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(54) **ELECTRIC POWER STEERING APPARATUS**

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(57) **ABSTRACT**

(51) **Int. Cl.**

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<b>B62D 5/04</b>	(2006.01)
<b>B62D 6/00</b>	(2006.01)

An ECU includes two drive circuits corresponding to the motor coils of two systems independent of each other, and a microcomputer that outputs control signals of two independent systems to the drive circuits. The microcomputer includes a first control signal output portion that outputs the control signal to the drive circuit of the first system by executing an electric current control so as to generate a motor torque that corresponds to the assist force. The microcomputer further includes a second control signal output portion that outputs the control signal to the drive circuit of the second system by executing a position control on the basis of a steering angle command value that is input from a superior ECU via an in-vehicle network so as to change the steering angle of the steering road wheels.

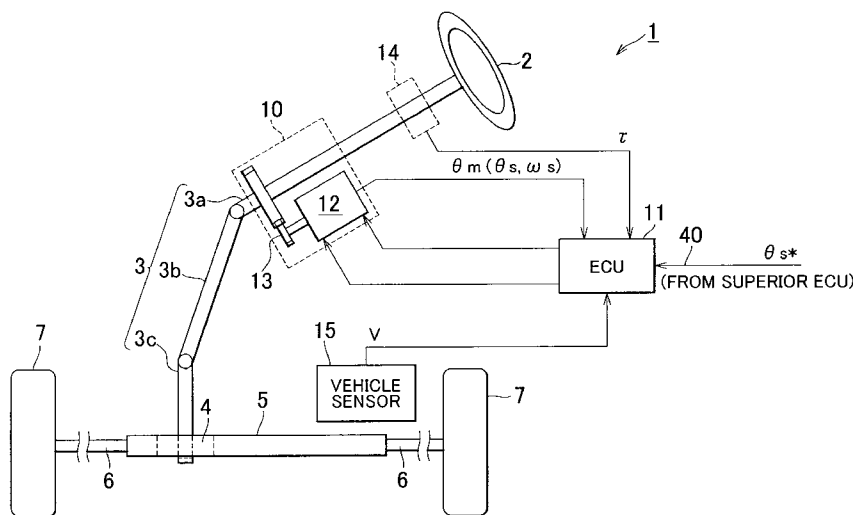
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USPC ..... **701/41**; 701/44

(58) **Field of Classification Search**

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See application file for complete search history.

**4 Claims, 5 Drawing Sheets**



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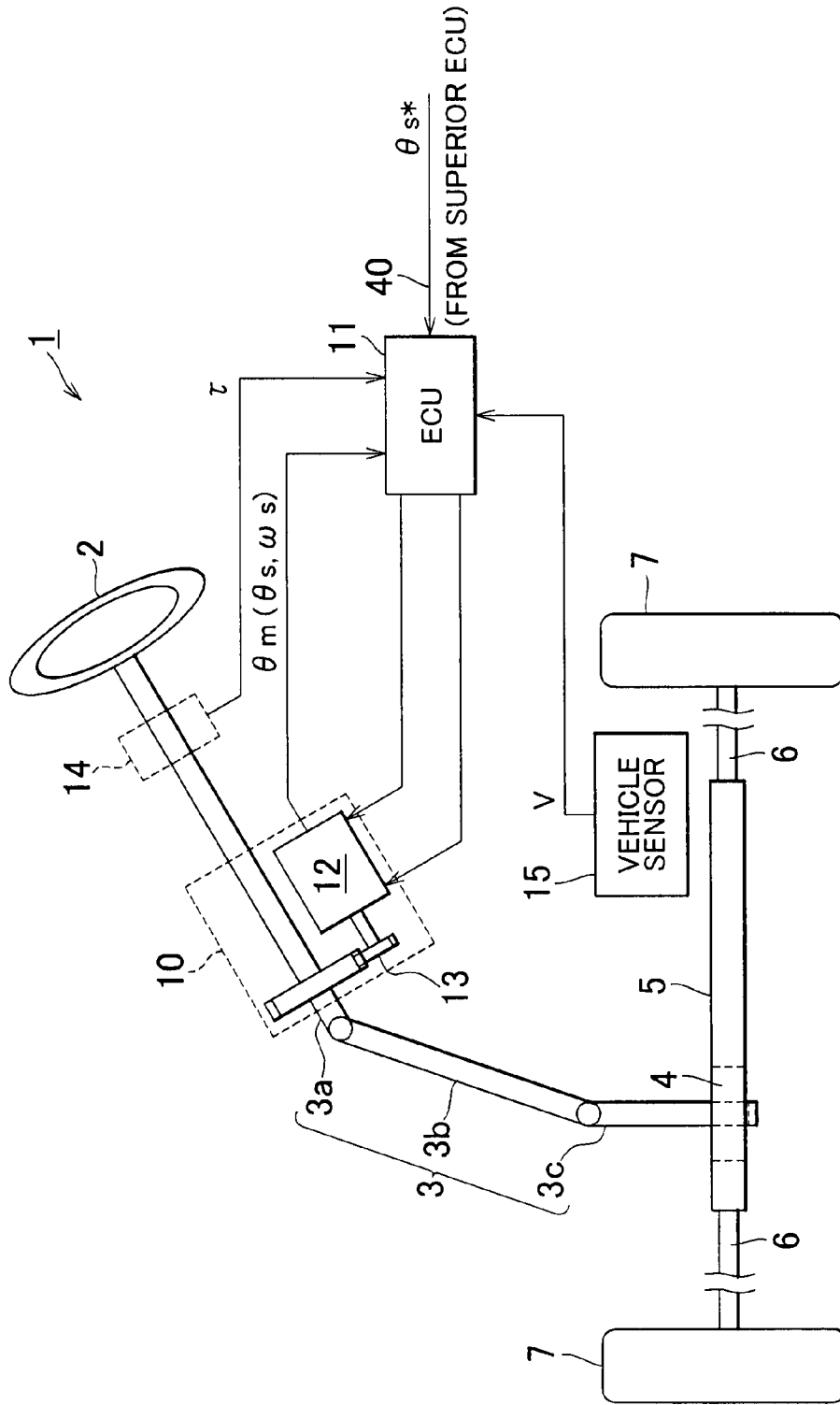
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FIG. 1



# FIG. 2

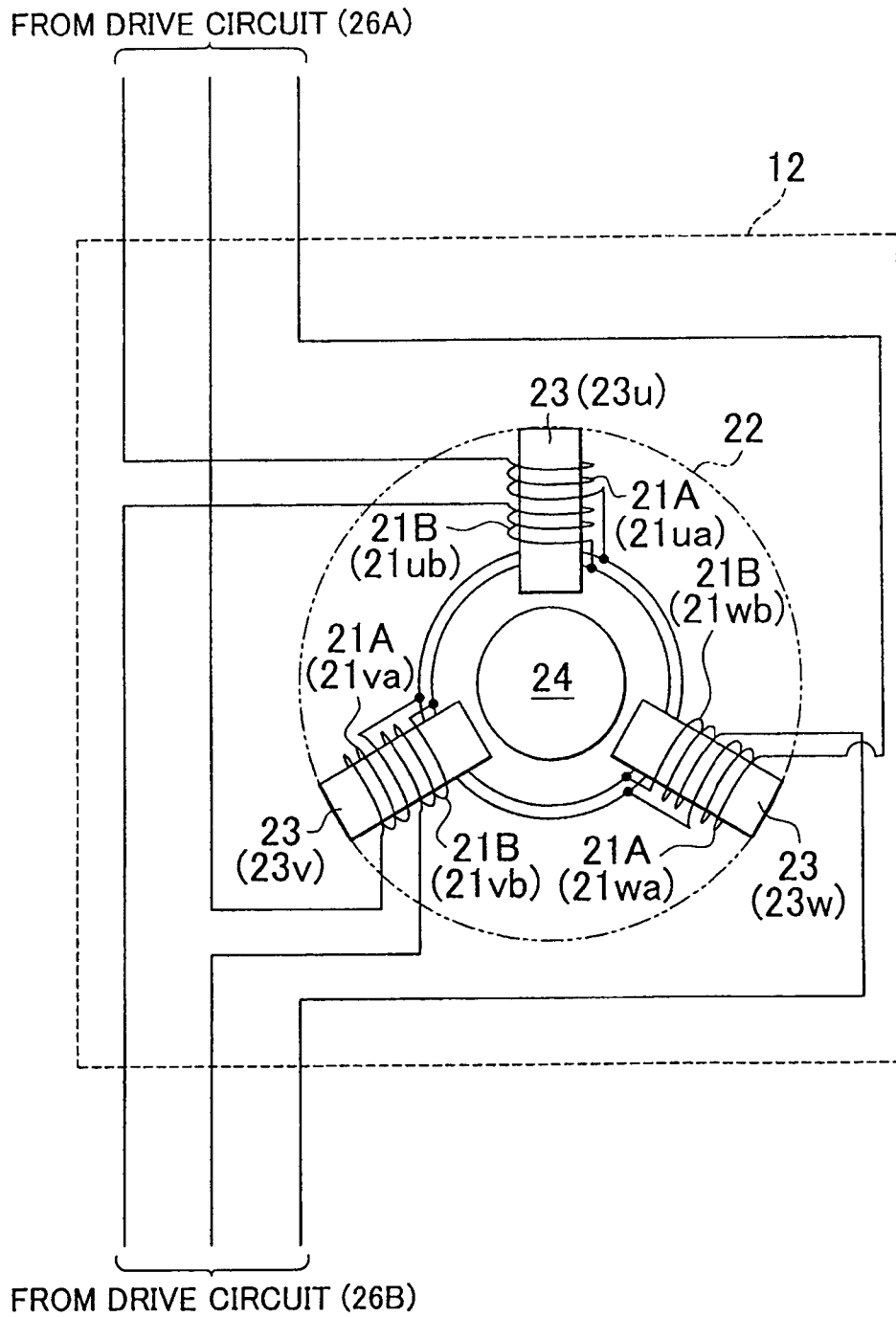


FIG. 3

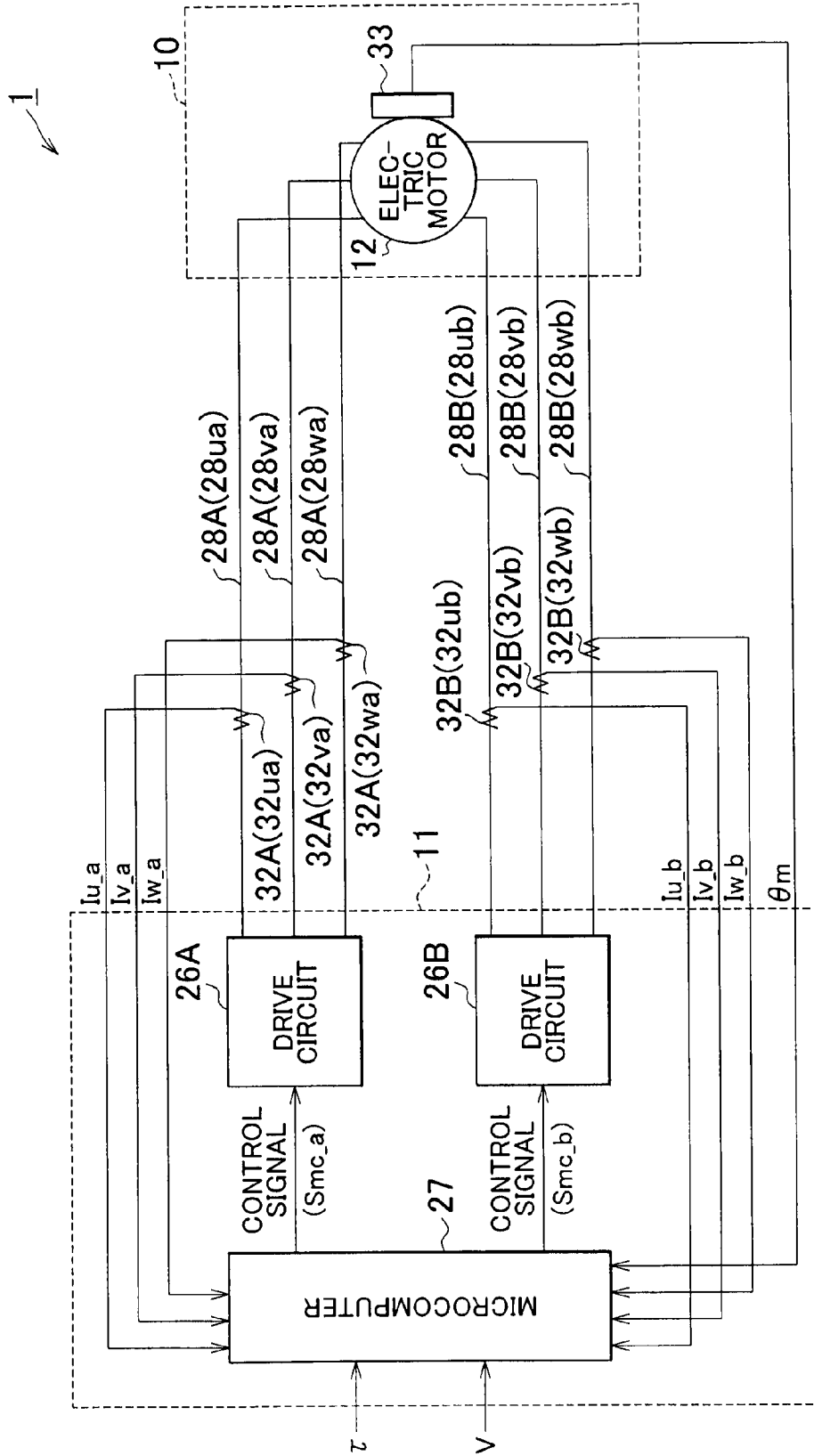


FIG. 4

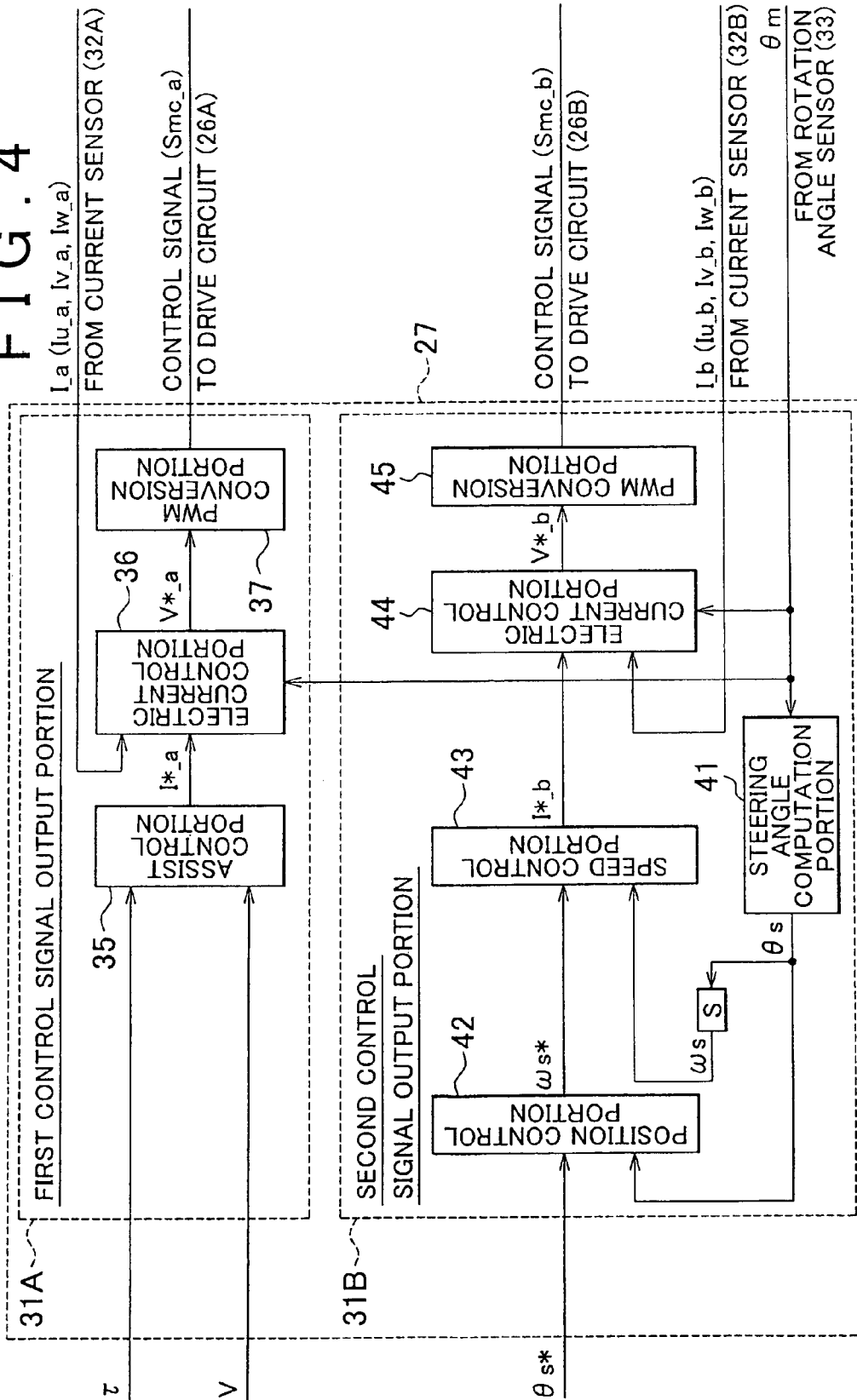
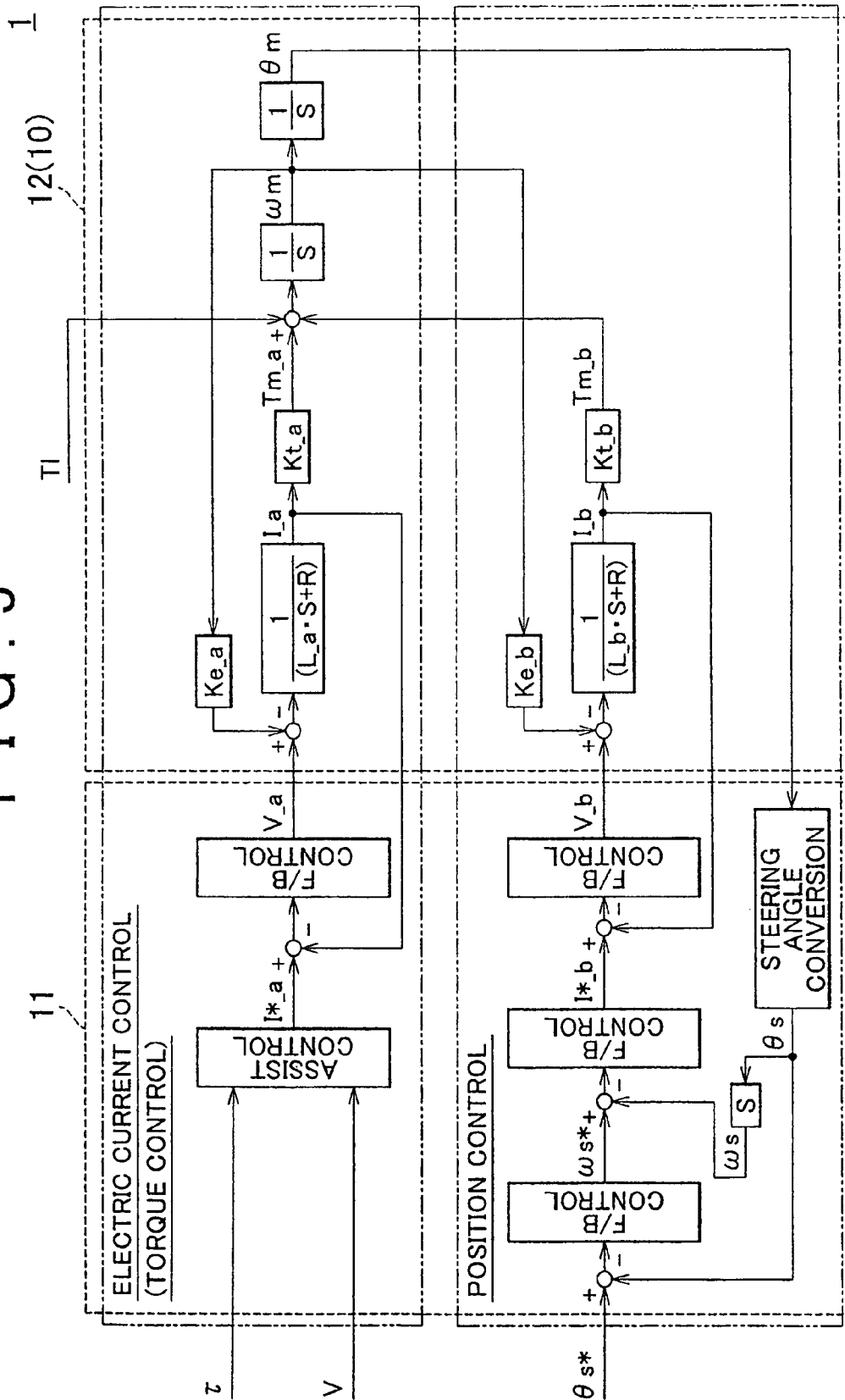


FIG. 5



**ELECTRIC POWER STEERING APPARATUS**

## BACKGROUND OF THE INVENTION

## 1. Field of the Invention

The invention relates to an electric power steering apparatus.

## 2. Description of Related Art

Among electric power steering apparatuses (EPSs), there is an apparatus that is equipped with an automatic control function of controlling the travel path of a vehicle by changing the steering angle of the vehicle's steering road wheels independently of the steering operation performed by a driver. Examples of this manner of automatic control includes a so-called lane keep assist control of recognizing a travel lane and assisting in the travel of the vehicle along the travel lane (see, e.g., Japanese Patent Application Publication No. 2005-343260 (JP-A-2005-343260)), a so-called parking assist control of assisting in the parking into a parking space (see, e.g., Japanese Patent Application Publication No. 2004-345468 (JP-A-2004-345468)), etc. In many cases, these automatic controls are performed on the basis of an assist command that is input from a superior or host control device (superior or host ECU) via an in-vehicle network.

However, in the construction in which the assist command is transferred via a network, it is inevitable that, due to differences in the communication protocol or specifications, the transfer of the assist command is delayed and therefore the responsiveness declines. Therefore, in an environment with an external disturbance such as a slope of the road surface, side wind, etc., there is a tendency toward large fluctuations of the value of the assist command that is computed so as to control the steering angle position of the steering road wheels. In consequence, particularly in the automatic control that is executed at the time of high-speed travel of the vehicle, there is a possibility of the locus of travel of the vehicle being disturbed.

## SUMMARY OF THE INVENTION

The invention provides an electric power steering apparatus capable of smoothly executing an automatic control by restraining the disturbance of the locus of travel of a vehicle even in an environment where an external disturbance exists.

An aspect of the invention relates to an electric power steering apparatus that includes: a steering force assist device that gives an assist force to a steering system based on magnetomotive force that is generated by motor coils of two systems that are provided independently of each other, and control means for controlling operation of the steering force assist device through supply of electric power to the motor coils. The control means includes drive circuits of two systems that are provided independently of each other corresponding to the motor coils. The control means includes first control signal output means for executing output of a control signal to the drive circuit of the first system by executing an electric current control so as to generate a motor torque that corresponds to the assist force. The control means includes second control signal output means for executing output of a control signal to the drive circuit of the second system by executing a position control based on a position command that is input so as to change steering angle of a steering road wheel.

That is, fundamentally, automatic controls, such as a lane keep assist control and the like, are realized by controlling the steering angle position. Then, the position control does not require such a high response as the power assist control (elec-

tric current control) requires. Therefore, by executing the position control for executing the automatic control independently of an electric current control (torque control) for executing the power assist control as in the foregoing construction, it is possible to optimize the responsiveness of the position control without causing a decline in the responsiveness in the power assist control, and therefore restrain the influences of fluctuations of the position command.

As a result, it becomes possible to smoothly execute the automatic control while restraining disturbance of the locus of travel of a vehicle even in an environment where an external disturbance exists. Besides, this makes it possible to smoothly and simultaneously perform the torque control and the position control even in an environment where an external disturbance exists.

In the foregoing aspect, the steering force assist device may use, as a drive source, an electric motor that includes a stator and a rotor that are used commonly for the motor coils.

According to this construction, the electric current control (torque control) for executing the power assist control, and the position control for executing the automatic control can be executed simultaneously and independently without increasing the size of the apparatus.

In the foregoing aspect, the electric motor may be a brushless electric motor.

According to this construction, the space allowance resulting from the absence of the brush of the electric motor becomes conspicuous if the electric motor has motor coils of two systems that are independent of each other. Therefore, this construction makes it possible to simplify and reduce the size of the electric motor as a drive source.

In the foregoing aspect, the control means may execute a position feedback loop of the position control, and may execute, as a minor loop of the position feedback loop, a feedback loop of at least one of a speed control, an electric current control and a voltage control.

According to this construction, the automatic control can be more smoothly executed.

According to the foregoing aspect of the invention, it is possible to provide an electric power steering apparatus capable of smoothly executing the automatic control while restraining disturbance in the locus of travel of a vehicle even in an environment where an external disturbance exists.

## BRIEF DESCRIPTION OF THE DRAWINGS

Features, advantages, and technical and industrial significance of exemplary embodiments of the invention will be described below with reference to the accompanying drawings, in which like numerals denote like elements, and wherein:

FIG. 1 is a schematic construction diagram of an electric power steering apparatus (EPS);

FIG. 2 is a schematic construction diagram of an electric motor;

FIG. 3 is a control block diagram of the EPS;

FIG. 4 is another control block diagram of the EPS; and

FIG. 5 is a block diagram showing a manner of an electric motor control in an embodiment of the invention.

## DETAILED DESCRIPTION OF EMBODIMENTS

Hereinafter, an embodiment of the invention will be described with reference to the drawings. As shown in FIG. 1, in an electric power steering apparatus (EPS) 1 of the embodiment, a steering shaft 3 to which a steering wheel 2 is fixed is linked to a rack shaft 5 via a rack-and-pinion mechanism 4.



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Rotation of the steering shaft **3** involved in the steering operation is converted into linear motion of the rack shaft **5** in either one of two opposite directions by the rack-and-pinion mechanism **4**. Incidentally, the steering shaft **3** in this embodiment is made up of a column shaft **3a**, an intermediate shaft **3b** and a pinion shaft **3c** that are linked together. Linear motion of the rack shaft **5** caused by rotation of the steering shaft **3** is transmitted to knuckles (not shown) via tie rods **6** that are connected to two ends of the rack shaft **5**, so that the steering angle of the steering road wheels **7**, that is, the travel direction of the vehicle, is changed.

Besides, the EPS **1** includes an EPS actuator as a steering force assist device that gives assist force for assisting in steering operation to a steering system, and an ECU **11** as control means for controlling the actuation of the EPS actuator **10**.

In this embodiment, the EPS actuator **10** is constructed as a so-called column-type EPS actuator whose electric motor **12** employed as a drive source is drivingly connected to the column shaft **3a** via a speed reduction mechanism **13**. The EPS actuator **10** transmits rotation of the electric motor **12** to the column shaft **3a** while reducing the speed of the rotation, whereby the motor torque is given as assist force to the steering system.

On the other hand, the ECU **1** is connected to a torque sensor **14** and a vehicle speed sensor **15**. On the basis of the steering torque  $\tau$  and the vehicle speed  $V$  detected from output signals of the sensors, the ECU **11** computes the assist force (target assist force) that is to be given to the steering system. Then, in order to cause the EPS actuator **10** to generate the target assist torque, the ECU **11** controls the actuation of the EPS actuator **10**, that is, controls the assist force given to the steering system, through supply of the electric power to the electric motor **12** provided as the drive source (power assist control).

Next, an electric construction of the EPS of the embodiment will be described. As shown in FIG. 2, the electric motor **12** in the embodiment is formed by winding motor coils **21A** and **21B** of two independent systems around a single stator **22**. Concretely, the motor coil **21A** (**21ua**, **21va** and **21wa**) of a first one of the two systems and the motor coil **21B** (**21ub**, **21vb** and **21wb**) of a second system are each wound separately for a corresponding one of phases (U, V and W) on a corresponding one of teeth **23** (**23u**, **23v** and **23w**) of the stator **22**. Then, at a radially inward side of the teeth **23** (**23u**, **23v** and **23w**), a rotor **24** is rotatably supported.

Specifically, the electric motor **12** in the embodiment has the stator **22** and the rotor **24** that are used commonly for the motor coils **21A** and **21B** of the two systems. The rotor **24** rotates on the basis of the magnetomotive force generated by motor coils **21A** and **21B** that are wound around the teeth **23** (**23u**, **23v** and **23w**). Then, the ECU **11** in the embodiment controls the motor torque of the electric motor **12** by supplying drive electric power to the motor coils **21A** and **21B** independently of each other.

As shown in FIG. 3, the ECU **11** in the embodiment includes two drive circuits **26A** and **26B** that are provided independently of each other corresponding to the motor coils **21A** and **21B**, and a microcomputer **27** that outputs control signals  $S_{mc\_a}$  and  $S_{mc\_b}$  to the drive circuits **26A** and **26B**, respectively, independently of each other.

Concretely, the drive circuit **26A** is connected to the motor coils **21A** of the first system via power lines **28A** (**28ua**, **28va** and **28wa**), and the drive circuit **26B** is connected to the motor coils **21B** of the second system via power lines **28B** (**28ub**, **28vb** and **28wb**). Besides, the control signal  $S_{mc\_a}$  that the microcomputer **27** outputs is input to the drive circuit **26A**,

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and the control signal  $S_{mc\_b}$  that the microcomputer **27** outputs is input to the drive circuit **26B**. Incidentally, in the embodiment, each of the drive circuits **26A** and **26B** employs a well-known PWM inverter made up of three basic units (three arms) each of which includes a pair of switching elements connected in parallel, and which correspond to the three phases and are connected in parallel. The control signals  $S_{mc\_a}$  and  $S_{mc\_b}$  that the microcomputer **27** outputs define the on-duty ratios of the three phase arms. The ECU **11** in the embodiment supplies drive electric power that the drive circuits **26A** and **26B** output on the basis of the control signals  $S_{mc\_a}$  and  $S_{mc\_b}$  to the corresponding motor coils **21A** and **21B** independently of each other.

This will be described in detail. As shown in FIG. 4, the microcomputer **27** in the embodiment includes a first control signal output portion **31A** as first control signal output means for outputting the control signal  $S_{mc\_a}$  to the drive circuit **26A** of the first system, and a second control signal output portion **31B** as second control signal output means for outputting the control signal  $S_{mc\_b}$  to the drive circuit **26B** of the second system.

In this embodiment, the first control signal output portion **31A** receives input of the steering torque  $\tau$  and the vehicle speed  $V$  detected by the torque sensor **14** and the vehicle speed sensor **15**. The first control signal output portion **31A** computes an electric current command value  $I^*_a$  that corresponds to a target assist force on the basis of the steering torque  $\tau$  and the vehicle speed  $V$ . Besides, the first control signal output portion **31A** also receives input of an actual value  $I_a$  of electric current that is passed through the motor coils **21A** of the first system and that is detected by the electric current sensors **32A**, and an electric motor rotation angle  $\theta_m$  that is detected by an electric motor resolver **33** (see FIG. 3). Then, the first control signal output portion **31A** outputs the control signal  $S_{mc\_a}$  to the drive circuit **26A** of the first system that corresponds to the first control signal output portion **31A**, by executing an electric current feedback control of causing the detected actual electric current value  $I_a$  to follow the electric current command value  $I^*_a$  that the first control signal output portion **31A** computes.

Concretely, in the first control signal output portion **31A** in the embodiment, the steering torque  $\tau$  and the vehicle speed  $V$  are input to an assist control portion **35**. The assist control portion **35** computes the electric current command value  $I^*_a$  so that greater motor torque, that is, greater assist force, is generated the greater the steering torque  $\tau$  is and the slower the vehicle speed  $V$  is. Furthermore, the electric current command value  $I^*_a$  are input to an electric current control portion **36**, together with the actual electric current value  $I_a$  detected by the electric current sensors **32A**. Then, the electric current control portion **36** executes an electric current feedback computation on the basis of an electric current deviation between the electric current command value  $I^*_a$  and the actual electric current value  $I_a$ .

In this embodiment, electric current sensors **32A** (**32ua**, **32va** and **32wa**) detect, as the actual electric current value  $I_a$ , the phase current values  $I_{u\_a}$ ,  $I_{v\_a}$  and  $I_{w\_a}$  of current passed through the motor coils **21A** of the first system. Then, the electric current control portion **36** in the embodiment executes the electric current feedback computation in a d/q coordinate system by converting the phase current values  $I_{u\_a}$ ,  $I_{v\_a}$  and  $I_{w\_a}$  into d-axis currents and q-axis current in the d/q coordinate system (d/q conversion).

That is, the assist control portion **35** in the embodiment computes a q-axis electric current command value as the electric current command value  $I^*_a$  (the d-axis electric current command value is "0"). Then, the electric current control

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portion 36 computes a voltage command value  $V^*_a$  that corresponds to each of the phases of the motor coils 21A by mapping on a three-phase alternating-current coordinates a voltage command value in the d/q coordinate system obtained through execution of the electric current feedback computation (inverse d/q conversion).

Then, the first control signal output portion 31A in the embodiment outputs the control signal  $Smc\_a$  that a PWM conversion portion 37 generates on the basis of the voltage command value  $V^*_a$ , to the corresponding drive circuit 26A of the first system.

On the other hand, the second control signal output portion 31B receives input of a position command regarding the steering wheel 2, that is, a steering angle command value  $\theta s^*$ , that is input from the superior ECU via the in-vehicle network (CAN: Controller Area Network) 40 (see FIG. 1). Incidentally, in the embodiment, the steering angle command value  $\theta s^*$  is input as a control command for automatically controlling the path of the vehicle and, more specifically, a control command for executing a so-called lane keep assist control, by changing the steering angle of the steering road wheels 7 independently of the steering operation of the driver. Besides, the second control signal output portion 31B in the embodiment detects the actual steering angle of the steering wheel 2, that is, the steering angle  $\theta s$ , on the basis of the electric motor rotation angle  $\theta m$  that is detected by the electric motor resolver 33. Then, the second control signal output portion 31B outputs the control signal  $Smc\_b$  to the corresponding drive circuit 26B of the second system by executing the position feedback control so as to cause the steering angle  $\theta s$  detected as the actual steering angle to follow the steering angle command value  $\theta s^*$  input to the second control signal output portion 31B.

Concretely, the electric motor rotation angle  $\theta m$  input to the second control signal output portion 31B is converted into the steering angle  $\theta s$  by the steering angle computation portion 41. The steering angle  $\theta s$  is input together with the steering angle command value  $\theta s^*$  to a position control portion 42. Then, the position control portion 42 executes a position feedback computation on the basis of a positional deviation between the steering angle command value  $\theta s^*$  and the steering angle  $\theta s$ .

The second control signal output portion 31B in the embodiment includes a speed control portion 43 and an electric current control portion 44 that form feedback loops of a speed control and an electric current control (torque control), respectively, as minor loops of a position feedback loop that the position control portion 42 forms.

That is, the position control portion 42 computes a steering angular speed command value  $\omega s^*$  through execution of the position feedback computation, and the speed control portion 43 computes an electric current command value  $I^*_b$  on the basis of a speed deviation between the steering angular speed command value  $\omega s^*$  and an actual steering angular speed  $\omega s$ . Furthermore, the electric current control portion 44 computes a voltage command value  $V^*_b$  by executing the electric current feedback computation on the basis of an electric current deviation between the electric current command value  $I^*_b$  and an actual electric current value  $I_b$  that is detected by electric current sensors 32B. Incidentally, the manner of the electric current detection performed by the electric current sensors 32B (32ub, 32vb and 32wb) (the detection of the three phase current values  $Iu\_b$ ,  $Iv\_b$  and  $Iw\_b$ ) and the manner of the electric current feedback computation that the electric current control portion 44 executes are substantially the same as the manner of the electric current detection that the electric current sensors 32A of the first system performs and the

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manner of the electric current feedback computation that the electric current control portion 36 executes, respectively. Then, the second control signal output portion 31B in the embodiment outputs the control signal  $Smc\_b$  that the PWM conversion portion 45 generates on the basis of the voltage command value  $V^*_b$ , to the corresponding drive circuit 26B of the second system.

In the foregoing manner, the microcomputer 27 in the embodiment outputs the control signals  $Smc\_a$  and  $Smc\_b$  to the drive circuits 26A and 26B of the two systems, respectively, independently of each other. Then, as shown in FIG. 5, the ECU 11 in the embodiment executes an electric current control (torque control) for executing the power assist control, and a position control for executing an automatic control, simultaneously and independently of each other.

In the block diagram of FIG. 5, “ $Tm$ ” is motor torque, and “ $Tl$ ” is load torque, and “ $Ke$ ” is a counter electromotive voltage constant. Furthermore, “ $1/(L \cdot S + R)$ ” is electric motor impedance (where R is armature winding wire resistance, L is inductance, and S is a differential operator).

According to the embodiment, operation and effects as follows can be obtained.

(1) The ECU 11 includes the two drive circuits 26A and 26B provided corresponding to the motor coils 21A and 21B of the two systems independent of each other, and the microcomputer 27 that outputs the independent control signals  $Smc\_a$  and  $Smc\_b$  of the two systems to the drive circuits 26A and 26B. The microcomputer 27 includes the first control signal output portion 31A that outputs the control signal  $Smc\_a$  to the drive circuit 26A of the first system by executing the electric current control so as to generate the motor torque that corresponds to the assist force. Furthermore, the microcomputer 27 also includes the second control signal output portion 31B that outputs the control signal  $Smc\_b$  to the drive circuit 26B of the second system by executing the position control on the basis of the steering angle command value  $\theta s^*$  that is input from the superior ECU via the in-vehicle network 40, so as to change the steering angle of the steering road wheels.

That is, fundamentally, the automatic control, such as the lane keep assist control or the like, is realized by controlling the steering angle position. In the position control, such a high response as required in the power assist control (electric current control) is not required. Therefore, as in the foregoing construction, by executing the position control for executing the automatic control independently of the electric current control (torque control) for executing the power assist control, it is possible to optimize the response of the position control without causing a decline in the responsiveness in the power assist control, and therefore to restrain the influence caused by changes of the position command (steering angle command value  $\theta s^*$ ). As a result, even in an environment with an external disturbance, it is possible to restrain the disturbance in the locus of travel and smoothly execute the automatic control.

(2) The EPS actuator 10 uses as a drive source the electric motor 12 that has the stator 22 and the rotor 24 that are common to the motor coils 21A and 21B of the two systems. Therefore, the electric current control (torque control) for executing the power assist control, and the position control for executing the automatic control can be executed simultaneously and independently of each other without increasing the size of the apparatus.

(3) The second control signal output portion 31B includes the speed control portion 43 and the electric current control portion 44 that form the feedback loops of the speed control and the electric current control (torque control) as minor

loops of the position feedback loop that the position control portion **42** forms. Therefore, the automatic control can be executed more smoothly.

Incidentally, the foregoing embodiment may be modified or changed as follows.

(a) Although in the foregoing embodiment, the invention is embodied as the so-called column type EPS **1**, the invention may also be applied to a so-called pinion type or rack-assist type EPS.

(b) In the embodiment, the EPS actuator **10** uses as a drive source the electric motor **12** that has the stator **22** and the rotor **24** that are used commonly for the motor coils **21A** and **21B** of the two systems. However, this construction is not restrictive, that is, each motor coil may have its own stator or its own rotor. Furthermore, the invention is also applicable to a construction that employs two electric motors as drive sources.

(c) Besides, the motor coils of each system may be disposed so as to have a relationship in which the phases of the coils are deviated from each other. Furthermore, the invention may also be embodied not only as the EPS but also as an electric motor control system that controls an electric motor that is equipped with motor coils of two systems provided independently of each other.

(d) Although in the foregoing embodiment, the electric motor **12** used is a brushless electric motor in which the motor coils **21A** and **21B** of the independent two systems are wound on the same stator **22**, the invention may also be embodied in a brush-equipped electric motor that includes an armature rotor that has motor coils of two systems.

(e) In the foregoing embodiment, the ECU **11** has the two drive circuits **26A** and **26B** that are provided independently corresponding to the motor coils **21A** and **21B**. However, the construction in which each system is equipped with a back-up drive circuit, and the like, and the numbers of drive circuits in each system, are not particularly limited.

(f) In the foregoing embodiment, the feedback loops of the speed control and the electric current control (torque control) are provided as minor loops of the position feedback loop. However, the minor loops may be changed as appropriate; for example, at least one of the speed feedback loop and the electric current feedback loop may be omitted, or a voltage feedback loop may be added.

(g) In the foregoing embodiment, the lane keep assist control is executed as an automatic control. However, this is not restrictive. The manner of the automatic control may be any manner as long as the control is realized by the position control regarding the steering angle (electric motor rotation angle); for example, the automatic control may be a parking

assist control, a control of controlling the steering angle of the steering road wheels so as to control the posture of the vehicle, etc.

(h) Although in the foregoing embodiment, the actual steering angle of the steering wheel **2**, that is, the steering angle  $\theta_s$ , is detected on the basis of the electric motor rotation angle  $\theta_m$  detected by the electric motor resolver **33**, it is also permissible to adopt a construction in which the steering angle  $\theta_s$  is directly detected by using a steering sensor.

The invention claimed is:

**1.** An electric power steering apparatus comprising:

a steering force assist device that gives an assist force to a steering system based on magnetomotive force that is generated by motor coils of two systems that are provided independently of each other, the two systems including a first system and a second system; and

a controller configured to control operation of the steering force assist device through supply of electric power to the motor coils,

the controller including:

a drive circuit of the first system and a drive circuit of the second system that are provided independently of each other, the first system being configured to control the assist force given to the steering system and the second system being configured to control a steering angle of a steering road wheel independently of a steering operation of a driver;

a first control signal output unit configured to output a first control signal to the drive circuit of the first system by executing an electric current control so as to generate a motor torque that corresponds to the assist force; and

a second control signal output unit configured to output a second control signal to the drive circuit of the second system by executing a position control based on a position command that is input so as to change the steering angle of the steering road wheel.

**2.** The electric power steering apparatus according to claim **1**, wherein the steering force assist device uses, as a drive source, an electric motor that includes a stator and a rotor.

**3.** The electric power steering apparatus according to claim **2**, wherein the electric motor is a brushless electric motor.

**4.** The electric power steering apparatus according to claim **1**, wherein the controller executes a position feedback loop of the position control, and executes, as a minor loop of the position feedback loop, a feedback loop of at least one of a speed control, an electric current control and a voltage control.

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