is performed.

To the contrary, if the steering speed Ns is smaller than the apparent motor speed Nm′, the flow goes to 332, where a decreasing correction is made of the voltage control signal T_5 to thereby lower the actual motor speed Nm as well as of the clutch current control signal T_6. Thereafter, the flow goes to output stage 334.

Incidentally, by the correction of the control signals T_5, T_6 through the stages 324, 326, 328, 330 and 332, there are eliminated very small variations in action of the electric motor 33, as well as fluctuations of steering feeling due to very small variations in action of friction elements of the electromagnetic clutch 63 and the reduction gearing 50.

At the output stage 334, there are output the motor rotation direction controlling signals T_3, T_4 and the armature voltage control signal T_5, as it is corrected when necessary, to the electric motor drive circuit 100 and the clutch current control signal T_6, as it is corrected when necessary, to the electromagnetic clutch drive circuit 108.

As described, at the motor drive circuit 100, a PWM control is made of the armature voltage Va of the electric motor 33, depending on the rotation direction controlling signals T_3, T_4 and the voltage control signal T_5. Concurrently, at the clutch drive circuit 108, the excitation current Ic to the electromagnetic clutch 63 is PWM controlled, depending on the clutch current control signal T_6, so that the clutch 63 has a controlled clutching force porportional to the armature current Ia or output torque Tm of the electric motor 33, thereby effectively preventing useless or extra consumption of electric power at the clutch 63.

Finally, the flow again goes to the stage 304.

Figure 15 is a graph showing, for manual or powerless operation and power-asisted operation, respective relations between steering torque Ts acting on the input shaft 4 and load torque T1 imposed from the steering gearbox onto the output shaft 7. Designated by small letter *l* is a straight-linear characteristic curve to be experienced in the powerless operation of the steering system, exemplarily in the case where the operation of the steering system is stopped at the stage 306, and capital letter L is a characteristic curve proper to the power-assisted operation of the steering system.

As will be seen from Figure 15, according to this embodiment in which the quantity of the armature current Ia is determined from the magnitude D of steering torque by use of such an interrelation therebetween as shown in Figure 12, the power-assisted characteristic substantially overlaps the powerless characteristic in a region of small load torque T1, but in other regions in which the load torque T1 is increased therebeyond the characteristic curve L of power-assisted operation is successfully kept substantially flat. As the load torque T1 is further increased along a range Re covering such values thereof that correspond to those values of the steering angle Th which are found between the predetermined value Th_1 and the maximum value Thmax, the power-assisted characteristic curve L gradually rises, finally becoming coincident with the powerless characteristic curve *l*. The reason why the power-assisted characteristic is variable as illustrated by the curve L of Figure 15 resides in that the armature current Ia is determined relative to the magnitude D of steering torque as shown in Figure 12 on the one hand and, on the other hand, the magnitude D of steering torque is corrected in advance, at the stages 315 to 318, as described, in consideration of the steering angle Th, with the effect that the armature current Ia is varied relative to the load torque T1 as illustrated by the broken line of Figure 15. In this connection, it will be understood from Figure 14 that the clutch excitation current Ic is varied in proportion to the armature current Ia.

It is advised in respect of the foregoing matter that, while the vehicle is travelling, the load torque T1 practically is in substantial proportion to the steering angle Th.

Figure 16 is a schematic block diagram in which various functions of the control circuit 75 are described by showing interrelations between essential elements of the circuit 75 as shown in Figure 6 and associated process stages in the flow chart of Figure 9, with an eye to the unloading control process, thus eliminating such circuitry, detection signals, process stages, and control signals that have no direct relations to the unloading control process.

According to the preferred embodiment of the present invention, the armature voltage Va of the electric motor 33 basically is determined depending on the steering torque signals S_1, S_2 and the steering speed signal S_4, so that the actual rotation speed Nm of the motor 33 is favorably matched to the steering speed Ns of the input shaft 4 and hence of the steering wheel, thus assuring optimum steering feeling.

Moreover, as a particular distinct point, at the stages 315 to 318 there is executed the unloading control process which permits, as the steering wheel approaches either of both steering ends thereof, the armature voltage Va applied across the electric motor 33 to be gradually reduced, finally becoming zero at the steering end, so that auxiliary torque being developed at the motor 33 also becomes correspondingly reduced, finally to zero at the steering end.

As a result, the durability of the electric motor 33 itself as well as that of the entirety of the power steering system is effectively increased, and concurrently electric power consumption is successfully reduced to be saved in the entire system and particularly in the motor 33, in addition to that the unloading control process contributes to further improved steering feeling.

Incidentally, in the foregoing embodiment, until the steering angle Th after exceeding the predetermined value Th_1 thereof reaches the maximum steering angle Thmax, the magnitude D of steering torque as based on data thereof is gradually and continuously decreasingly corrected, to be finally reduced to zero. In this respect, the magnitude of torque as based on such data may advantageously be decreased to be corrected in any desired manner such as by straight-linear or stepwise reduction, or even in one step in extreme cases, in the eay to a zero state to be achieved at the steering end.

As will be comprehended, the point of the present invention resides in that, in an electric power steering system, auxiliary torque to be developed at an electric motor is made small or zero when a steering wheel is rotated close to either of both steering ends thereof. Accordingly, the present invention is effectively applicable to any power steering system that is provided with an electric motor adapted for development of auxiliary torque.

In this respect, the necessary mechanism for detecting the steering end may be of any desired type. Exemplarily, a code wheel may advantageously be fixed on a steering shaft to thereby detect a steering angle range in the vicinity of the steering end, and further a limit switch for detecting the steering end may preferably be provided on a steering shaft or in a rack and pinion mechanism itself.

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 including an input shaft operatively connected to a steering wheel, an output shaft operatively connected to a steered wheel, an electric motor for operatively supplying auxiliary torque to said output shaft, means for detecting steering torque acting on said input shaft, and driving control means for feeding said electric motor with a motor drive signal in dependence on an output signal from said steering torque detecting means, means for detecting a steering angle of said steering wheel, and correction means for operatively correcting to decrease said motor drive signal to thereby reduce said auxiliary torque to be developed at said electric motor, under the condition that said steering angle of said steering wheel is detected to be exceeding a predetermined angle by said steering angle detecting means.

2. An electric power steering system according to claim 1, wherein said correction means is adapted for decreasingly correcting said motor drive signal to zero, when said steering angle has excceded said predetermined angle, to thereby stop the operation of said electric motor.

3. An electric power steering system according to claim 1 or 2, wherein said predetermined angle is in the vicinity of a maximum steering angle of said steering wheel.

4. An electric power steering system according to claim 1, wherein said correction means is adapted for operatively correcting to decrease said motor drive signal, finally reducing to zero, as said steering angle is varied from said predetermined angle to a maximum steering angle, to thereby reduce said auxiliary torque to be developed at said electric motor, finally stopping the operation of said electric motor.

5. An electric power steering system according to claim 4, wherein said correction means is adapted for operatively and continuously correcting said motor drive signal till zero.

6. An electric power steering system according to any preceding claim, wherein said motor drive signal to be fed from said driving control means to said electric motor comprises an armature voltage signal.

7. An electric power steering system according to any preceding claim, further comprising electromagnetic clutch means for transmitting torque developed at said electric motor to said output shaft, and said driving control means being adapted for feeding said electromagnetic clutch means with a clutch drive signal dependent on said output signal from said steering torque detecting means.

8. An electric power steering system according to claim 7, further comprising a reduction mechanism for transmitting said torque developed at said electric motor to said electromagnetic clutch means, while reducing the speed thereof.

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

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