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Inventor(s)	Sonoda; Hiroki et al.

Steer-by-wire type steering device

Abstract

A steering device according to the present invention includes: a steering input device including a reaction force actuator that applies a steering reaction force to a steering operation input member; and a control device including a steering gear ratio change unit that changes a steering gear ratio in accordance with a vehicle speed, a reaction force actuator control unit that controls an output amount of the reaction force actuator in accordance with an operation angular velocity of the steering operation input member, and a reaction force actuator output amount change unit that changes, based on the steering gear ratio, the output amount of the reaction force actuator. This makes it possible to set an appropriate steering reaction force applied to the steering operation input member, thereby stably reducing the operational burden on a driver.

Inventors:	**Sonoda; Hiroki (Hitachinaka, JP), Hasegawa; Yoshiji (Hitachinaka, JP), Fujibayashi; Tomoaki (Hitachinaka, JP)**
Applicant:	**HITACHI ASTEMO, LTD.** (Hitachinaka, JP)
Family ID:	**1000008762356**
Assignee:	**HITACHI ASTEMO, LTD. (Hitachinaka, JP)**
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Primary Examiner: Amick; Jacob M

Attorney, Agent or Firm: FOLEY & LARDNER LLP

Background/Summary

TECHNICAL FIELD
(1) The present invention relates to a steer-by-wire type steering device.
BACKGROUND ART
(2) A vehicle steering device of Patent Document 1 calculates a steering gear ratio G and a turning angle δ based on a vehicle speed V and further calculates a steering reaction force T from the sum of a steering reaction force component T (V, θ) corresponding to the vehicle speed V and a steering angle θ, a friction component Tf, and a steering reaction force component T (θ′) corresponding to a steering angular velocity θ′, and the steering reaction force component T (V, θ) is characterized in having a smaller value as the vehicle speed V increases.
REFERENCE DOCUMENT LIST

Patent Document
(3) Patent Document 1: JP 2013-23145 A
SUMMARY OF THE INVENTION
Problem to be Solved by the Invention
(4) In a steer-by-wire type steering device, when a steering gear ratio is set to be variable and a steering reaction force applied to a steering operation input member such as a steering wheel is set to be variable in accordance with an operation angular velocity [deg/s] of the steering operation input member, a set value of the steering reaction force may become too small or too large depending on the steering gear ratio, which may increase the operational burden on a driver.
(5) The present invention has been made in view of conventional circumstances, and an object thereof is to provide a steer-by-wire type steering device capable of setting an appropriate steering reaction force applied to a steering operation input member, thereby stably reducing the operational burden on a driver.
Means for Solving the Problem
(6) According to the present invention, in one aspect, a steer-by-wire type steering device mounted in a vehicle includes: a steering input device including a steering operation input member, and a reaction force actuator that applies a steering reaction force to the steering operation input member; and a control device including a steering gear ratio change unit that changes a steering gear ratio in accordance with a vehicle speed of the vehicle, the steering gear ratio being a ratio of a steering angle of a wheel of the vehicle to an operation angle of the steering operation input member, a reaction force actuator control unit that controls an output amount of the reaction force actuator in accordance with an operation angular velocity of the steering operation input member, and a reaction force actuator output amount change unit that changes, based on the steering gear ratio, the output amount of the reaction force actuator corresponding to the operation angular velocity.
Effects of the Invention
(7) According to the present invention, it is possible to set an appropriate steering reaction force applied to the steering operation input member, thereby stably reducing the operational burden on a driver, even under different conditions of the steering gear ratio and the operation angular velocity of the steering operation input member.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
(1) FIG. **1** is a system configuration diagram of a steer-by-wire type steering device.
(2) FIG. **2** is a functional block diagram of a steering control device.
(3) FIG. **3** is a diagram illustrating, as an example, the correlation between a vehicle speed V and a steering gear ratio Kg.
(4) FIG. **4** is a functional block diagram illustrating a first embodiment of a reaction force torque calculation unit.
(5) FIG. **5** is a diagram illustrating the correlation between an operation angle θ and a steering reaction force torque Ts−θ.
(6) FIG. **6** is a diagram illustrating the correlation between the vehicle speed V and a first gain G**1**.
(7) FIG. **7** is a diagram illustrating the correlation between an operation angular velocity $\Delta\theta$ and the steering reaction force torque Ts−0.
(8) FIG. **8** is a diagram illustrating the correlation between the steering gear ratio Kg and a second gain G**2**.
(9) FIG. **9** is a diagram illustrating differences in a second steering reaction force torque Ts**2** corresponding to the operation angular velocity $\Delta\theta$ caused by the steering gear ratio Kg.
(10) FIG. **10** is a flowchart illustrating a procedure of a process of calculating a steering reaction

force torque Ts.
(11) FIG. **11** is a time chart illustrating the correlation between the operation angle θ, the operation angular velocity Δθ, and the steering reaction force torque Ts.
(12) FIG. **12** is a functional block diagram illustrating a second embodiment of the reaction force torque calculation unit.
(13) FIG. **13** is a diagram illustrating switching of the correlation between the steering gear ratio Kg and the second gain G**2** in accordance with an operation direction (additional steering and turning-back steering).
(14) FIG. **14** is a functional block diagram illustrating a third embodiment of the reaction force torque calculation unit.
MODE FOR CARRYING OUT THE INVENTION
(15) Hereinbelow, embodiments of a steer-by-wire type steering device according to the present invention will be described with reference to the drawings.
(16) FIG. **1** is a system configuration diagram illustrating one aspect of a steer-by-wire type steering device **200** mounted on a vehicle **100** such as a motor vehicle. Reference character Fr in FIG. **1** indicates the front of the vehicle.
(17) Steering device **200** is a steering system in which front wheels **101** and **102** to be turned are mechanically separated from a steering wheel **310** serving as a steering operation input member.
(18) Steering device **200** includes a steering input device **300** including steering wheel **310**, a steering actuator device **400**, and a steering control device **500**.
(19) Steering input device **300** includes steering wheel **310**, a steering shaft **320**, a reaction force actuator **330**, and an operation angle sensor **340**.
(20) Steering shaft **320** rotates in response to turning of steering wheel **310**, but is mechanically separated from front wheels **101** and **102**.
(21) Reaction force actuator **330** is a device that applies a steering reaction force to steering shaft **320** using a motor and the like and includes, for example, a torque damper, an operation angle limiting mechanism, and a speed reducer in addition to the motor.
(22) Since steering device **200** includes reaction force actuator **330** described above, a difference between an operation torque generated by a driver of vehicle **100** operating steering wheel **310** and a steering reaction force torque generated by reaction force actuator **330** turns steering wheel **310**.
(23) Operation angle sensor **340** is a sensor that detects a rotation angle of steering shaft **320**, in other words, an operation angle θ of steering wheel **310**.
(24) Operation angle sensor **340**, for example, detects that the operation angle θ is zero when steering wheel **310** is located at a neutral position, and indicates the operation angle θ in the right direction with a plus and the operation angle θ in the left direction with a minus.
(25) Note that, in the present application, an increase in the operation angle θ includes both an increase in the operation angle θ in the right direction and an increase in the operation angle θ in the left direction.
(26) Steering actuator device **400** includes a steering actuator **410** such as a motor, a turning mechanism **420** that turns front wheels **101** and **102** using the steering actuator, and a steering angle sensor **430** that detects a steering angle δ of front wheels **101** and **102** (in other words, a turning angle of the front wheels) from a position of steering actuator **410**.
(27) Steering control device **500** is an electronic control device mainly composed of a microcomputer **510** including a microprocessor unit (MPU), a read only memory (ROM), and a random access memory (RAM). Steering control device **500** performs an arithmetic process based on various signals acquired from the outside and outputs a control signal for reaction force actuator **330** and a control signal for steering actuator **410**.
(28) Also, vehicle **100** includes wheel speed sensors **621** to **624** that detect wheel speeds, which are rotation speeds of wheels **101** to **104**, respectively.
(29) Steering control device **500** acquires detection signals output from operation angle sensor **340**,

steering angle sensor **430**, and wheel speed sensors **621** to **624**.
(30) Then, steering control device **500** calculates a target steering angle δtg based on a detection value of the operation angle θ of steering wheel **310** and a set value of a steering gear ratio Kg and calculates a control signal to be output to steering actuator **410** so that the steering angle δ of front wheels **101** and **102** approaches the target steering angle δtg.
(31) Note that the steering gear ratio Kg is a value defined as "Steering gear ratio Kg=Operation angle θ of steering wheel **310**/Steering angle δ of front wheels **101** and **102**" and can be set to any value in steer-by-wire type steering device **200**.
(32) As the steering gear ratio Kg decreases, the steering angle δ of front wheels **101** and **102** relative to the operation angle θ of steering wheel **310** increases, and a slight turn of steering wheel **310** greatly changes the turning angle of front wheels **101** and **102**.
(33) On the other hand, as the steering gear ratio Kg increases, the steering angle δ of front wheels **101** and **102** relative to the operation angle θ of steering wheel **310** decreases, and steering wheel **310** needs to be turned much more to change the turning angle of front wheels **101** and **102**.
(34) Hereinbelow, a process of setting the steering gear ratio Kg and a steering reaction force torque Ts (in other words, an output amount of reaction force actuator **330**) by steering control device **500** will be described in detail.
(35) FIG. **2** is a functional block diagram illustrating one aspect of steering control device **500** (more specifically, microcomputer **510**).
(36) Steering control device **500** has functions as an operation angle acquisition unit **520**, a vehicle speed acquisition unit **530**, a steering gear ratio calculation unit **540**, and a reaction force torque calculation unit **550**.
(37) Operation angle acquisition unit **520** captures a signal output from operation angle sensor **340** to acquire information on the operation angle θ [deg] of steering wheel **310**.
(38) Note that the operation angle θ is signed data and indicates whether steering wheel **310** is operated in the right direction or the left direction from the neutral position using a sign.
(39) Vehicle speed acquisition unit **530** captures signals output from wheel speed sensors **621** to **624** to acquire information on the vehicle speed V [km/h] of vehicle **100**.
(40) Note that vehicle speed acquisition unit **530** may capture an output from a vehicle speed sensor that detects the vehicle speed V from a rotation speed of a driving shaft of vehicle **100** to acquire information on the vehicle speed V.
(41) Steering gear ratio calculation unit **540** captures information on the vehicle speed V from vehicle speed acquisition unit **530** and changes the set value of the steering gear ratio Kg in accordance with the information on the vehicle speed V.
(42) That is, steering gear ratio calculation unit **540** functions as a steering gear ratio change unit.
(43) FIG. **3** is a diagram illustrating one aspect of the correlation between the vehicle speed V and the steering gear ratio Kg.
(44) Steering gear ratio calculation unit **540** maintains the steering gear ratio Kg at a minimum value Kgmin in a speed range of the vehicle speed V from a vehicle speed V**2** to a vehicle speed V**3** (V**2**<V**3**).
(45) Steering gear ratio calculation unit **540** proportionally increases the steering gear ratio Kg as the vehicle speed V increases in a speed range of the vehicle speed V from the vehicle speed V**3** to a vehicle speed V**4** (V**3**<V**4**) and maintains the steering gear ratio Kg at a maximum value Kgmax in a speed range of the vehicle speed V equal to or greater than the vehicle speed V**4**.
(46) Steering gear ratio calculation unit **540** proportionally increases the steering gear ratio Kg as the vehicle speed V decreases in a speed range of the vehicle speed V from a vehicle speed V**1** to the vehicle speed V**2** (V**1**<V**2**) and maintains the steering gear ratio Kg at a median value Kgmid (Kgmin<Kgmid<Kgmax) in a speed range of the vehicle speed V equal to or less than the vehicle speed V**1**.
(47) That is, in the example illustrated in FIG. **3**, the steering gear ratio Kg is decreased as the

vehicle speed V decreases in the speed range equal to or greater than the vehicle speed V**2**.
(48) When vehicle **100** turns, while a low-speed turn often has a small turn radius and thus requires a large steering angle δ, a high-speed turn often has a large turn radius and thus usually does not require a large steering angle δ.
(49) Thus, if the steering gear ratio Kg is constant regardless of the vehicle speed V, the driver may frequently change hand positions holding steering wheel **310** in a low-speed turn, which may increase the operational burden on the driver, and the direction of vehicle **100** may excessively change in response to an operation on steering wheel **310** in a high-speed turn, which may deteriorate the steering stability.
(50) Thus, steering gear ratio calculation unit **540** basically decreases the steering gear ratio Kg as the vehicle speed V decreases, thereby ensuring a sufficient steering stability in a high speed range while reducing the operational burden on the driver in a low speed range. Note that the vehicle speeds V**1** to V**4** in FIG. **3** are, for example, the vehicle speed V**1**=5 km/h, the vehicle speed V**2**=10 km/h, the vehicle speed V**3**=20 km/h, and the vehicle speed V**4**=60 km/h.
(51) However, the correlation between the vehicle speed V and the steering gear ratio Kg is not limited to the correlation illustrated in FIG. **3**.
(52) For example, steering gear ratio calculation unit **540** may maintain or increase the steering gear ratio Kg in response to an increasing change of the vehicle speed V without decreasing the steering gear ratio Kg in response to an increasing change of the vehicle speed V, so that the steering gear ratio Kg has a minimum value when the vehicle speed Vis zero and is increased as the vehicle speed V increases.
(53) Reaction force torque calculation unit **550** captures information on the vehicle speed V acquired by vehicle speed acquisition unit **530**, the operation angle θ of steering wheel **310** acquired by operation angle acquisition unit **520**, and the steering gear ratio Kg calculated by steering gear ratio calculation unit **540**.
(54) Then, reaction force torque calculation unit **550** obtains a command value of the steering reaction force torque Ts [Nm] (in other words, the output amount of reaction force actuator **330**) based on the vehicle speed V, the operation angle θ, an operation angular velocity Δθ [deg/s] calculated from the operation angle θ, and the steering gear ratio Kg.
(55) Note that reaction force torque calculation unit **550** calculates the steering reaction force torque Ts with a sign and indicates the direction of the steering reaction force torque Ts using the sign.
(56) As will be described further later, reaction force torque calculation unit **550** has a function as a reaction force actuator control unit that controls the steering reaction force torque Ts in accordance with the operation angular velocity Δθ of steering wheel **310** and a function as a reaction force actuator output amount change unit that changes, based on the steering gear ratio Kg, the steering reaction force torque Ts corresponding to the operation angular velocity Δθ.
First Embodiment
(57) FIG. **4** is a functional block diagram illustrating a first embodiment of reaction force torque calculation unit **550**.
(58) Reaction force torque calculation unit **550** illustrated in FIG. **4** includes a first reaction force torque calculation unit **551**, an operation angular velocity calculation unit **552**, a second reaction force torque calculation unit **553**, and an adder unit **554**.
(59) First reaction force torque calculation unit **551** calculates a first steering reaction force torque Ts**1** based on an operation angle θ and a vehicle speed V.
(60) Specifically, first reaction force torque calculation unit **551** calculates a steering reaction force torque Ts−θ based on the operation angle θ and calculates a first gain G**1** based on the vehicle speed V. Then, first reaction force torque calculation unit **551** multiplies the steering reaction force torque Ts−θ by the first gain G**1** to calculate the first steering reaction force torque Ts**1** (Ts**1**=Ts−θ.Math.G**1**).

(61) FIG. **5** is a diagram illustrating one aspect of the correlation between the operation angle θ and the steering reaction force torque Ts−θ.
(62) First reaction force torque calculation unit **551** sets the steering reaction force torque Ts−θ to zero when the operation angle θ is zero and steering wheel **310** is located at the neutral position.
(63) First reaction force torque calculation unit **551** gradually increases the absolute value of the steering reaction force torque Ts−θ as the absolute value of the operation angle θ increases.
(64) FIG. **6** is a diagram illustrating one aspect of the correlation between the vehicle speed V and the first gain G**1**.
(65) First reaction force torque calculation unit **551** sets the first gain G**1** (G**1**>0) to a larger value as the vehicle speed V decreases.
(66) Accordingly, first reaction force torque calculation unit **551** sets the first steering reaction force torque Ts**1** to a larger value as the absolute value of the operation angle θ of steering wheel **310** increases and also as the vehicle speed V at the time decreases.
(67) Operation angular velocity calculation unit **552** differentiates data of the operation angle θ by time to calculate an operation angular velocity Δθ [deg/s].
(68) Specifically, operation angular velocity calculation unit **552** obtains a difference between a latest value of the operation angle θ and a value of the operation angle θ acquired earlier by a predetermined time and obtains the operation angular velocity Δθ, which is a change amount of the operation angle θ per unit time.
(69) Second reaction force torque calculation unit **553** calculates a second steering reaction force torque Ts**2** based on the operation angular velocity Δθ and a steering gear ratio Kg.
(70) Specifically, second reaction force torque calculation unit **553** calculates a steering reaction force torque Ts−Δθ based on the operation angular velocity Δθ and also calculates a second gain G**2** based on the steering gear ratio Kg. Then, second reaction force torque calculation unit **553** multiplies the steering reaction force torque Ts−Δθ by the second gain G**2** to calculate the second steering reaction force torque Ts**2** (Ts**2**=Ts−Δθ .Math. G**2**).
(71) The function of second reaction force torque calculation unit **553** that calculates the steering reaction force torque Ts−Δθ based on the operation angular velocity Δθ corresponds to the function of the reaction force actuator control unit that controls the steering reaction force torque Ts in accordance with the operation angular velocity Δθ of steering wheel **310**.
(72) Also, the function of second reaction force torque calculation unit **553** that corrects the second steering reaction force torque Ts**2** using the second gain G**2** obtained based on the steering gear ratio Kg corresponds to the function of the reaction force actuator output amount change unit that changes, based on the steering gear ratio Kg, the steering reaction force torque Ts−Δθ corresponding to the operation angular velocity Δθ.
(73) Adder unit **554** captures the first steering reaction force torque Ts**1** from first reaction force torque calculation unit **551**, further captures the second steering reaction force torque Ts**2** from second reaction force torque calculation unit **553**, and obtains the sum of the first steering reaction force torque Ts**1** and the second steering reaction force torque Ts**2** as a command value of the final steering reaction force torque Ts (Ts=Ts**1**+Ts**2**).
(74) That is, reaction force torque calculation unit **550** determines the steering reaction force torque Ts using the first steering reaction force torque Ts**1** corresponding to the operation angle θ and the second steering reaction force torque Ts**2** corresponding to the operation angular velocity Δθ, corrects the first steering reaction force torque Ts**1** corresponding to the operation angle θ in accordance with the vehicle speed V, and corrects the second steering reaction force torque Ts**2** corresponding to the operation angular velocity Δθ in accordance with the steering gear ratio Kg.
(75) Hereinbelow, a process of calculating the second steering reaction force torque Ts**2** by second reaction force torque calculation unit **553** will be described in detail.
(76) FIG. **7** is a diagram illustrating one aspect of the correlation between the operation angular velocity Δθ and the steering reaction force torque Ts−Δθ

(77) Second reaction force torque calculation unit **553** sets the steering reaction force torque Ts−Δθ to zero when the operation angular velocity Δθ is zero and there is no change in the operation angle θ of steering wheel **310**, in other words, the operation angle θ is maintained constant.
(78) Second reaction force torque calculation unit **553** increases the absolute value of the steering reaction force torque Ts−Δθ as the absolute value of the operation angular velocity Δθ increases, and increases a steering reaction force torque applied to steering wheel **310** as the speed of turning steering wheel **310** increases.
(79) FIG. **8** is a diagram illustrating one aspect of the correlation between the steering gear ratio Kg and the second gain G**2**.
(80) Second reaction force torque calculation unit **553** sets the second gain G**2** to a larger value as the steering gear ratio Kg decreases.
(81) As the steering gear ratio Kg decreases, a steering angle δ relative to the operation angle θ increases, and a slight turn of steering wheel **310** greatly changes the turning angle of front wheels **101** and **102**.
(82) Thus, second reaction force torque calculation unit **553** sets the second gain G**2** to a greater value as the steering angle δ relative to the operation angle θ increases.
(83) Furthermore, second reaction force torque calculation unit **553** sets the second gain G**2** to a positive value when the steering gear ratio Kg is less than a predetermined value Kgth, sets the second gain G**2** to a negative value when the steering gear ratio Kg is greater than the predetermined value Kgth, and sets the second gain G**2** to zero when the steering gear ratio Kg is the predetermined value Kgth.
(84) Second reaction force torque calculation unit **553** increases the absolute value of the second gain G**2** as the absolute value of the deviation between the steering gear ratio Kg and the predetermined value Kgth increases.
(85) FIG. **9** is a diagram illustrating the correlation between the second steering reaction force torque Ts**2** obtained by multiplying the steering reaction force torque Ts−Δθ by the second gain G**2** and the steering gear ratio Kg.
(86) When the steering gear ratio Kg is less than the predetermined value Kgth, the second gain G**2** is positive. Thus, the second steering reaction force torque Ts**2** is calculated to have the same sign as the sign of the steering reaction force torque Ts−Δθ and the calculated value corrects the first steering reaction force torque Ts**1** in an increasing manner.
(87) The absolute value of the second steering reaction force torque Ts**2** increases as the absolute value of the operation angular velocity Δθ increases and increases as the steering gear ratio Kg decreases.
(88) That is, when the steering gear ratio Kg is less than the predetermined value Kgth, the steering reaction force torque applied to steering wheel **310** (in other words, the output amount of reaction force actuator **330**) increases as the operation angular velocity Δθ increases and increases as the steering gear ratio Kg decreases.
(89) Accordingly, when the driver suddenly operates steering wheel **310**, which increases the operation angular velocity Δθ, in the low speed range in which the steering gear ratio Kg is set to a small value, second reaction force torque calculation unit **553** increases the second steering reaction force torque Ts**2** to increase the steering reaction force torque Ts, thereby preventing an excessive turning of steering wheel **310**.
(90) On the other hand, even in the low speed range in which the steering gear ratio Kg is set to a small value, when the driver holds steering wheel **310** and the operation angular velocity Δθ becomes close to zero, second reaction force torque calculation unit **553** sets the steering reaction force torque Ts−Δθ to a value close to zero, thereby decreasing the second steering reaction force torque Ts**2**.
(91) This reduces the operational burden on the driver holding steering wheel **310** and improves operating feel of the driver.

(92) On the other hand, when the steering gear ratio Kg is greater than the predetermined value Kgth, the second gain G**2** is set to a negative value. Thus, the sign of the second steering reaction force torque Ts**2** is the inverse of the sign of the steering reaction force torque Ts−Δθ and the steering reaction force torque Ts−θ and the value of the second steering reaction force torque Ts**2** corrects the first steering reaction force torque Ts**1** in a decreasing manner.
(93) Second reaction force torque calculation unit **553** increases the absolute value of the second steering reaction force torque Ts**2** as the absolute value of the operation angular velocity Δθ increases and increases the absolute value of the second steering reaction force torque Ts**2** as the steering gear ratio Kg increases.
(94) Thus, when the steering gear ratio Kg is greater than the predetermined value Kgth, as the operation angular velocity Δθ increases, the absolute value of the second steering reaction force torque Ts**2** with the inverted sign increases, and the steering reaction force torque Ts becomes less than that when the operation angular velocity Δθ is small.
(95) That is, when the steering gear ratio Kg is greater than the predetermined value Kgth, second reaction force torque calculation unit **553** decreases the second steering reaction force torque Ts**2** as the operation angular velocity Δθ increases.
(96) Accordingly, even in the high speed range in which a large steering angle δ is usually not required, for example, when the driver suddenly operates steering wheel **310** to avoid an obstacle (in other words, when it is necessary to greatly turn steering wheel **310**), the steering reaction force torque Ts becomes less than that in a case in which the operation angular velocity Δθ is small.
(97) This reduces the operational burden on the driver and improves the steerability (obstacle avoiding performance) of vehicle **100**.
(98) Also, in the high speed range in which a large steering angle δ is usually not required, when the driver holds steering wheel **310** and the operation angular velocity Δθ is small, the steering reaction force torque Ts becomes greater than that in a case in which the operation angular velocity Δθ is large, which enables prevention of wobbling of steering wheel **310**.
(99) Note that the characteristic of the second gain G**2** used to calculate the second steering reaction force torque Ts**2** is not limited to the characteristic in FIG. **8**, that is, the characteristic of gradually increasing from a negative value to a positive value as the steering gear ratio Kg decreases.
(100) For example, second reaction force torque calculation unit **553** may set the second gain G**2** to G**2**>0 and gradually increases the second gain G**2** as the steering gear ratio Kg degreases.
(101) FIG. **10** is a flowchart illustrating a procedure of calculating the steering reaction force torque Ts by steering control device **500** (more specifically, reaction force torque calculation unit **550**).
(102) In step S**801** (first reaction force torque calculation unit **551**), steering control device **500** calculates the first steering reaction force torque Ts**1** based on the vehicle speed V and the operation angle θ.
(103) Then, in step S**802** (operation angular velocity calculation unit **552**), steering control device **500** calculates the operation angular velocity Δθ from the operation angle θ.
(104) Furthermore, in the next step S**803** (second reaction force torque calculation unit **553**), steering control device **500** calculates the second steering reaction force torque Ts**2** based on the operation angular velocity Δθ and the steering gear ratio Kg.
(105) Then, in step S**804** (adder unit **554**), steering control device **500** adds the first steering reaction force torque Ts**1** and the second steering reaction force torque Ts**2** to obtain the steering reaction force torque Ts and outputs a command signal of the steering reaction force torque Ts to reaction force actuator **330**.
(106) FIG. **11** is a time chart illustrating, as an example, the correlation between the operation angle θ, the operation angular velocity Δθ, and the steering reaction force torque Ts in the low speed range in which the second gain G**2** is set to a positive value.
(107) In FIG. **11**, a solid line indicates the steering reaction force torque Ts when the steering gear

ratio Kg is a first steering gear ratio Kg**1**, and a broken line indicates the steering reaction force torque Ts when the steering gear ratio Kg is a second steering gear ratio Kg**2** greater than the first steering gear ratio Kg**1** (Kg**1**<Kg**2**).
(108) As described above, the steering reaction force torque Ts is the sum of the first steering reaction force torque Ts**1** corresponding to the operation angle θ and the second steering reaction force torque Ts**2** corresponding to the operation angular velocity Δθ.
(109) The first steering reaction force torque Ts**1** increases as the absolute value of the operation angle θ increases.
(110) On the other hand, the second steering reaction force torque Ts**2** is set to zero when the operation angular velocity Δθ is zero (in other words, when the operation angle θ is constant) and increases as the absolute value of the operation angular velocity Δθ increases.
(111) Thus, in a state in which steering wheel **310** is in a held state and the operation angular velocity Δθ is zero from time t**0** to time t**2** and the operation angular velocity Δθ is zero from time t**3** to time t**4**, the steering reaction force torque Ts is equal to the first steering reaction force torque Ts**1**, and the steering reaction force torque Ts corresponding to the operation angle θ is set.
(112) Also, in a state in which the operation angle θ changes from time t**1** to time t**3**, the first steering reaction force torque Ts**1** changes in an increasing manner as the operation angle θ increases. In addition, since the operation angular velocity Δθ is not zero, the second steering reaction force torque Ts**2** is set to be greater as the operation angular velocity **40** increases, and the steering reaction force torque Ts greater than the first steering reaction force torque Ts**1** is set.
(113) In addition, since the second steering reaction force torque Ts**2** increases as the steering gear ratio Kg decreases, in a state in which the operation angle θ changes from time t**1** to time t**3**, the steering reaction force torque Ts when the steering gear ratio Kg is the first steering gear ratio Kg**1** is greater than the steering reaction force torque Ts when the steering gear ratio Kg is the second steering gear ratio Kg**2** (Kg**1**<Kg**2**).
(114) Accordingly, the steering reaction force torque Ts is greater when the steering gear ratio Kg is small in a state in which the driver operates steering wheel **310** to turn than when the steering gear ratio Kg is large.
(115) In this manner, in the low speed range, steering control device **500** decreases the steering gear ratio Kg to prevent the driver from frequently changing hand positions holding steering wheel **310** and also increases the steering reaction force torque Ts to prevent an operation on steering wheel **310**, the operation excessively increasing the steering angle δ when the steering gear ratio Kg is decreased.
(116) Thus, steering control device **500** can prevent vehicle behavior such as entanglement caused by a too small turning radius of vehicle **100**, which enables the driver to more appropriately steer vehicle **100**.
(117) For example, when vehicle **100** enters an intersection, reaction force torque calculation unit **550** decreases the steering gear ratio Kg as the vehicle speed V decreases and, in parallel with this decreasing change of the steering gear ratio Kg, increases the second steering reaction force torque Ts**2** corresponding to the operation angular velocity Δθ in response to the decrease in the steering gear ratio Kg.
(118) Thus, even if the steering gear ratio Kg decreases when vehicle **100** enters an intersection, the turning radius of vehicle **100** is prevented from becoming too small, which improves the trace performance of vehicle **100** in turning at the intersection.
(119) In addition, when the state of the driver goes from turning steering wheel **310** to holding steering wheel **310** in turning of vehicle **100**, reaction force torque calculation unit **550** decreases the steering reaction force torque Ts in response to the occurrence of self-aligning torque.
(120) Accordingly, the operational burden on the driver in a turning state can be reduced.
Second Embodiment
(121) FIG. **12** is a functional block diagram illustrating a second embodiment of reaction force

torque calculation unit **550**.
(122) In the second embodiment, reaction force torque calculation unit **550** includes first reaction force torque calculation unit **551**, operation angular velocity calculation unit **552**, second reaction force torque calculation unit **553**, and adder unit **554** as with the first embodiment, and further includes an operation direction determination unit **555** additionally.
(123) Operation direction determination unit **555** captures information on an operation angle θ and information on an operation angular velocity Δθ, determines whether steering wheel **310** is operated in the direction of additional steering or turning-back steering based on the operation angle θ and the operation angular velocity Δθ, and outputs a signal indicating the operation direction.
(124) Operation direction determination unit **555** determines that the operation direction is the additional steering direction when the operation angle θ is positive and the operation angular velocity Δθ is positive and when the operation angle θ is negative and the operation angular velocity Δθ is negative.
(125) Operation direction determination unit **555** determines that the operation direction is the turning-back steering direction when the operation angle θ is positive and the operation angular velocity Δθ is negative and when the operation angle θ is negative and the operation angular velocity Δθ is positive.
(126) Second reaction force torque calculation unit **553** captures information on the operation direction from operation direction determination unit **555** in addition to information on the operation angular velocity Δθ and information on a steering gear ratio Kg and calculates a second steering reaction force torque Ts**2** based on these pieces of information.
(127) As with the first embodiment, second reaction force torque calculation unit **553** obtains a steering reaction force torque Ts−Δθ based on the operation angular velocity Δθ, obtains a second gain G**2** based on the steering gear ratio Kg, and multiplies the steering reaction force torque Ts−Δθ by the second gain G**2** to calculate a second steering reaction force torque Ts**2**.
(128) Furthermore, second reaction force torque calculation unit **553** switches the second gain G**2** in accordance with information on the operation direction, that is, in accordance with whether the operation direction of steering wheel **310** is the additional steering direction or the turning-back steering direction.
(129) That is, second reaction force torque calculation unit **553** sets different gains G**2** in accordance with the operation direction of steering wheel **310** even with the same the steering gear ratio Kg, and, as a result, changes the magnitude of the second steering reaction force torque Ts**2** in accordance with the operation direction of steering wheel **310**.
(130) FIG. **13** is a diagram illustrating the correlation between the steering gear ratio Kg and the second gain G**2**. A solid line in FIG. **13** indicates the second gain G**2** used in additional steering, and a broken line in FIG. **13** indicates the second gain G**2** used in turning-back steering.
(131) Note that second reaction force torque calculation unit **553** may include a table used for additional steering and a table used for turning-back steering as tables (or functions) for obtaining the second gain G**2** from the steering gear ratio Kg and switch the table to be referred to based on a result of the determination of operation direction determination unit **555**.
(132) Second reaction force torque calculation unit **553** increases the second gain G**2** as the steering gear ratio Kg decreases and makes the second gain G**2** larger in turning-back steering than in additional steering.
(133) Specifically, the gradient of an increasing change in the second gain G**2** relative to a decreasing change in the steering gear ratio Kg is made greater in turning-back steering than in additional steering, and the difference between the second gain G**2** in turning-back steering and the second gain G**2** in additional steering is increased as the steering gear ratio Kg decreases.
(134) Accordingly, when the operation angular velocity Δθ increases in turning-back steering, second reaction force torque calculation unit **553** makes the second steering reaction force torque

Ts**2** and, in turn, the steering reaction force torque Ts, greater than those in additional steering to prevent a rough operation on steering wheel **310** in turning-back steering.
(135) That is, an operation of the driver on steering wheel **310** tends to be rougher in turning-back steering of steering wheel **310** than in additional steering, which may deteriorate the turn trace performance of vehicle **100**.
(136) Thus, second reaction force torque calculation unit **553** makes the second steering reaction force torque Ts**2** corresponding to the operation angular velocity Δθ greater in a turning-back steering operation than in an additional steering operation, thereby giving the driver a sense of response to the turning-back steering operation on steering wheel **310**.
(137) This prevents a rough operation on steering wheel **310** in turning-back steering and improves the turn trace performance of vehicle **100**.
(138) Note that the characteristic of switching the second gain G**2** in accordance with the operation direction is not limited to the characteristic in FIG. **13**.
(139) For example, second reaction force torque calculation unit **553** may set the difference between the second gain G**2** in the turning-back steering operation and the second gain G**2** in the additional steering operation to a constant value or set the second gain G**2** in the turning-back steering operation and the second gain G**2** in the additional steering operation to the same value in an extremely low speed range.
Third Embodiment
(140) FIG. **14** is a functional block diagram illustrating a third embodiment of reaction force torque calculation unit **550**.
(141) In the third embodiment, reaction force torque calculation unit **550** includes first reaction force torque calculation unit **551**, operation angular velocity calculation unit **552**, second reaction force torque calculation unit **553**, and adder unit **554** as with the first embodiment, and further includes a change limiter unit **556** additionally.
(142) Change limiter unit **556** acquires a second steering reaction force torque Ts**2** calculated by second reaction force torque calculation unit **553** based on an operation angular velocity Δθ and a steering gear ratio Kg, performs processing to limit a change in the acquired second steering reaction force torque Ts**2**, and outputs the processed second steering reaction force torque Ts**2** to adder unit **554**.
(143) Specifically, when the difference between the second steering reaction force torque Ts**2** output to adder unit **554** at the previous time in an arithmetic operation cycle and the second steering reaction force torque Ts**2** acquired this time from second reaction force torque calculation unit **553** exceeds an upper limit value, change limiter unit **556** outputs, to adder unit **554**, the second steering reaction force torque Ts**2**, of which the difference from the previous value of the second steering reaction force torque Ts**2** is equal to the upper limit value.
(144) By performing such an arithmetic process, change limiter unit **556** limits a change amount per unit time in the second steering reaction force torque Ts**2** captured by adder unit **554** to the upper limit value or less.
(145) If control of reaction force actuator **330** on the steering reaction force torque has a response delay, an overshoot or an undershoot of an actual steering reaction force torque give the driver an uncomfortable feeling of steering wheel **310** being returned.
(146) When change limiter unit **556** changes the second steering reaction force torque Ts**2** within a followable range of reaction force actuator **330**, it is possible to prevent an overshoot and an undershoot of the actual steering reaction force torque and prevent an uncomfortable feeling of the driver caused by the change in the steering reaction force torque.
(147) That is, a specification of change limiter unit **556** (specifically, the upper limit value used in the process of limiting the change in the second steering reaction force torque Ts**2**) is determined in accordance with the response delay of reaction force actuator **330** and applied so as to prevent an overshoot and an undershoot of the actual steering reaction force torque.

(148) The technical ideas described in the embodiments may be combined as appropriate as long as they do not conflict.
(149) Also, although the details of the present invention have been specifically described with reference to the preferred embodiments, it is obvious that those skilled in the art can conceive various modifications based on the basic technical ideas and teachings of the present invention.
(150) For example, reaction force torque calculation unit **550** may include both operation direction determination unit **555** illustrated in FIG. **12** and change limiter unit **556** illustrated in FIG. **14**.
(151) Also, a change limiter unit that limits a change in the steering reaction force torque Ts obtained by adder unit **554** adding the first steering reaction force torque Ts**1** and the second steering reaction force torque Ts**2** and outputs the steering reaction force torque Ts to reaction force actuator **330** may be provided.
(152) Also, the process of calculating the second steering reaction force torque Ts**2** based on the operation angular velocity Δθ and the steering gear ratio Kg in second reaction force torque calculation unit **553** is not limited to the process of multiplying the steering reaction force torque Ts−Δθ calculated based on the operation angular velocity Δθ by the second gain G**2** corresponding to the steering gear ratio Kg, and a calculation process that can obtain the second steering reaction force torque Ts**2** with a characteristic equivalent to that in the embodiments may be employed as appropriate.
(153) For example, second reaction force torque calculation unit **553** may have a plurality of conversion tables (or functions) for obtaining the second steering reaction force torque Ts**2** from the operation angular velocity Δθ for different steering gear ratios Kg in one-to-one correspondence and obtain the second steering reaction force torque Ts**2** corresponding to the operation angular velocity Δθ using the conversion table selected based on the steering gear ratio Kg at the time.
(154) Steering device **200** may include a first electronic control device that controls steering input device **300** and a second electronic control device that controls steering actuator device **400** separately.
(155) For example, the second electronic control device that controls steering actuator device **400** may have the function of the steering gear ratio change unit, and the first electronic control device that controls steering input device **300** may have the functions of the reaction force actuator control unit and the reaction force actuator output amount change unit.
REFERENCE SYMBOL LIST
(156) **100** Vehicle **101-104** Wheel **200** Steer-by-wire type steering device **300** Steering input device **310** Steering wheel (steering operation input member) **330** Reaction force actuator **340** Operation angle sensor **400** Steering actuator device **500** Steering control device (control device) **540** Steering gear ratio calculation unit (steering gear ratio change unit) **550** Reaction force torque calculation unit **551** First reaction force torque calculation unit **552** Operation angular velocity calculation unit **553** Second reaction force torque calculation unit (reaction force actuator control unit, reaction force actuator output amount change unit) **554** Adder unit **621-624** Wheel speed sensor

Claims

1. A steer-by-wire type steering device mounted in a vehicle, the steer-by-wire type steering device comprising: a steering input device including: a steering operation input member; and a reaction force actuator that applies a steering reaction force to the steering operation input member; and a control device including: a steering gear ratio change unit that changes a steering gear ratio in accordance with a vehicle speed of the vehicle, the steering gear ratio being a ratio of a steering angle of a wheel of the vehicle to an operation angle of the steering operation input member; a reaction force actuator control unit that controls an output amount of the reaction force actuator in accordance with an operation angular velocity of the steering operation input member; and a reaction force actuator output amount change unit that changes, based on the steering gear ratio, the

output amount of the reaction force actuator corresponding to the operation angular velocity: wherein the reaction force actuator output amount change unit: increases the output amount of the reaction force actuator corresponding to the operation angular velocity as the operation angular velocity increases when the steering gear ratio is less than a predetermined value, and decreases the output amount of the reaction force actuator corresponding to the operation angular velocity as the operation angular velocity increases when the steering gear ratio is greater than the predetermined value.

2. The steer-by-wire type steering device according to claim 1, wherein the control device further includes a change limiter unit that limits a change in the output amount of the reaction force actuator corresponding to the operation angular velocity.

3. The steer-by-wire type steering device according to claim 1, wherein; the control device further includes an operation direction determination unit that determines whether an operation direction of the steering operation input member is additional steering or turning-back steering, and the reaction force actuator output amount change unit increases the output amount of the reaction force actuator corresponding to the operation angular velocity as the steering gear ratio decreases and makes the output amount of the reaction force actuator corresponding to the operation angular velocity greater in the turning-back steering of the steering operation input member than in the additional steering.

4. The steer-by-wire type steering device according to claim 1, wherein the reaction force actuator control unit controls the output amount of the reaction force actuator based on a sum of a command value of the output amount of the reaction force actuator corresponding to the vehicle speed of the vehicle and the operation angle of the steering operation input member and a command value of the output amount of the reaction force actuator corresponding to the operation angular velocity.

5. A steer-by-wire type steering device mounted in a vehicle, the steer-by-wire type steering device comprising: a steering input device including: a steering operation input member; and a reaction force actuator that applies a steering reaction force to the steering operation input member; and a control device including: a steering gear ratio change unit that changes a steering gear ratio in accordance with a vehicle speed of the vehicle, the steering gear ratio being a ratio of a steering angle of a wheel of the vehicle to an operation angle of the steering operation input member; a reaction force actuator control unit that controls an output amount of the reaction force actuator in accordance with an operation angular velocity of the steering operation input member; and a reaction force actuator output amount change unit that changes, based on the steering gear ratio, the output amount of the reaction force actuator corresponding to the operation angular velocity, wherein the reaction force actuator output amount change unit changes the output amount of the reaction force actuator corresponding to the operation angular velocity using a gain, the gain being set to be greater as the steering gear ratio decreases.

6. The steer-by-wire type steering device according to claim 5, wherein: the reaction force actuator control unit sets the output amount of the reaction force actuator corresponding to the operation angular velocity to zero when the operation angular velocity is zero and increases the output amount of the reaction force actuator corresponding to the operation angular velocity as the operation angular velocity increases.

7. The steer-by-wire type steering device according to claim 5, wherein: the steering gear ratio change unit decreases the steering gear ratio as the vehicle speed of the vehicle decreases, the reaction force actuator control unit decreases the output amount of the reaction force actuator corresponding to the operation angular velocity as the operation angular velocity decreases and increases the output amount of the reaction force actuator corresponding to the operation angular velocity as the operation angular velocity increases.