



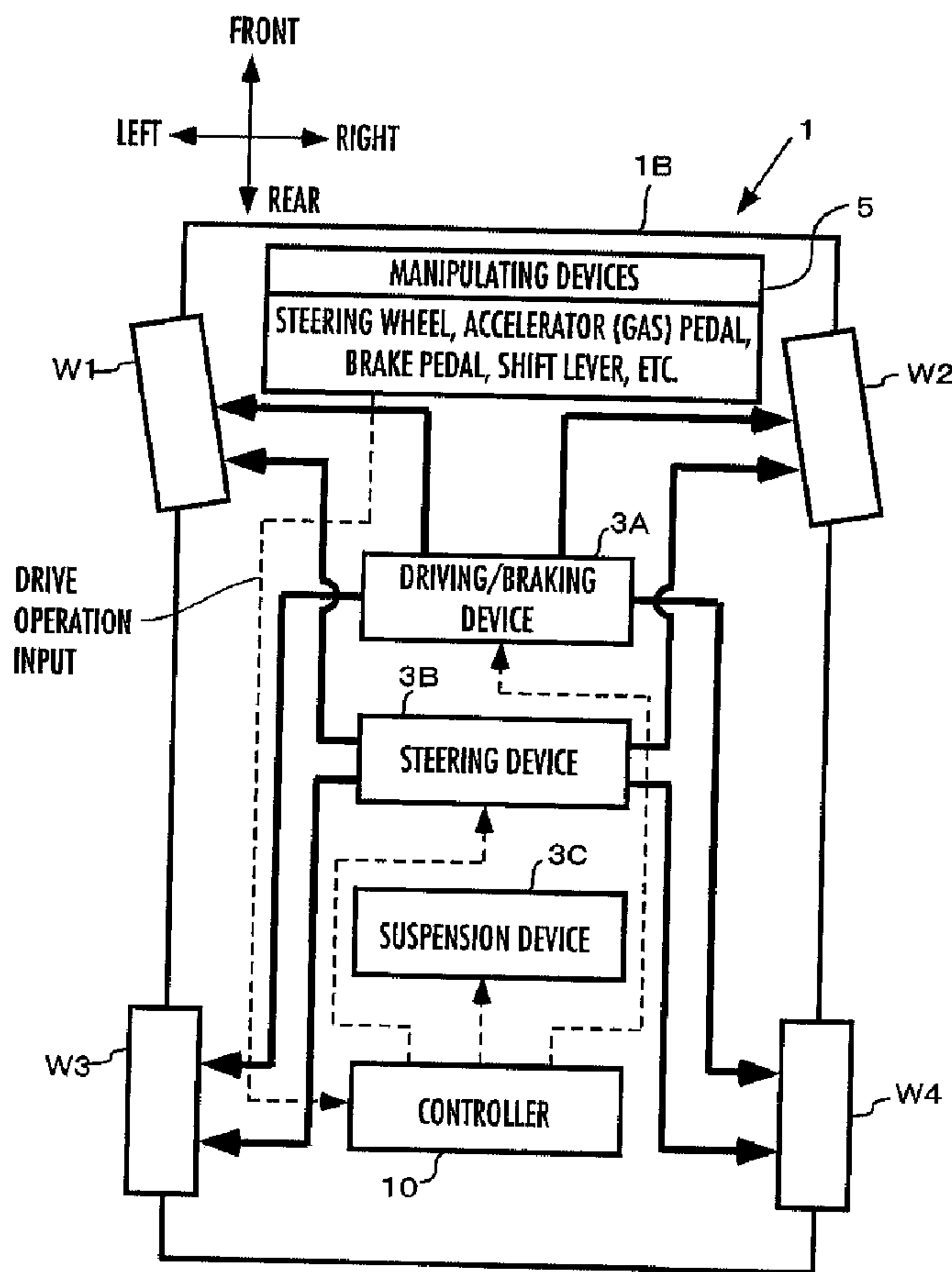
(86) Date de dépôt PCT/PCT Filing Date: 2007/05/24
 (87) Date publication PCT/PCT Publication Date: 2008/01/03
 (45) Date de délivrance/Issue Date: 2011/05/10
 (85) Entrée phase nationale/National Entry: 2008/08/12
 (86) N° demande PCT/PCT Application No.: JP 2007/060593
 (87) N° publication PCT/PCT Publication No.: 2008/001560
 (30) Priorité/Priority: 2006/06/30 (JP2006-181984)

(51) Cl.Int./Int.Cl. *B60W 30/02* (2006.01),
B60G 17/016 (2006.01), *B60G 17/018* (2006.01),
B60G 17/0195 (2006.01), *B60T 8/1755* (2006.01),
B60W 10/04 (2006.01), *B60W 10/12* (2006.01),
B60W 10/18 (2006.01), *B60W 10/20* (2006.01),
B60W 10/22 (2006.01), *B60W 30/00* (2006.01),
B60W 50/06 (2006.01), *B62D 5/04* (2006.01),
B62D 6/00 (2006.01), *B60G 17/015* (2006.01)

(72) Inventeurs/Inventors:
 TAKENAKA, TORU, JP;
 KONO, HIROSHI, JP;
 TOYOSHIMA, TAKAYUKI, JP;
 URABE, HIROYUKI, JP

(73) Propriétaire/Owner:

(54) Titre : DISPOSITIF DE COMMANDE DE VEHICULE
 (54) Title: VEHICLE CONTROL DEVICE



(57) Abrégé/Abstract:

An actual vehicle actuator operation control input and a model operation control input are determined by an FB distribution law 20 such that the difference between a reference state amount determined in a vehicle model 16 and an actual state amount of an

(73) Propriétaires(suite)/Owners(continued):HONDA MOTOR CO., LTD., JP

(74) Agent: GOUDREAU GAGE DUBUC

(57) Abrégé(suite)/Abstract(continued):

actual vehicle 1 (a state amount error) approximates zero, and then an actuator device 3 of the actual vehicle 1 and the vehicle model 16, respectively, are operated on the basis of the control inputs. The value of a parameter of the vehicle model 16 is variably set according to a motional state of the actual vehicle 1 such that the attenuation property of a reference state amount when a drive manipulated variable (a steering angle) is changed in steps is higher than the attenuation property of an actual state amount. With this arrangement, the actuator device 3 of the actual vehicle 1 is properly controlled independently of a motional state of the actual vehicle 1 such that a state amount related to a motion of the actual vehicle (an actual state amount) approximates a vehicle state amount (reference state amount) on a dynamic characteristic model (the vehicle model 16).

ABSTRACT

An actual vehicle actuator operation control input and a model operation control input are determined by an FB distribution law 20 such that the difference between a reference state amount determined in a vehicle model 16 and an actual state amount of an actual vehicle 1 (a state amount error) approximates zero, and then an actuator device 3 of the actual vehicle 1 and the vehicle model 16, respectively, are operated on the basis of the control inputs. The value of a parameter of the vehicle model 16 is variably set according to a motional state of the actual vehicle 1 such that the attenuation property of a reference state amount when a drive manipulated variable (a steering angle) is changed in steps is higher than the attenuation property of an actual state amount. With this arrangement, the actuator device 3 of the actual vehicle 1 is properly controlled independently of a motional state of the actual vehicle 1 such that a state amount related to a motion of the actual vehicle (an actual state amount) approximates a vehicle state amount (reference state amount) on a dynamic characteristic model (the vehicle model 16).

DESCRIPTION

VEHICLE CONTROL DEVICE

Technical Field

[0001] The present invention relates to a control device of a vehicle having a plurality of wheels, such as an automobile (engine automobile), a hybrid car, and a two-wheeled motor vehicle.

Background Art

[0002] Hitherto, there has been known a technique for controlling an actuator device provided in an actual vehicle, whereby a model representing the dynamic characteristics of a vehicle is used to set the target values of the motional state amounts, such as a yaw rate and a lateral velocity, of a vehicle, and then an actual device provided in an actual vehicle is controlled such that the state amounts of the actual vehicle follow the target values, as disclosed in, for example, Japanese Patent Application Laid-Open No. H11-91608 (hereinafter referred to as patent document 1) and Japanese Patent Application Laid-Open No. 2000-15938 (hereinafter referred to as patent document 2).

[0003] According to the technique disclosed in these patent documents 1 and 2, a target yaw rate and a target lateral velocity are set from a detection value of a vehicle velocity and a detection value of a steering angle of a steering wheel by a dynamic characteristic model having a yaw rate and a lateral velocity of a vehicle as

state amounts. Then, a target value of a steering angle of a rear wheel of the vehicle required relative to the target yaw rate (a first target rear wheel steering angle) and a target value of a steering angle of a rear wheel of the vehicle required relative to the target lateral velocity (a second target rear wheel steering angle) are calculated. Further, a value (a weighted mean value) obtained by linearly coupling the first target rear wheel steering angle and the second target rear wheel steering angle is determined as the final target value of the steering angle of the rear wheel. Then, an actuator for steering the rear wheel is controlled to make the steering angle of the rear wheel of an actual vehicle follow the target value.

[0004] Further, as disclosed in, for example, PCT international publication WO2006/013922A1 (hereinafter referred to as patent document 3), the present applicant has proposed a technique whereby an actuator device of an actual vehicle is controlled to bring a state amount of the actual vehicle close to a state amount on a dynamic characteristic model of the vehicle and also the dynamic characteristic model is operated (an additional control input is supplied to the dynamic characteristic model) to bring a state amount on the dynamic characteristic model close to a state amount of the actual vehicle.

[0005] Meanwhile, when carrying out the control to make a state amount related to a motion of an actual vehicle

follow a state amount on a dynamic characteristic model of a vehicle, if a change in an input, such as a steering angle of a steering wheel, causes the state amount on the dynamic characteristic model of the vehicle to develop an oscillatory response, then a state amount of the actual vehicle, which is to follow the state amount on the dynamic characteristic model, will also develop an oscillatory response. It is considered desirable, therefore, that the response characteristic (the transient response characteristic) of a state amount on the dynamic characteristic model relative to a change in an input, such as the steering angle of the steering wheel, exhibits a response characteristic having a highest possible attenuation property independently of a motional state of the actual vehicle in order to maintain a good behavior characteristic of the actual vehicle as much as possible.

[0006] Here, in the present description, "the high attenuation property" means a short time constant of attenuation of an amplitude value of an oscillatory component of a state amount (a control amount) when an input to a target system is changed in steps, that is, a high attenuation speed of the amplitude value of the oscillatory component. Incidentally, the so-called critical braking (critical damping) or over-braking (over-damping) response characteristic is a non-oscillatory response characteristic with no oscillatory component; however, it is regarded as a characteristic with a highest

attenuation property.

[0007] Nevertheless, it has been difficult for the technique disclosed in the aforesaid patent documents 1 and 2 to fully satisfy the above requirement for the following reason. In general, the response characteristic of a state amount, such as a yaw rate or a lateral velocity, of an actual vehicle relative to a change in the steering angle of a steering wheel tends to exhibit an oscillatory response characteristic (a characteristic in which a state amount converges to a steady-state value while oscillating) when a traveling velocity is relatively high.

[0008] Hence, if the response characteristic of a dynamic characteristic model of a vehicle is set to a characteristic with a high attenuation property, such as a critical braking or over-braking characteristic (non-oscillatory characteristic), independently of the traveling velocity of the actual vehicle (at an arbitrary traveling velocity) according to the technique disclosed in patent documents 1 and 2, then there will be a significant discrepancy between the response characteristic of a state amount of a vehicle on the dynamic characteristic model and the response characteristic of a state amount of an actual vehicle especially when the traveling velocity of the vehicle is high. As a result, the difference between a yaw rate and a lateral velocity as the state amounts on the dynamic

characteristic model and a yaw rate and a lateral velocity of an actual vehicle according to the technique disclosed in patent documents 1 and 2 will become large.

Consequently, a required manipulated variable of an actuator device for making a state amount of the actual vehicle follow a state amount on the dynamic characteristic model tends to be excessive. As a result, a situation wherein it actually becomes impossible to satisfy the required manipulated variable within the capability of the actuator device frequently occurs. Further, in this case, it actually becomes difficult to make the state amount of the actual vehicle follow the state amount on the dynamic characteristic model.

[0009] Hence, according to the technique disclosed in patent documents 1 and 2, it is actually impossible to set the response characteristic of a state amount on the dynamic characteristic model of a vehicle to a characteristic with a high attenuation property, such as a non-oscillatory characteristic, independently of a traveling velocity of an actual vehicle. This means that, actually, the response characteristic of a state amount on the dynamic characteristic model of a vehicle can be set to a characteristic with a high attenuation property only in limited motional states (motional states wherein the response characteristic of a state amount of the actual vehicle becomes a characteristic with a high attenuation property), such as in a situation wherein the traveling

velocity of a vehicle is low. For this reason, the technique disclosed in patent documents 1 and 2 cannot fully satisfy the aforesaid requirement.

[0010] Meanwhile, according to the technique disclosed in the aforesaid patent document 3, in addition to operating the actuator device of the actual vehicle on the basis of the difference between a state amount of the actual vehicle and a state amount on the dynamic characteristic model, the dynamic characteristic model of the vehicle is also operated so as to bring the state amount on the dynamic characteristic model close to the state amount of the actual vehicle. In other words, the difference is fed back not only to the actual vehicle but also to the dynamic characteristic model. This makes it possible to restrain the difference between the state amount of the actual vehicle and the state amount on the dynamic characteristic model from becoming excessive. Thus, as shown in patent document 3, if the difference between the state amount of the actual vehicle and the state amount on the dynamic characteristic model is fed back to both the actual vehicle and the dynamic characteristic model, then it is considered possible to restrain a required manipulated variable of the actuator device from becoming excessive even when there is a relatively large discrepancy between the response characteristic of a state amount of the actual vehicle and the response characteristic of a state amount of the vehicle on the

dynamic characteristic model. Therefore, it is considered possible to make the state amount of the actual vehicle properly follow the state amount on the dynamic characteristic model.

[0011] Hence, as disclosed in patent document 3, if the difference between a state amount of the actual vehicle and a state amount on the dynamic characteristic model is fed back to both the actual vehicle and the dynamic characteristic model, then it is considered possible to set the response characteristic of a state amount on the dynamic characteristic model of a vehicle to a response characteristic with a high attenuation property independently of a motional state of the actual vehicle.

[0012] The present invention has been made in view of the background described above, and it is an object of the present invention to provide a vehicle control device capable of properly controlling an actuator device of a vehicle, independently of a motional state of the vehicle, by using a dynamic characteristic model with a high attenuation property such that the state amount related to a motion of an actual vehicle approximates the state amount of a vehicle on the dynamic characteristic model, thus allowing a good behavior characteristic of the vehicle to be maintained.

Disclosure of Invention

[0013] To fulfill the object, according to the present invention, there is provided a vehicle control device

equipped with a drive manipulated variable detecting means which detects a drive manipulated variable that indicates a state of drive manipulation of a vehicle by a driver of the vehicle having a plurality of wheels, an actuator device provided in the vehicle so as to permit the manipulation of a predetermined motion of the vehicle, an actual state amount grasping means which detects or estimates an actual state amount vector, which is a set of the values of a plurality of types of state amounts related to a predetermined motion of an actual vehicle, a model state amount determining means which determines a model state amount vector, which is a set of the values of a plurality of types of state amounts of a vehicle on a vehicle model established beforehand as a model representing the dynamic characteristic of the vehicle, and a state amount error calculating means which calculates a state amount error, which is the difference between the value of each type of state amount of the detected or estimated actual state amount vector and the value of a state amount of each type of the determined model state amount vector, to control the operation of at least the actuator device such that the state amount error approximates zero, the vehicle control device comprising:

 a state amount error response control means which determines an actual vehicle actuator operation control input for operating the actuator device of the actual vehicle and a vehicle model operation control input for

manipulating a motion of the vehicle on the vehicle model on the basis of at least the calculated state amount error such that the state amount error approximates zero;

an actuator device control means which controls the operation of the actuator device on the basis of at least the determined actual vehicle actuator operation control input;

the model state amount determining means being a means which determines the model state amount vector on the basis of at least the detected drive manipulated variable and the determined vehicle model operation control input; and

a vehicle model characteristics setting means which variably sets the value of at least one parameter of the vehicle model on the basis of a motional state of the actual vehicle such that the attenuation property of the value of each type of state amount of the model state amount vector based on a stepped change in the drive manipulated variable in a state wherein the vehicle model operation control input is maintained at zero will be a high attenuation characteristic which is a characteristic higher than the attenuation property of the value of each type of state amount of the actual state amount vector based on a stepped change in the drive manipulated variable in a state wherein the actual vehicle actuator operation control input is maintained at zero (a first invention).

[0014] According to the first invention, the attenuation property of the value of each type of state amount of the model state amount vector can be set to the high attenuation characteristic that is higher than the attenuation property of the value of each type of state amount of an actual state amount vector in any motion state of the vehicle by variably setting at least one parameter of the vehicle model on the basis of a motional state of the actual vehicle. In this case, especially in a motional state of the vehicle wherein the response characteristic of the value of each type of state amount of the actual state amount vector becomes an oscillatory characteristic, there will be a discrepancy between the response characteristic of the value of each type of state amount of the actual state amount vector and the response characteristic of the value of each type of state amount of the model state amount vector. However, the vehicle model operation control input supplied to the vehicle model restrains the state amount error from becoming excessive and therefore restrains the actual actuator operation control input from becoming excessive. This arrangement makes it possible to make the value of each type of state amount of the actual state amount vector properly approximate (follow) the value of each type of state amount of the model state amount vector. Moreover, the attenuation property of the value of each type of state amount of the model state amount vector is the high

attenuation characteristic, so that the value of the state amount quickly converges to a steady-state value. As a result, the oscillation of the value of each type of state amount of the actual state amount vector when the drive manipulated variable changes can be restrained, allowing a good vehicle behavior characteristic to be maintained.

[0015] Thus, the first invention makes it possible to properly control the actuator device of the vehicle, independently of a motional state of a vehicle, such that a state amount related to a motion of the actual vehicle approximates a state amount of the vehicle on the vehicle model by using the vehicle model as the dynamic characteristic model with a high attenuation property. Consequently, an excellent behavior characteristic of the vehicle can be maintained.

[0016] In the present description, as described above, the response characteristic of critical braking or over-braking is a response characteristic with a highest attenuation property. Hence, in the present invention, the high attenuation characteristic in a motional state of the vehicle wherein the response characteristic of the value of each type of state amount of the actual state amount vector (the response characteristic based on the stepped change of the drive manipulated variable in the situation wherein the actual vehicle actuator operation control input is maintained at zero) leads to critical braking or over-braking means a critical braking or over-

braking characteristic.

[0017] In the aforesaid first invention, preferably, the response characteristic of the value of each type of state amount of the model state amount vector based on the stepped change in the drive manipulated variable does not have an oscillatory component as much as possible in any motional state of the vehicle. Accordingly, the high attenuation characteristic is ideally a response characteristic of critical braking or over-braking (a second invention).

[0018] The second invention makes it possible to effectively restrain or remove the oscillation of the value of each type of state amount of an actual state amount vector when the drive manipulated variable changes. As a result, the behavior characteristic of the vehicle can be turned into a further improved characteristic.

[0019] Further, in the first or the second invention described above, if the plurality of types of state amounts includes, for example, two or more types of state amounts related to a side slip and a rotation about a yaw axis of the vehicle, then the attenuation property of the value of each type of state amount of the actual state amount vector based on the stepped change in the drive manipulated variable changes according to the traveling velocity of the actual vehicle. In this case, therefore, the vehicle model characteristics setting means variably sets the value of a parameter of the vehicle model is

variably set according to the traveling velocity of the actual vehicle (a third invention).

[0020] The third invention makes it possible to accurately turn the attenuation property of the value of each type of state amount of a model state amount vector into the aforesaid high attenuation characteristic. The two or more types of state amounts may not separately include a state amount related to a side slip of the vehicle and a state amount related to the rotation about the yaw axis. For instance, the two or more types of state amounts may include two types of linear coupling values of a state amount related to a side slip of the vehicle and a state amount related to the rotation about the yaw axis.

[0021] In the third invention described above, if the value of a parameter of the vehicle model is variably set according to the traveling velocity of the vehicle so as to enhance the attenuation property of the value of each type of state amount of the model state amount vector, then the absolute value of an eigenvalue of the vehicle model tends to be excessive especially in a motional state of the vehicle in which the traveling velocity is relatively high. The "eigenvalue" of the vehicle model means the "eigenvalue" in a usual sense when the vehicle model is a linear model. If the vehicle model is a nonlinear model, then the above "eigenvalue" means the eigenvalue of a model obtained by linearly approximating

the vehicle model at any value of each type of state amount of the model state amount vector with the vehicle model operation control input being set to zero (a model that has linearity in the vicinity of the value of the state amount).

[0022] In the motional state of the vehicle in which the traveling velocity is a relatively high velocity, as described above, the absolute value of an eigenvalue of the vehicle model is apt to become excessive. For this reason, in a velocity range wherein the traveling velocity of the vehicle is relatively high, there is a danger that the responsiveness of the value of each type of state amount of the model state amount vector based on a change in the drive manipulated variable (the changing rate of the value of each type of state amount immediately after a change in the drive manipulated variable) may become excessively higher than the responsiveness of the value of each type of state amount of an actual state amount vector. In this case, it is possible to control the state amount error to be small by the model operation control input. However, especially when the gain of the model operation control input relative to the state amount error is set to a small value, there is a danger that the state amount error immediately after a change in the drive manipulated variable becomes excessively large, causing the actual actuator operation control input to become excessive.

[0023] According to the third invention, therefore,

preferably, the vehicle model characteristics setting means variably sets the value of a parameter of the vehicle model according to the traveling velocity such that the absolute value of the eigenvalue of the vehicle model becomes a predetermined value or less at least when the traveling velocity is higher than a predetermined velocity (a fourth invention).

[0024] According to the fourth invention, in addition to setting the attenuation property of the value of each type of state amount of the model state amount vector to the high attenuation characteristic, the value of a parameter of the vehicle model is set according to the traveling velocity such that the absolute value of the eigenvalue of the vehicle model becomes a predetermined value or less at least when the traveling velocity is higher than a predetermined velocity. This arrangement makes it possible to prevent the responsiveness of the value of the state amount from becoming excessively high in relation to the responsiveness of the value of each type of state amount of the actual state amount vector, while enhancing the attenuation property of the value of each type of state amount of the model state amount vector on the basis of a stepped change in the drive manipulated variable. As a result, it is possible to further securely prevent the state amount error from becoming excessive. This in turn makes it possible to further securely prevent the actual actuator operation control input from becoming excessive.

Thus, it is possible to further properly carry out the control for making the value of each type of state amount of the actual state amount vector follow the value of each type of state amount of the model state amount vector.

[0025] Incidentally, in the fourth invention, the attenuation property and the responsiveness of the value of each type of state amount of the model state amount vector are to be manipulated on the basis of a traveling velocity, thus requiring two or more parameters of the vehicle model to be variably set according to the traveling velocity.

[0026] Further, in the first to the fourth inventions described above, the vehicle model characteristics setting means preferably variably sets the value of a parameter of the vehicle model such that the relationship between the steady-state value of the drive manipulated variable when the drive manipulated variable is changed in steps in a state wherein the vehicle model operation control input is maintained at zero and the steady-state value of the value of each type of state amount of the model state amount vector is maintained at a certain relationship (a fifth invention).

[0027] According to the fifth invention, the relationship between the steady-state value of a drive manipulated variable when the drive manipulated variable is changed in steps and the steady-state value of the value of each type of state amount of the

model state amount vector, that is, the steady-state characteristic of the vehicle model, is maintained to be constant even if the value of a parameter of the vehicle model is variably set (independently of a change in the value of the parameter). Therefore, the steady-state characteristic of the vehicle model can be turned into a characteristic that is substantially equivalent to the steady-state characteristic of the actual vehicle (more precisely, the relationship between the steady-state value of a drive manipulated variable in the situation wherein the actual vehicle actuator operation control input is maintained at zero and the steady-state value of each type of state amount of the actual state amount vector). As a result, the state amount error in the steady state when the actual vehicle is in motion (in a state wherein the drive manipulated variable is constant and an environmental condition, such as a road surface or the like, is constant or uniform, and sufficient time has elapsed for a transient behavior to disappear) can be always controlled to be minute. Thus, the actual actuator operation control input in the steady state of the actual vehicle can be controlled to a minimum, preventing the actuator device from being excessively actuated.

Best Mode for Carrying Out the Invention

[0028] The following will describe embodiments of the vehicle control device in accordance with the present invention.

[0029] First, referring to Fig. 1, a schematic construction of a vehicle in the embodiments in the present description will be described. Fig. 1 is a block diagram illustrating the schematic construction of the vehicle. A vehicle illustrated in the embodiments in the present description is a car provided with four wheels (two wheels each at the front and the rear of the vehicle). The construction itself of the car may be a publicly known one, so that detailed illustration and explanation will be omitted in the present description.

[0030] As illustrated in Fig. 1, a vehicle 1 (car) is provided with a driving/braking device 3A (a driving/braking system) that imparts a rotational driving force (a rotational force that provides an impelling force for the vehicle 1) to driving wheels among four wheels W1, W2, W3, and W4, or imparting a braking force (a rotational force that provides a braking force for the vehicle 1) to each of the wheels W1 to W4, a steering device 3B (a steering system) for controlling steering control wheels among the four wheels W1 to W4, and a suspension device 3C (a suspension system) that resiliently supports a vehicle body 1B on the four wheels W1 to W4, as with a publicly known regular car. The wheels W1, W2, W3, and W4 are a front left wheel, a front right wheel, a rear left wheel, and a rear right wheel, respectively, of the vehicle 1. Further, the driving wheel and the steering control wheel are the two front wheels W1 and W2 in the embodiments to

be described in the present description. Hence, the rear wheels W3 and W4 are driven wheels and non-steering-control wheels.

[0031] However, the driving wheels may alternatively be the two rear wheels W3 and W4 or both the front wheels W1, W2 and the rear wheels W3, W4 (the four wheels W1 through W4). Further, the steering control wheels may include not only the two front wheels W1 and W2 but the rear wheels W3 and W4 also.

[0032] These devices 3A, 3B and 3C have functions for manipulating the motions of the vehicle 1. For example, the driving/braking device 3A has a function for mainly manipulating the motions in advancing directions of the vehicle 1 (positions, velocities, accelerations and the like in the advancing directions of the vehicle 1). The steering device 3B has a function for mainly manipulating the rotational motions in the yaw direction of the vehicle 1 (postures, angular velocities, angular accelerations and the like in the yaw direction of the vehicle 1). The suspension device 3C has a function for primarily manipulating the motions in the pitch direction and the roll direction of a vehicle body 1B of the vehicle 1 (postures and the like in the pitch direction and the roll direction of the vehicle body 1B of the vehicle 1) or the motions in the vertical directions of the vehicle body 1B (mainly a height of the vehicle body 1B from a road surface (a vertical position of the vehicle body 1B

- 20 -

relative to the wheels W1 to W4)). Incidentally, a "posture" of the vehicle 1 or the vehicle body 1B means a spatial orientation in the present description.

[0033] Supplementally, in general, side slips of the wheels W1 to W4 occur when the vehicle 1 makes turns or the like. The side slips are subjected to the influences of the steering angles of the steering control wheels of the vehicle 1, a yaw rate (an angular velocity in the yaw direction) of the vehicle 1, the driving/braking forces of the wheels W1 to W4, and the like. For this reason, the driving/braking device 3A and the steering device 3B have functions for manipulating the translational motions in lateral directions (right/left directions) of the vehicle 1. Incidentally, the "driving/braking force" of a wheel means a translational force component, which is in a longitudinal direction of the wheel, of a road surface reaction force acting on the wheel from a road surface (more specifically, in the direction of a line of intersection between a rotational plane of the wheel (a plane which passes the central point of the wheel and which is orthogonal to the rotational axis of the wheel) and a road surface or a horizontal plane). Further, in the road surface reaction force, a translational force component in the direction of the width of a wheel (the direction parallel to the rotational axis of the wheel) is referred to as a "lateral force." In the road surface reaction force, a translational force component in a

direction perpendicular to a road surface or a horizontal plane is referred to as a "ground contact load."

[0034] Although not illustrated in detail, more specifically, the driving/braking device 3A is equipped with a driving system constructed of an engine (an internal-combustion engine) serving as a motive power generating source of the vehicle 1 (an impellent force generating source of the vehicle 1) and a motive power transmitting system for transmitting an output (a rotational driving force) of the engine to the driving wheels among the wheels W1 to W4, and a braking device (a braking system) that imparts braking forces to the wheels W1 to W4. The motive power transmitting system includes a transmission, a differential gear, and the like.

[0035] The vehicle 1 to be described in the embodiments is equipped with an engine as a motive power generating source; however, the vehicle 1 may alternatively be a vehicle provided with an engine and an electric motor as motive power generating sources (a so-called parallel type hybrid vehicle) or a vehicle provided with an electric motor as a motive power generating source (a so-called electric car or a series type hybrid vehicle).

[0036] Further, a steering wheel (driver's wheel), an accelerator (gas) pedal, a brake pedal, a shift lever, and the like functioning as manipulating devices 5 (man-induced manipulating devices) operated by a driver to steer the vehicle 1 (car) are provided in a vehicle

interior of the vehicle 1. The illustration of the elements of the manipulating devices 5 is omitted.

[0037] The steering wheel among the manipulating devices 5 is related to an operation of the steering device 3B. More specifically, as the steering wheel is rotationally manipulated, the steering device 3B is operated in response thereto, thus steering the steering control wheels W1 and W2 among the wheels W1 to W4.

[0038] The accelerator (gas) pedal, the brake pedal, and the shift lever among the manipulating devices 5 are related to the operations of the driving/braking device 3A. More specifically, the opening of a throttle valve provided in the engine changes according to a manipulated variable (a depression amount) of the accelerator (gas) pedal so as to adjust an intake air volume and a fuel injection amount of the engine (consequently an output of the engine). Further, the braking device is operated according to a manipulated variable (a depression amount) of a brake pedal, and a braking torque based on the manipulated variable of the brake pedal is imparted to the wheels W1 to W4. Further, manipulating the shift lever changes an operation state of the transmission, such as a change gear ratio of the transmission, thus effecting the adjustment or the like of the driving torque transmitted from the engine to the driving wheels.

[0039] The drive manipulation states of the manipulating devices 5, such as the steering wheel operated by the

driver (the steerer of the vehicle 1) are detected by appropriate sensors, which are not shown. Hereinafter, detection values (detection outputs of the sensors) of the drive manipulation states will be referred to as drive manipulation inputs. The drive manipulation inputs include the detection values of a steering angle, which is a rotational angle of the steering wheel, an accelerator (gas) pedal manipulated variable, which is a manipulated variable of the accelerator (gas) pedal, a brake pedal manipulated variable, which is a manipulated variable of the brake pedal, and a shift lever position, which is a manipulation position of the shift lever. The sensors that output the drive manipulation inputs correspond to the drive manipulated variable detecting means in the present invention.

[0040] In the embodiments in the present description, the driving/braking device 3A and the steering device 3B described above are adapted to permit active control of the operations thereof (consequently the motions of the vehicle 1) in response to not only the drive manipulation inputs but also factors other than the drive manipulation inputs (e.g., a motion state of the vehicle 1 or an environmental condition). Here, "to permit active control" means that the operations of the devices 3A and 3B can be controlled into the operations obtained by correcting basic operations based on the drive manipulation inputs (basic desired operations determined

on the basis of drive manipulation inputs).

[0041] Specifically, the driving/braking device 3A is a driving/braking device having a function that makes it possible to actively control the difference or the ratio between a driving/braking force of the left wheels W1, W3 and a driving/braking force of the right wheels W2, W4 on at least one of the pair of the front wheels W1, W2 and the pair of the rear wheels W3, W4 through the intermediary of actuators, such as a hydraulic actuator, an electric motor, and an electromagnetic control valve, provided in the driving/braking device 3A (hereinafter, the control function will be referred to as the right/left motive power distribution control function).

[0042] To be more specific, according to the embodiments in the present description, the driving/braking device 3A is a driving/braking device capable of actively controlling the driving/braking forces to be applied to the wheels W1 to W4 (specifically, the driving/braking forces in the braking direction of the vehicle 1) by operating a braking device through the intermediary of actuators provided in the braking device (a driving/braking device capable of controlling the driving/braking forces to be applied to the wheels W1 to W4 by the braking device by increasing or decreasing the basic driving/braking forces determined on the basis of the manipulated variables of the brake pedal). Hence, the driving/braking device 3A is a driving/braking device

capable of actively controlling, through the intermediary of the actuators, the difference or the ratio between a driving/braking force of the left wheels W1, W3 and a driving/braking force of the right wheels W2, W4 by the braking device on both pairs, namely, the pair of the front wheels W1, W2 and the pair of the rear wheels W3, W4 (a driving/braking device that has the right/left motive power distribution control function for both pairs of the pair of the front wheels W1, W2 and the pair of the rear wheels W3, W4).

[0043] The driving/braking device 3A may have a function that permits active control, through the intermediary of actuators provided in the driving system, of the difference or the ratio between the driving/braking forces to be applied to the front wheels W1 and W2, which are driving wheels, by operating the driving system of the driving/braking device 3A, in addition to the function for actively controlling the driving/braking forces of the wheels W1 to W4 by operating the braking device.

[0044] As the driving/braking device 3A having the right/left motive power distribution control function as described above, a publicly known one may be used.

[0045] Supplementally, the driving/braking device 3A having the right/left motive power distribution control function as described above will have a function for actively manipulating a rotational motion in the yaw direction of the vehicle 1 or a translational motion in

the lateral direction by the control function thereof.

[0046] Incidentally, the driving/braking device 3A includes an actuator for generating braking torque for the braking device, an actuator for driving a throttle valve of the engine, an actuator for driving a fuel injection valve, an actuator for performing speed change drive of the transmission, and the like in addition to the actuators associated with the right/left motive power distribution control function.

[0047] Further, the steering device 3B is a steering device capable of secondarily steering the front wheels W1 and W2 by an actuator, such as an electric motor, as necessary, in addition to, for example, a function for mechanically steering the front wheels W1 and W2, which are steering control wheels, through the intermediary of a steering mechanism, such as a rack-and-pinion, according to a rotational operation of the steering wheel (a steering device capable of controlling the steering angle of the front wheels W1 and W2 by increasing or decreasing the steering angle mechanically determined on the basis of the rotational angle of the steering wheel).

Alternatively, the steering device 3B is a steering device which steers the front wheels W1 and W2 by using only a driving force of an actuator (a so-called steering-by-wire steering device). Therefore, the steering device 3B is a steering device capable of actively controlling the steering angle of the front wheels W1 and W2 through the

intermediary of an actuator (hereinafter referred to as an active steering device).

[0048] If the steering device 3B is an active steering device which secondarily steers the steering control wheels by an actuator in addition to mechanically steering the steering control wheels W1 and W2 according to a rotational operation of the steering wheel (hereinafter, such an active steering device will be referred to as an actuator-assisted steering device), then the resultant angle of the steering angle of a steering control wheel mechanically determined by a rotational operation of the steering wheel and a steering angle based on an operation of an actuator (a correction amount of a steering angle) will be the steering angle of the steering control wheel.

[0049] If the steering device 3B is an active steering device which steers the steering control wheels W1 and W2 by using only a driving force of an actuator (hereinafter, such an active steering device will be referred to as an actuator-driven type steering device), then a target value of the steering angle of the steering control wheels is determined on the basis of at least a detection value of the steering angle and the actuator is controlled such that the actual steering angle of the steering control wheels takes the target value.

[0050] As the steering device 3B capable of actively controlling the steering angle of the steering control wheels W1 and W2 through the intermediary of an actuator

(the active steering device), a publicly known one may be used.

[0051] The steering device 3B in the embodiments in the present description is an active steering device capable of actively controlling the steering angle of the front wheels W1 and W2 through the intermediary of an actuator; alternatively, however, the steering device 3B may be a type that performs only the mechanical steering of the front wheels W1 and W2 on the basis of a rotational operation of the steering wheel (hereinafter referred to as a mechanical type steering device). Further, in a vehicle having all wheels W1 to W4 as steering control wheels, the steering device may be capable of actively controlling the steering angles of both the front wheels W1, W2 and the rear wheels W3, W4 through the intermediary of actuators. Alternatively, the steering device may be a type which steers the front wheels W1 and W2 on the basis of a rotational operation of the steering wheel only by a mechanical means, such as a rack-and-pinion, and which is capable of actively controlling only the steering angles of the rear wheels W3 and W4 through the intermediary of an actuator.

[0052] According to the embodiments in the present description, the suspension device 3C is a suspension device which passively operates on the basis of, for example, a motion of the vehicle 1.

[0053] However, the suspension device 3C may be a

suspension device capable of variably controlling, for example, a damping force, hardness or the like of a damper interposed between the vehicle body 1B and the wheels W1 to W4 through the intermediary of an actuator, such as an electromagnetic control valve or an electric motor. Alternatively, the suspension device 3C may be a suspension device capable of directly controlling a stroke (an amount of vertical displacement between the vehicle body 1B and the wheels W1 to W4) of a suspension (a mechanical portion, such as a spring, of the suspension device 3C) or a vertical expanding/contracting force of the suspension generated between the vehicle body 1B and the wheels W1 to W4 by a hydraulic cylinder or a pneumatic cylinder (a so-called electronically controlled suspension). If the suspension device 3C is a suspension device capable of controlling the damping force or the hardness of the damper and the stroke or the expanding/contracting force of the suspension as described above (hereinafter referred to as the active suspension device), then the suspension device 3C permits active control of the operations thereof.

[0054] In the following explanation, among the driving/braking device 3A, the steering device 3B, and the suspension device 3C, those devices capable of actively controlling the operations as described above may be referred to generically as actuator devices 3. In the embodiments in the present description, the actuator

devices 3 include the driving/braking device 3A and the steering device 3B. If the suspension device 3C is an active suspension device, then the suspension device 3C is also included in the actuator devices 3.

[0055] Further, the vehicle 1 is provided with a controller 10 which determines a manipulated variable of an actuator (a control input to the actuator; hereinafter referred to as an actuator manipulated variable) provided in each of the actuator devices 3 on the basis of the above-mentioned drive manipulation inputs and the like, and controls the operation of each of the actuator devices 3 on the basis of the actuator manipulated variable. This controller 10 is constituted of an electronic circuit unit that includes a microcomputer and the like. The controller 10 receives the drive manipulation inputs from sensors of the manipulating devices 5 and also the detection values of the state amounts of the vehicle 1, such as a traveling velocity, a yaw rate and the like of the vehicle 1, and information on traveling environments and the like of the vehicle 1 from various sensors, which are not shown. Then, based on those inputs, the controller 10 sequentially determines actuator manipulated variables at a predetermined control processing cycle so as to sequentially control the operations of the actuator devices 3.

[0056] The above has described the general schematic construction of the vehicle 1 (the car) of the embodiments

in the present description. This schematic construction will be the same in all embodiments to be described below.

[0057] Supplementally, according to the embodiments in the present description, among the driving/braking device 3A, the steering device 3B, and the suspension device 3C described above, those corresponding to the actuator devices in the present invention (the actuator devices to which the present invention will be applied to carry out operation control) will be the driving/braking device 3A or the driving/braking device 3A and the steering device 3B.

[0058] Further, the controller 10 implements a variety of means in the present invention by the control processing functions thereof.

[0059]

[First Embodiment]

The control processing by a controller 10 in a first embodiment will now be schematically described with reference to Fig. 2. Fig. 2 is a functional block diagram illustrating an overview of the entire control processing function of the controller 10. In the description from now on, a real vehicle 1 will be referred to as an actual vehicle 1.

[0060] The portion excluding the actual vehicle 1 in Fig. 2 (more precisely, the portion excluding the actual vehicle 1 and sensors included in a sensor/estimator 12, which will be discussed later) corresponds to the primary

control processing function of the controller 10. The actual vehicle 1 in Fig. 2 is provided with the driving/braking device 3A, the steering device 3B, and the suspension device 3C described above.

[0061] As illustrated, the controller 10 is equipped with, as its main processing function components, the sensor/estimator 12, a reference manipulated variable determiner 14, a reference dynamic characteristic model 16, a subtracter 18, a feedback distribution law (FB distribution law) 20, a feedforward law (FF law) 22, the actuator operation target value synthesizer 24, and an actuator drive control unit 26. The solid-line arrows in Fig. 2 indicate primary inputs to the processing function components and the dashed-line arrows indicate secondary inputs to the processing function components.

[0062] The controller 10 carries out the processing by these processing function components at a predetermined control processing cycle to sequentially determine actuator manipulated variables at each control processing cycle. Then, the controller 10 sequentially controls the operations of the actuator devices 3 of the actual vehicle 1 on the basis of the actuator manipulated variables.

[0063] The following will present an outline of each processing function component of the controller 10 and an outline of the overall processing. Hereinafter, regarding the values of the variables determined at each control processing cycle of the controller 10, a value finally

obtained by the processing at a current (a latest) control processing cycle will be referred to as a current time value, and a value finally obtained by a last time control processing cycle will be referred to as a last time value.

[0064] At each control processing cycle, the controller 10 first detects or estimates a state amount of the actual vehicle 1 or a state amount of a traveling environment of the actual vehicle 1 by the sensor/estimator 12. In the present embodiment, detection targets or estimation targets of the sensor/estimator 12 include, for example, a yaw rate $\dot{\gamma}_{act}$, which is an angular velocity in the yaw direction of the actual vehicle 1, a traveling velocity V_{act} (ground speed) of the actual vehicle 1, a vehicle center-of-gravity point side slip angle β_{act} , which is a side slip angle of the center-of-gravity point of the actual vehicle 1, a front wheel side slip angle β_{f_act} , which is a side slip angle of the front wheels W1 and W2 of the actual vehicle 1, a rear wheel side slip angle β_{r_act} , which is a side slip angle of the rear wheels W3 and W4 of the actual vehicle 1, a road surface reaction force (a driving/braking force, a lateral force, and a ground contact load), which is a reaction force acting on the wheels W1 to W4 of the actual vehicle 1 from a road surface, a slip ratio of each of the wheels W1 to W4 of the actual vehicle 1, and a steering angle δ_{f_act} of the front wheels W1 and W2 of the actual vehicle 1.

[0065] Among these detection targets or estimation

targets, the vehicle center-of-gravity point side slip angle β_{act} is an angle formed by the vector of the traveling velocity V_{act} of the actual vehicle 1 with respect to the longitudinal direction of the actual vehicle 1 when the actual vehicle 1 is observed from above (on the horizontal plane). The front wheel side slip angle β_{f_act} is an angle formed by the advancing velocity vector of the front wheels W1 and W2 with respect to the longitudinal direction of the front wheels W1 and W2 when the actual vehicle 1 is observed from above (on the horizontal plane). The rear wheel side slip angle β_{r_act} is an angle formed by the advancing velocity vector of the rear wheels W3 and W4 with respect to the longitudinal direction of the rear wheels W3 and W4 when the actual vehicle 1 is observed from above (on the horizontal plane). The steering angle δ_{f_act} is an angle formed by the rotational surfaces of the front wheels W1 and W2 with respect to the longitudinal direction of the actual vehicle 1 when the actual vehicle 1 is observed from above (on the horizontal plane).

[0066] The front wheel side slip angle β_{f_act} may be detected or estimated on each of the front wheels W1 and W2; alternatively, however, the side slip angle of one of the front wheels W1 and W2 may be detected or estimated representatively as β_{f_act} , or a mean value of the side slip angles of both may be detected or estimated as β_{f_act} . The same applies to the rear wheel side slip angle β_{r_act} .

[0067] Further, the estimation targets of the sensor/estimator 12 include a coefficient of friction between the wheels W1 to W4 of the actual vehicle 1 and an actual road surface in contact therewith (hereinafter, an estimated value of the friction coefficient will be referred to as the estimated friction coefficient μ_{estm}). Preferably, the processing for estimating a friction coefficient includes filtering or the like of a low-pass characteristic so as to restrain frequent fluctuation in the estimated friction coefficient μ_{estm} .

[0068] The sensor/estimator 12 is equipped with various sensors mounted on the actual vehicle 1 to detect or estimate the above-mentioned detection targets or estimation targets. The sensors include, for example, a rate sensor for detecting angular velocities of the actual vehicle 1, an acceleration sensor for detecting accelerations in the longitudinal direction and the lateral direction of the actual vehicle 1, a velocity sensor for detecting the traveling velocity (ground speed) of the actual vehicle 1, a rotational velocity sensor for detecting the rotational velocities of the wheels W1 to W4 of the actual vehicle 1, and a force sensor for detecting road surface reaction forces acting on the wheels W1 to W4 of the actual vehicle 1 from a road surface.

[0069] In this case, for an estimation target that cannot be directly detected by a sensor installed in the actual vehicle 1 among the detection targets or the estimation

targets, the sensor/estimator 12 estimates the estimation target by an observer or the like on the basis of a detection value of a state amount correlated to the estimation target or the value or a target value of an actuator manipulated variable determined by the controller 10. For instance, the vehicle center-of-gravity point side slip angle β_{act} is estimated on the basis of mainly a detection value of the acceleration sensor installed in the actual vehicle 1. Further, for example, the friction coefficient is estimated by a publicly known method on the basis of mainly a detection value of the acceleration sensor.

[0070] Supplementally, the sensor/estimator 12 has a function as an actual state amount grasping means in the present invention. In the present embodiment, the type of a first state amount related to vehicle motions includes a vehicle yaw rate and a vehicle center-of-gravity point side slip angle. In this case, the yaw rate has a meaning as a state amount related to the rotational motions in the yaw direction of the vehicle, and the vehicle center-of-gravity point side slip angle has a meaning as a state amount related to the side slip of the vehicle (the lateral translational motion of the vehicle). Hence, the set of the yaw rate γ_{act} and the vehicle center-of-gravity point side slip angle β_{act} is detected or estimated by the sensor/estimator 12 as an actual state amount vector in the present invention.

[0071] Hereinafter, the designations of the state amounts or the like of the actual vehicle 1 to be detected or estimated by the sensor/estimator 12 will be frequently accompanied by "actual." For instance, the yaw rate γ_{act} of the actual vehicle 1, the traveling velocity V_{act} of the actual vehicle 1, and the vehicle center-of-gravity point side slip angle β_{act} of the actual vehicle 1 will be referred to as the actual yaw rate γ_{act} , the actual traveling velocity V_{act} , and the actual vehicle center-of-gravity point side slip angle β_{act} , respectively.

[0072] Subsequently, the controller 10 determines, by a reference manipulated variable determiner 14, a reference model manipulated variable as an input to a reference dynamic characteristic model 16, which will be discussed later. In this case, the reference manipulated variable determiner 14 receives a drive manipulation input detected by a sensor of the manipulating devices 5 and determines the reference model manipulated variable on the basis of at least the drive manipulation input.

[0073] More specifically, in the present embodiment, the reference model manipulated variable determined by the reference manipulated variable determiner 14 is the steering angle of the front wheels of a vehicle on a reference dynamic characteristic model 16, which will be discussed later, (hereinafter referred to as the model front wheel steering angle). To determine the model front wheel steering angle, a steering angle θ_h (current time

value) of the drive manipulation input is input as a main input amount to the reference manipulated variable determiner 14. Further, the actual traveling velocity V_{act} (current time value) and the estimated friction coefficient μ_{estm} (current time value) detected or estimated by the sensor/estimator 12, and a state amount (last time value) of the vehicle on the reference dynamic characteristic model 16 are input to the reference manipulated variable determiner 14. Then, the reference manipulated variable determiner 14 determines the model front wheel steering angle on the basis of these inputs. Basically, the model front wheel steering angle may be determined on the basis of the steering angle θ_h . In the present embodiment, however, a predetermined restriction is placed on the model front wheel steering angles input to the reference dynamic characteristic model 16. To place the restriction, V_{act} , μ_{estm} and the like in addition to the steering angle θ_h are supplied to the reference manipulated variable determiner 14.

[0074] Supplementally, the type of reference model manipulated variable generally depends on the form of the reference dynamic characteristic model 16 or the type of state amount to be determined by the reference dynamic characteristic model 16. The reference dynamic characteristic model 16 may include the reference manipulated variable determiner 14. If the reference dynamic characteristic model 16 is constructed to require

a drive manipulation input itself, then the reference manipulated variable determiner 14 may be omitted.

[0075] Subsequently, the controller 10 determines and outputs a reference state amount, which is the state amount of a reference motion of the actual vehicle 1 (hereinafter referred to as the reference motion), by the reference dynamic characteristic model 16. The reference dynamic characteristic model 16 is a model which is established beforehand and which represents dynamic characteristics of a vehicle, and it sequentially determines a state amount of a reference motion (a reference state amount) on the basis of predetermined inputs, including the reference model manipulated variable mentioned above. The reference motion basically means an ideal motion or a motion close thereto of the actual vehicle 1 which is considered desirable to a driver.

[0076] In this case, the reference dynamic characteristic model 16 receives mainly the reference model manipulated variable determined by the reference manipulated variable determiner 14 and control inputs (feedback control inputs) M_{vir} and F_{vir} for operating the reference dynamic characteristic model 16 determined by an FB distribution law 20, which will be discussed later. Then, the reference dynamic characteristic model 16 determines a reference motion (eventually the time series of a reference state amount) on the basis of the inputs.

[0077] More specifically, in the present embodiment, a

reference state amount determined and output by the reference dynamic characteristic model 16 is composed of a set of a reference state amount related to a rotational motion in the yaw direction of a vehicle and a reference state amount related to a translational motion in the lateral direction (a side slip motion) of a vehicle. A reference state amount related to the rotational motion in the yaw direction of the vehicle is, for example, a yaw rate reference value γ_d (hereinafter referred to as the reference yaw rate γ_d in some cases) and the reference state amount related to the translational motion in the lateral direction of the vehicle is, for example, a vehicle center-of-gravity point side slip angle reference value β_d (hereinafter referred to as the reference vehicle center-of-gravity point side slip angle β_d in some cases). To sequentially determine these reference state amounts γ_d and β_d at each control processing cycle, the model front wheel steering angle (current time value) and the feedback control inputs M_{vir} and F_{vir} (last time values) as reference model manipulated variables are supplied. In this case, in the present embodiment, the traveling velocity of the vehicle on the reference dynamic characteristic model 16 is set to agree with the actual traveling velocity V_{act} . Thus, the actual traveling velocity V_{act} (current time value) detected or estimated by the sensor/estimator 12 is also supplied to the reference dynamic characteristic model 16. Then, based on

these inputs, the reference dynamic characteristic model 16 determines the yaw rate and the vehicle center-of-gravity point side slip angle of the vehicle on the reference dynamic characteristic model 16 and outputs the determined results as the reference state amounts γ_d and β_d .

[0078] Incidentally, the feedback control inputs M_{vir} and F_{vir} supplied to the reference dynamic characteristic model 16 are feedback control inputs additionally supplied to the reference dynamic characteristic model 16 in order to restrain alienation (separation) between a motion of the actual vehicle 1 and a reference motion due to, for example, a change in a traveling environment (such as a road surface condition) of the actual vehicle 1 (a change not considered in the reference dynamic characteristic model 16), a modeling error in the reference dynamic characteristic model 16, or a detection error or an estimation error of the sensor/estimator 12 (or in order to approximate a reference motion to a motion of the actual vehicle 1). In the present embodiment, the feedback control inputs M_{vir} and F_{vir} are virtual external forces virtually applied to the vehicle on the reference dynamic characteristic model 16. M_{vir} of the virtual external forces M_{vir} and F_{vir} denotes a virtual moment in the yaw direction which is to act about the center-of-gravity point of the vehicle 1 on the reference dynamic characteristic model 16, and F_{vir} denotes a virtual

translational force in the lateral direction which is to act on the center-of-gravity point.

[0079] Supplementally, the set of the reference state amounts γ_d and β_d corresponds to the model state amount vector in the present invention, and the reference dynamic characteristic model 16 corresponds to the vehicle model in the present invention. Further, the processing by the reference manipulated variable determiner 14 and the reference dynamic characteristic model 16 constitutes the model state amount determining means in the present invention. In the present embodiment, the processing by the reference dynamic characteristic model 16 includes a function as the vehicle model characteristics setting means in the present invention.

[0080] Subsequently, the controller 10 calculates, by a subtracter 18, a state amount error, which is the difference between the actual state amount (an actual state amount of the same type as a reference state amount) detected or estimated by the sensor/estimator 12 and the reference state amount determined by the reference dynamic characteristic model 16.

[0081] More specifically, the subtracter 18 determines, as state amount errors, the differences $\gamma_{err}(=\gamma_{act}-\gamma_d)$ and $\beta_{err}(=\beta_{act}-\beta_d)$ between the values (current time values) of the actual yaw rate γ_{act} and the actual vehicle center-of-gravity point side slip angle β_{act} and the values (current time values) of the reference yaw rate γ_d and the

reference vehicle center-of-gravity point side slip angle β_d determined by the reference dynamic characteristic model 16.

[0082] Supplementally, the processing by the subtracter 18 constitutes the state amount error calculating means in the present invention.

[0083] Subsequently, the controller 10 supplies the state amount errors γ_{err} and β_{err} determined as described above to the FB distribution law 20. The FB distribution law 20 determines the virtual external forces M_{vir} and F_{vir} , which are feedback control inputs for manipulating the reference dynamic characteristic model 16 and an actuator operation feedback target value (actuator operation FB target value), which is a feedback control input for operating the actuator devices 3 of the actual vehicle 1.

[0084] In the present embodiment, the actuator operation FB target value includes a feedback control input related to the operation of the braking device of the driving/braking device 3A (more specifically, a feedback control input for manipulating a driving/braking force to be applied to the wheels W1 to W4 by operating the braking device). Alternatively, the actuator operation FB target value includes a feedback control input related to the operation of the steering device 3B (more specifically, a feedback control input for manipulating the lateral forces of the front wheels W1 and W2 by operating the steering device 3B) in addition to a feedback control input related

to the operation of the driving/braking device 3A. The actuator operation FB target value is, in other words, a feedback control input for manipulating (correcting) a road surface reaction force, which is an external force to be applied to the actual vehicle 1.

[0085] The FB distribution law 20 basically determines the virtual external forces M_{vir} and F_{vir} and the actuator operation FB target value such that the received state amount errors γ_{err} and β_{err} are approximated to zero. However, when determining the virtual external forces M_{vir} and F_{vir} , the FB distribution law 20 determines the virtual external forces M_{vir} and F_{vir} such that not only the state amount errors γ_{err} and β_{err} are approximated to zero but the deviation of a predetermined restriction object amount of the actual vehicle 1 or the vehicle on the reference dynamic characteristic model 16 from a predetermined permissible range is restrained. Further, the FB distribution law 20 determines, as the actuator operation FB target value, a feedback control input related to the operation of the braking device of the driving/braking device 3A or the feedback control input and a feedback control input related to the operation of the steering device 3B such that a predetermined moment in the yaw direction for approximating the state amount errors γ_{err} and β_{err} to zero is generated about the center-of-gravity point of the actual vehicle 1 (more generally, such that a predetermined external force (road

surface reaction force) for approximating the state amount errors γ_{err} and β_{err} to zero acts on the actual vehicle 1).

[0086] To determine the virtual external forces M_{vir} , F_{vir} and the actuator operation FB target value, the FB distribution law 20 receives not only the state amount errors γ_{err} and β_{err} but also at least either the reference state amounts γ_d and β_d , which are outputs of the reference dynamic characteristic model 16, or the actual state amounts γ_{act} and β_{act} detected or estimated by the sensor/estimator 12. Furthermore, the FB distribution law 20 also receives actual state amounts, such as the actual traveling velocity V_{act} , the actual front wheel side slip angle β_{f_act} , and the actual rear wheel side slip angle β_{r_act} , detected or estimated by the sensor/estimator 12. Then, based on these inputs, the FB distribution law 20 determines the virtual external forces M_{vir} , F_{vir} and the actuator operation FB target value.

[0087] Supplementally, the virtual external forces M_{vir} , F_{vir} correspond to the vehicle model operation control inputs in the present invention, and the actuator operation FB target value corresponds to the actual vehicle actuator operation control input in the present invention. Thus, the FB distribution law 20 has a function as a state amount error response control means.

[0088] Meanwhile, in parallel to the control processing (or by time-sharing processing) by the reference manipulated variable determiner 14, the reference dynamic

characteristic model 16, the subtracter 18, and the FB distribution law 20 described above, the controller 10 supplies the aforesaid drive manipulation inputs to an FF law 22 to determine an actuator operation FF target value, which is a feedforward target value (basic target value) of the operation of the actuator devices 3, by the FF law 22.

[0089] According to the present embodiment, the actuator operation FF target value includes the feedforward target values related to the driving/braking forces of the wheels W1 to W4 of the actual vehicle 1 by the operation of the braking device of the driving/braking device 3A, the feedforward target values related to the driving/braking forces of the driving wheels W1 and W2 of the actual vehicle 1 by the operation of the driving system of the driving/braking device 3A, the feedforward target values related to the reduction gear ratio (change gear ratio) of the transmission of the driving/braking device 3A, and the feedforward target values related to the steering angles of the steering control wheels W1 and W2 of the actual vehicle 1 by the steering device 3B.

[0090] To determine these actuator operation FF target values, the FF law 22 receives the drive manipulation input and also receives the actual state amount (the actual traveling velocity V_{act} or the like) detected or estimated by the sensor/estimator 12. Then, based on these inputs, the FF law 22 determines the actuator

operation FF target value. The actuator operation FF target value is an operation target value of the actuator devices 3 which is determined without depending on the state amount errors γ_{err} and β_{err} .

[0091] Supplementally, if the suspension device 3C is an active suspension device, then the actuator operation FF target value generally includes a feedforward target value related to an operation of the suspension device 3C.

[0092] Subsequently, the controller 10 inputs the actuator operation FF target value (the current time value) determined by the FF law 22 and the actuator operation FB target value (the current time value) determined by the FB distribution law 20 to the actuator operation target value synthesizer 24. Then, the controller 10 synthesizes the actuator operation FF target value and the actuator operation FB target value by the actuator operation target value synthesizer 24 to determine the actuator operation target value, which is a target value defining the operation of the actuator devices 3.

[0093] According to the present embodiment, the actuator operation target values include a target value of the driving/braking forces of the wheels W1 to W4 of the actual vehicle 1 (a target value of the total driving/braking force by the operations of the driving system of the driving/braking device 3A and the braking device), a target value of a slip ratio of the wheels W1

to W4 of the actual vehicle 1, a target value of a steering angle of the steering control wheels W1 and W2 of the actual vehicle 1 by the steering device 3B, a target value of the driving/braking force of the driving wheels W1 and W2 of the actual vehicle 1 by the operation of the driving system of the driving/braking device 3A, and a target value of a reduction gear ratio of the transmission of the driving/braking device 3A.

[0094] To determine these actuator operation target values, the actuator operation target value synthesizer 24 receives not only the actuator operation FF target value and the actuator operation FB target value but also the actual state amounts (the actual side slip angle β_{f_act} of the front wheels W1, W2 and the estimated friction coefficient μ_{estm} , etc.) detected or estimated by the sensor/estimator 12. Then, based on these inputs, the actuator operation target value synthesizer 24 determines the actuator operation target value.

[0095] Supplementally, the actuator operation target value is not limited to the types of target values described above. For example, in place of the target values, the target values of the actuator manipulated variables of the actuator devices that are associated with the aforesaid target values may be determined as actuator operation target values. Basically, the actuator operation target values may take any values as long as they make it possible to define the operations of the

actuator devices. For instance, as the actuator operation target value related to an operation of the braking device, the target value of a braking pressure may be determined or the target value of the actuator manipulated variable of the braking device associated therewith may be determined.

[0096] Subsequently, the controller 10 inputs the actuator operation target value, which has been determined by the actuator operation target value synthesizer 24, into the actuator drive control unit 26, and determines the actuator manipulated variable of each of the actuator devices 3 of the actual vehicle 1 by the actuator drive control unit 26. Then, the actuator of each of the actuator devices 3 of the actual vehicle 1 is controlled on the basis of the determined actuator manipulated variable.

[0097] In this case, the actuator drive control unit 26 determines the actuator manipulated variable such that the input actuator operation target value is satisfied or in exact accordance with the actuator operation target value. Further, for this determination, the actuator drive control unit 26 also receives the actual state amounts of the actual vehicle 1 detected or estimated by the sensor/estimator 12 in addition to the actuator operation target value. Among the control functions of the actuator drive control unit 26, the control function related to the braking device of the driving/braking device 3A desirably

incorporates a so-called antilock braking system.

[0098] The above has provided an overview of the control processing for each control processing cycle of the controller 10.

[0099] The order of the processing of each control processing function section of the controller 10 may be changed, as necessary. For example, the processing by the sensor/estimator 12 may be executed at the end of each control processing cycle and a detected value or an estimated value obtained thereby may be used for the processing of the next control processing cycle.

[0100]

More detailed processing of the control processing function section of the controller 10 in the present embodiment will now be described.

[0101] [About a reference dynamic characteristic model]

First, the reference dynamic characteristic model 16 in the present embodiment will be described by referring to Fig. 3. Fig. 3 is a diagram illustrating the construction of a vehicle on the reference dynamic characteristic model 16 in the present embodiment. This reference dynamic characteristic model 16 is a model which expresses the dynamic characteristics of a vehicle in terms of the dynamic characteristics (kinetic characteristics) on a horizontal plane of a vehicle

equipped with one front wheel W_f and one rear wheel W_r at the front and the back (a so-called two-wheeled model). Hereinafter, the vehicle on the reference dynamic characteristic model 16 (the vehicle corresponding to the actual vehicle 1 on the reference dynamic characteristic model 16) will be referred to as the model vehicle. The front wheel W_f of the model vehicle corresponds to a wheel that combines the two front wheels W_1 and W_2 of the actual vehicle 1 into one piece and provides the steering control wheel of the model vehicle. The rear wheel W_r corresponds to a wheel that combines the rear wheels W_3 and W_4 of the actual vehicle 1 into one piece and provides a non-steering control wheel in the present embodiment.

[0102] An angle β_d formed with respect to the longitudinal direction of the model vehicle by the velocity vector V_d (the vector of the traveling velocity V_d of the model vehicle) on the horizontal plane of a center-of-gravity point G_d of the model vehicle (i.e., a vehicle center-of-gravity point side slip angle β_d of the model vehicle) and the angular velocity γ_d about the vertical axis of the model vehicle (i.e., the yaw rate γ_d of the model vehicle) are the reference state amounts sequentially determined by the reference dynamic characteristic model 16 as the reference vehicle center-of-gravity point side slip angle and the reference yaw rate, respectively. Further, an angle δf_d formed with respect to the longitudinal direction of the model vehicle

by a line of intersection of the rotational plane of the front wheel W_f of the model vehicle and the horizontal plane is the reference model manipulated variable input to the reference dynamic characteristic model 16 as the model front wheel steering angle. Further, a translational force F_{vir} in the lateral direction additionally applied to the center-of-gravity point G_d of the model vehicle (in the lateral direction of the model vehicle) and a moment M_{vir} in the yaw direction (about the vertical axis) additionally applied about the center-of-gravity point G_d of the model vehicle are the feedback control inputs supplied as the virtual external forces to the reference dynamic characteristic model 16.

[0103] In Fig. 3, V_{f_d} denotes an advancing velocity vector of the front wheel W_f of the model vehicle on the horizontal plane, V_{r_d} denotes an advancing velocity vector of the rear wheel W_r of the model vehicle on the horizontal plane, β_{f_d} denotes a side slip angle of the front wheel W_f (an angle formed with respect to the longitudinal direction of the front wheel W_f (the direction of the line of intersection of the rotational plane of the front wheel W_f and the horizontal plane) by the advancing velocity vector V_{f_d} of the front wheel W_f . Hereinafter referred to as the front wheel side slip angle β_{f_d}), β_{r_d} denotes a side slip angle of the rear wheel W_r (an angle formed with respect to the longitudinal direction of the rear wheel W_r (the direction of the line

of intersection of the rotational plane of the rear wheel W_r and the horizontal plane) by the advancing velocity vector V_{r_d} of the rear wheel W_r . Hereinafter this angle is referred to as the rear wheel side slip angle β_{r_d} , and β_{f0} denotes an angle formed with respect to the longitudinal direction of the model vehicle by the advancing velocity vector V_{f_d} of the front wheel W_f of the model vehicle (hereinafter referred to as the vehicle front wheel position side slip angle β_{f0}).

[0104] Supplementally, according to the embodiments in the present description, regarding a side slip angle of a vehicle or a wheel, a steering angle of a wheel, a yaw rate of the vehicle and a moment in the yaw direction, the counterclockwise direction as observed from above the vehicle is defined as the positive direction. Further, of the virtual external forces M_{vir} and F_{vir} , the translational force F_{vir} defines the leftward direction of the vehicle as the positive direction. For a driving/braking force of a wheel, the direction of a force for accelerating the vehicle forward in the direction of the line of intersection of the rotational surface of a wheel and a road surface or a horizontal plane (road surface reaction force) is defined as the positive direction. In other words, a driving/braking force in the direction that provides a driving force relative to the advancing direction of the vehicle takes a positive value, while a driving/braking force in the direction that

provides a braking force relative to the advancing direction of the vehicle takes a negative value.

[0105] Specifically, the dynamic characteristics (the dynamic characteristics in a continuous system) of the model vehicle are represented by expression 01 given below. The expression which defines "K" of the right side of the expression 01 as a unit matrix and which excludes the third term (the term including Fvir and Mvir) in the parenthesis of the right side is equivalent to, for example, the publicly known expressions (3.12), (3.13) shown in the publicly known document titled "Motion and Control of Automobile" (written by Masato Abe; published by Sankaido Co., Ltd.; and 2nd printing, 2nd edition published on July 23, 2004: hereinafter referred to as non-patent document 1).

[0106] [Mathematical Expression 1]

$$\frac{d}{dt} \begin{bmatrix} \beta d \\ \gamma d \end{bmatrix} = K \cdot \left(\begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} \cdot \begin{bmatrix} \beta d \\ \gamma d \end{bmatrix} + \begin{bmatrix} b_1 \\ b_2 \end{bmatrix} \cdot \delta f_d + \begin{bmatrix} b_{11} & 0 \\ 0 & b_{22} \end{bmatrix} \cdot \begin{bmatrix} F_{vir} \\ M_{vir} \end{bmatrix} \right) \dots\dots \text{Expression 01}$$

where

$$K = \begin{bmatrix} k_1 & 0 \\ 0 & k_2 \end{bmatrix}$$

$$a_{11} = - \frac{2 \cdot (K_f + K_r)}{m \cdot V_d}$$

$$a_{12} = - \frac{m \cdot V_d^2 + 2 \cdot (L_f \cdot K_f - L_r \cdot K_r)}{m \cdot V_d^2}$$

$$a_{21} = - \frac{2 \cdot (L_f \cdot K_f - L_r \cdot K_r)}{I}$$

$$a_{22} = - \frac{2 \cdot (L_f^2 \cdot K_f + L_r^2 \cdot K_r)}{I \cdot V_d}$$

$$b_1 = \frac{2 \cdot K_f}{m \cdot V_d}$$

$$b_2 = \frac{2 \cdot L_f \cdot K_f}{I}$$

$$b_{11} = \frac{1}{m \cdot V_d}$$

$$b_{22} = \frac{1}{I}$$

[0107] In the note of the expression 01, m denotes the

total mass of the model vehicle, K_f denotes the cornering power per wheel when the front wheel W_f of the model vehicle is regarded as a connected body of the two right and left front wheels, K_r denotes the cornering power per wheel when the rear wheel W_r of the model vehicle is regarded as a connected body of the two right and left rear wheels, L_f denotes the distance in the longitudinal direction between the center of the front wheel W_f of the model vehicle and the center-of-gravity point G_d (the distance in the longitudinal direction between the rotational axis of the front wheel W_f and the center-of-gravity point G_d when the steering angle of the front wheel W_f is zero. Refer to Fig. 3), L_r denotes the distance in the longitudinal direction between the center of the rear wheel W_r of the model vehicle and the center-of-gravity point G_d (the distance in the longitudinal direction between the rotational axis of the rear wheel W_r and the center-of-gravity point G_d . Refer to Fig. 3), and I denotes the inertia (inertial moment) about the yaw axis at the center-of-gravity point G_d of the model vehicle. The values of these parameters m , I , L_f , L_r , K_f , and K_r (or the values of the parameters a_{11} , a_{12} , a_{21} , a_{22} , b_1 , b_2 , b_{11} , and b_{22} of the right side of expression 01) are preset values. In this case, for example, m , I , L_f and L_r are set to the same or substantially the same values as those thereof in the actual vehicle 1. Further, K_f and K_r are set, by considering the characteristics of the tires

(or the characteristics required of the tires) of the front wheels $W1$, $W2$ and the rear wheels $W3$, $W4$, respectively, of the actual vehicle 1. For example, K_f and K_r are respectively set to be the same or substantially the same as the cornering power of the tires of the front wheels $W1$, $W2$ and the rear wheels $W3$, $W4$ of the actual vehicle 1.

[0108] More generally, the values of m , I , L_f , L_r , K_f , and K_r (or the values of a_{11} , a_{12} , a_{21} , a_{22} , b_1 , b_2 , b_{11} , and b_{22}) are set such that the motional characteristics of the model vehicle (the steady-state characteristics of the model vehicle) in a steady state (in a state wherein a drive manipulation input, such as the steering angle θ_h , is constant and an environmental condition of a road surface condition or the like is constant or uniform, and sufficient time has elapsed for a transient behavior to disappear) approximates the motional characteristics in the steady state of the actual vehicle 1 (the steady-state characteristics of the actual vehicle 1). In this case, the steady-state characteristics of the model vehicle in the present embodiment is represented by the relationship between the steering angle θ_h and the vehicle center-of-gravity point side slip angle β_d and the yaw rate γ_d of the model vehicle when the temporal changes in the motional state amounts β_d and γ_d of the model vehicle (the left side of expression 01) are set to zero and the virtual external forces F_{vir} and M_{vir} are set to zero

(provided $V_d=V_{act}$). Hence, the values of m , I , L_f , L_r , K_f , and K_r (or the values of a_{11} , a_{12} , a_{21} , a_{22} , b_1 , b_2 , b_{11} , and b_{22}) of the model vehicle are set such that the above relationship approximately coincides with the relationship between the steering angle θ_h and the actual vehicle center-of-gravity point side slip angle β_{act} and the actual yaw rate $\dot{\gamma}_{act}$ of the actual vehicle 1 in a steady state (the relationship when the actuator operation FB target value is set to zero).

[0109] Further, the matrix K in expression 01 is a characteristics adjusting matrix (diagonal matrix) for multiplying the values of the first row and the second row of each term in the parenthesis of the right side of expression 01 by k_1 and k_2 (provided $k_1 \neq 0$ and $k_2 \neq 0$), respectively, to adjust the dynamic characteristics of the model vehicle (more specifically, the transient response characteristics of the state amounts β_d and $\dot{\gamma}_d$ of the model vehicle). Hereinafter, the diagonal components k_1 and k_2 of the characteristics adjusting matrix K will be referred to as the model characteristics adjusting parameters.

[0110] In the present embodiment, the value of k_2 out of the model characteristics adjusting parameters k_1 and k_2 of the characteristics adjusting matrix K is variably set by the processing by the reference dynamic characteristic model 16 to adjust the transient response characteristics of the state amounts β_d and $\dot{\gamma}_d$ of the model vehicle.

Further, the value of k_1 is fixed to "1." Hence, in the present embodiment, the value of the model characteristics adjusting parameter k_2 for multiplying the value of the second row of each term in the parenthesis of the right side of expression 01 by k_2 is variably set thereby to adjust the transient response characteristics of the state amounts β_d and γ_d of the model vehicle. Incidentally, the method for setting the value of the model characteristics adjusting parameter k_2 will be discussed later.

[0111] Supplementally, the characteristics adjusting matrix K is a matrix used to equally multiply all terms of the same row in the parenthesis of the right side of expression 01, so that the steady state characteristics of the model vehicle are maintained constant without depending on the values of k_1 and k_2 unless the value of each of the diagonal components k_1 and k_2 of the characteristics adjusting matrix K is zero. Therefore, the characteristics adjusting matrix K (the model characteristics adjusting parameters k_1 and k_2) are used to adjust transient response characteristics while maintaining the steady-state characteristics of the model vehicle constant.

[0112] In the processing by the reference dynamic characteristic model 16 in the present embodiment, the arithmetic processing of the expression 1 (more specifically, the arithmetic processing of an expression obtained by representing expression 01 by means of a

discrete-time system) is sequentially implemented at a control processing cycle of the controller 10, using δf_d , F_{vir} , and M_{vir} of the above expression 01 as inputs, thereby to sequentially calculate β_d and γ_d in time series. In this case, at each control processing cycle, a latest value (a current time value) of the actual traveling velocity V_{act} detected or estimated by the sensor/estimator 12 is used as the value of the traveling velocity V_d of the model vehicle. In other words, the traveling velocity V_d of the model vehicle is always made to agree with the actual traveling velocity V_{act} . Based on the traveling velocity V_d of the model vehicle, which is made to coincide with the actual traveling velocity V_{act} as described above (in other words, based on the actual traveling velocity V_{act}), the value of k_2 out of the model characteristics adjusting parameters k_1 and k_2 is variably set. As the values of F_{vir} and M_{vir} , the latest values (the last time values) of the virtual external forces determined as will be discussed later by the FB distribution law 20 are used. As the value of δf_d , the latest value (the current time value) of the model front wheel steering angle determined as will be discussed later by the reference manipulated variable determiner 14 is used. Incidentally, the last time values of β_d and γ_d are also used to calculate new β_d and γ_d (current time values).

[0113] Supplementally, the relationship among β_{f0} , β_d ,

β_{f_d} , β_{r_d} , γ_d , and δ_{f_d} of the model vehicle is represented by expressions 02a, 02b, and 02c given below.

[0114]

$$\beta_{f_d} = \beta_d + L_f \cdot \gamma_d / V_d - \delta_{f_d} \quad \dots \text{Expression 02a}$$

$$\beta_{r_d} = \beta_d - L_r \cdot \gamma_d / V_d \quad \dots \text{Expression 02b}$$

$$\beta_{f0} = \beta_{f_d} + \delta_{f_d} = \beta_d + L_f \cdot \gamma_d / V_d \quad \dots \text{Expression 02c}$$

Further, as illustrated in Fig. 3, if the cornering force of the front wheel W_f of the model vehicle (\approx lateral force of the front wheel W_f) is denoted by F_{fy_d} and the cornering force of the rear wheel W_r of the model vehicle (\approx lateral force of the rear wheel W_r) is denoted by F_{ry_d} , then the relationship between F_{fy_d} and β_{f_d} and the relationship between F_{ry_d} and β_{r_d} are represented by expressions 03a and 03b given below.

[0115]

$$F_{fy_d} = -2 \cdot K_f \cdot \beta_{f_d} \quad \dots \text{Expression 03a}$$

$$F_{ry_d} = -2 \cdot K_r \cdot \beta_{r_d} \quad \dots \text{Expression 03b}$$

The following will describe the method for setting the value of the model characteristics adjusting parameter k_2 in the present embodiment.

[0116] In the dynamic characteristics (the dynamic characteristics in the situation wherein the actuator operation FB target value is maintained at zero) of the actual vehicle 1, generally, the response characteristic (the transient response characteristic) of the actual

state amounts β_{act} and γ_{act} when the steering angle θ_h among drive manipulation inputs is changed in steps (when the actual front wheel steering angle δf_{act} is consequently changed in steps) will be a non-oscillatory response characteristic (over-braking or critical-braking response characteristic) when the traveling velocity V_{act} is a certain value $V_{d_critical}$ or less. In other words, in response to the stepped change in the steering angle θ_h (in response to the stepped change in the actual front wheel steering angle δf_{act}), each of the actual state amounts β_{act} and γ_{act} will converge to a steady state value without having an oscillatory component which centers around a final steady state value. If $V_{act}=V_{d_critical}$, then the response characteristics of the actual state amounts β_{act} and γ_{act} will be critical braking characteristics. Hereinafter, $V_{d_critical}$ will be referred to as the critical braking velocity.

[0117] If the actual traveling velocity V_{act} becomes higher than the critical braking velocity $V_{d_critical}$, then the response characteristics of the actual state amounts β_{act} and γ_{act} when the steering angle θ_h is changed in steps will be response characteristics (oscillatory characteristics) which include oscillatory components. In other words, in response to the stepped change in the steering angle θ_h , the actual state amounts γ_{act} and β_{act} oscillate, centering around final steady state values, until they converge to the steady state

values, as indicated by dashed lines a and b shown in Figs. 4(a) and (b), respectively. Further, the attenuation velocities of the oscillatory components become lower as V_{act} increases (the time constants of the attenuations of the amplitudes of the oscillatory components become longer). Therefore, if the actual traveling velocity V_{act} exceeds the critical braking velocity $V_{d_critical}$, then the attenuation properties of the actual state amounts β_{act} and γ_{act} lower as V_{act} increases.

[0118] Meanwhile, in the present embodiment, the motion of the actual vehicle 1 is controlled through the intermediary of the actuator device 3 such that the state amount errors β_{err} and γ_{err} approximate zero, as described above. For this reason, if the state amounts β_d and γ_d of the model vehicle oscillate, then the state amounts β_{act} and γ_{act} of the actual vehicle 1 tend to oscillate accordingly. Therefore, in order to improve the behavior characteristics of the actual vehicle 1 while minimizing the chances of the occurrence of the situation wherein the state amounts β_{act} and γ_{act} of the actual vehicle 1 oscillate when the steering angle θ is changed, it is desired that the response characteristics of the state amounts β_d and γ_d of the model vehicle are non-oscillatory or the attenuation velocities of the oscillatory components of the state amounts β_d and γ_d are as high as possible. More generally, the attenuation properties in the response characteristics of the state amounts β_d and

γ_d of the model vehicle relative to stepped changes in the steering angle θ_h are preferably higher than at least the attenuation properties in the response characteristics of the state amounts β_{act} and γ_{act} of the actual vehicle 1.

[0119] According to the present embodiment, therefore, the value of the model characteristic adjusting parameter k_2 is variably set on the basis of the traveling velocity V_{act} ($=V_d$), so that the response characteristics (to be specific, the response characteristics when the virtual external forces F_{vir} and M_{vir} of expression 01 are steadily set to zero) of the state amounts β_d and γ_d of the model vehicle when the steering angle θ_h is changed in steps relative to an arbitrary traveling velocity V_{act} become non-oscillatory (become a critical braking or over-braking characteristic). This arrangement causes the attenuation properties of the state amounts β_d and γ_d of the model vehicle relative to changes in the steering angle θ_h to be higher than the attenuation properties of the state amounts β_{act} and γ_{act} of the actual vehicle 1.

[0120] To be more specific, according to the present embodiment, the value of the model characteristic adjusting parameter k_1 is set to "1" relative to an arbitrary traveling velocity $V_d (=V_{act})$ which leads to $V_d \leq V_{d_critical}$ ($V_{act} \leq V_{d_critical}$). Further, the value of the model characteristic adjusting parameter k_2 is set such that the response characteristics of the state amounts of β_d and γ_d of the model vehicle (a system

represented by expression 01 which includes the characteristic adjusting matrix K) become non-oscillatory characteristics, such as the critical braking characteristics, at an arbitrary traveling velocity $V_d(=V_{act})$ which leads to $V_d > V_{d_critical}$ ($V_{act} > V_{d_critical}$). More specifically, the value of k_2 is set on the basis of $V_d(=V_{act})$ such that, for an arbitrary value of $V_d(=V_{act})$ which leads to $V_d > V_{d_critical}$, the solution of a characteristics equation $\det(\lambda \cdot I - K \cdot A) = 0$ (where λ : scalar variable; $\det()$: matrix expression; and I : unit matrix) of a system (model vehicle) represented by expression 01 which includes the characteristics adjusting matrix K (provided $k_1=1$ in the present embodiment), i.e., the eigenvalue of the model vehicle, takes a multiple root. Incidentally, "A" denotes the matrix of the first term in the parenthesis of the right side of expression 01 (a matrix of 2 rows and 2 columns, having a_{11} , a_{12} , a_{21} , and a_{22} , as the components thereof).

[0121] The value of k_2 set as described above is the value of k_2 that satisfies the following expression 101 relative to an arbitrary value of $V_d(=V_{act})$ which leads to $V_d > V_{d_critical}$.

[0122]

$$(a_{11} + k_2 \cdot a_{22})^2 - 4 \cdot k_2 \cdot (a_{11} \cdot a_{22} + a_{12} \cdot a_{21}) = 0$$

..... Expression 101

Supplementally, the critical braking velocity

Vd_critical takes a value that approximates a value of Vd that causes the eigenvalue of matrix A of the first term in the parenthesis of the right side of expression 01 to take a multiple root. More specifically, the critical braking velocity Vd_critical takes a value approximating a value of Vd that causes the eigenvalue of a system, which is represented by an expression obtained by setting the characteristics adjusting matrix K of expression 01 to a unit matrix and by excluding the term that includes the virtual external forces Fvir and Mvir (this means an expression that linearly approximates the dynamic characteristic of the actual vehicle 1), to take a multiple root, the eigenvalue of the system being the solution of a characteristics equation $\det(\lambda \cdot I - A) = 0$ (where λ : scalar variable; $\det()$: matrix expression; and I: unit matrix). Thus, Vd_critical is set to a value of Vd that satisfies expression 102 given below (more specifically, a positive value among the values of Vd that satisfies expression 102 given below).

[0123]

$$(a_{11} + a_{22})^2 - 4 \cdot (a_{11} \cdot a_{22} + a_{12} \cdot a_{21}) = 0 \quad \dots \text{Expression 102}$$

Fig. 5 is a graph illustrating changes in the value of k2 set on the basis of the traveling velocity Vact(=Vd), as described above. As illustrated, the value of k2 is set to a value that is larger than "1" in a situation wherein $V_{act} > V_{d_critical}$ holds. At this time,

as $V_{act}(=V_d)$ increases, the value of k_2 monotonously increases.

[0124] As described above, variably setting the value of the model characteristics adjusting parameter k on the basis of the traveling velocity $V_{act}(=V_d)$ makes it possible to set the response characteristics of the state amounts γ_d and β_d of the model vehicle to non-oscillatory characteristics according to a stepped change in the steering angle θ_h , independently of the traveling velocity V_{act} . For instance, the response characteristics of the state amounts γ_d and β_d of the model vehicle at a traveling velocity V_{act} which is higher than the critical braking velocity $V_{d_critical}$ will be the critical braking characteristics (non-oscillatory characteristics), as illustrated by the solid lines c and d in the aforesaid Figs. 4(a) and (b), respectively. In Figs. 4(a) and (b), the motional characteristic of the model vehicle has been set such that the steady-state characteristics of the actual vehicle 1 and the model vehicle agree when the actual vehicle 1 and the model vehicle agree in the coefficient of friction μ between a wheel and a road surface. Further, the response characteristics of the state amounts γ_d and β_d of the model vehicle at the traveling velocity V_{act} of the critical braking velocity $V_{d_critical}$ or less will be the critical braking or over-braking characteristics.

[0125] Accordingly, in a velocity range of $V_{d_critical}$ or

more, the attenuation property of each of the state amounts γ_d and β_d of the model vehicle based on the stepped changes of the steering angle θ_h can be made higher than the attenuation property of each of the state amounts γ_{act} and β_{act} of the actual vehicle 1.

[0126] Further, the steady-state characteristics of the model vehicle, which do not depend on the value of k_2 as described above, can be maintained to characteristics that approximate the steady-state characteristics of the actual vehicle 1. This arrangement, therefore, makes it possible to prevent the response characteristics of the state amounts γ_d and β_d of the model vehicle based on the stepped changes in the steering angle θ_h from becoming oscillatory characteristics while maintaining the steady-state characteristics of the model vehicle at the characteristics which approximate the steady-state characteristics of the actual vehicle 1.

[0127] As described above, according to the present embodiment, in the processing by the reference dynamic characteristic model 16 at each control processing cycle of the controller 10, the value of the model characteristics adjusting parameter k_2 is variably set on the basis of the traveling velocity $V_{act}(=V_d)$. The processing for setting the value of k_2 corresponds to the vehicle model characteristics setting means in the present invention. In the processing by the reference dynamic characteristic model 16, when actually setting the value

of k_2 , a map or an arithmetic expression representing the relationship between the value of k_2 and the traveling velocity V_{act} of the actual vehicle 1 (the relationship shown in Fig. 5) may be established beforehand and then the value of k_2 may be determined from the value (the current time value) of V_{act} at each control processing cycle according to the map or the arithmetic expression.

[0128] Supplementally, the value of k_2 in the situation wherein $V_{act} > V_{d_critical}$ holds does not necessarily have to be set such that the response characteristics of the state amounts γ_d and β_d of the model vehicle become the critical braking characteristics; instead, the value of k_2 may be set such that the response characteristics become the over-braking characteristics. More specifically, the value of k_2 in the situation wherein $V_{act} > V_{d_critical}$ holds may be set such that the solution of the aforesaid characteristics equation $\det(\lambda \cdot I - K \cdot A) = 0$ (the eigenvalue of the model vehicle) takes the real number of two different values. In this case, the value of k_2 is set to a larger value than the value of k_2 which causes the response characteristics of the state amounts γ_d and β_d of the model vehicle to become the critical braking characteristics. However, in order to prevent the response characteristics (attenuation properties) of the state amounts γ_d and β_d of the model vehicle from developing a significant discrepancy from the response characteristics of the actual state amounts γ_{act} and β_{act}

in the motional state of the actual vehicle 1 wherein $V_{act} > V_{d_critical}$ holds, the value of k_2 is preferably set to a value close to the value of k_2 that turns the response characteristics of the state amounts γ_d and β_d of the model vehicle into the critical braking characteristics.

[0129] Further, the value of k_2 in the motional state of the actual vehicle 1 wherein $V_{act} > V_{d_critical}$ holds may be set to a value which is slightly closer to "1" than a value of k_2 that turns the response characteristics of the state amounts γ_d and β_d of the model vehicle into the critical braking characteristics in the range wherein the attenuation properties of the state amounts γ_d and β_d of the model vehicle are higher than the attenuation properties of the actual state amounts γ_{act} and β_{act} . This arrangement makes it possible to prevent the response characteristics (the attenuation properties) of the state amounts γ_d and β_d of the model vehicle from considerably deviating from the response characteristics of the actual state amounts γ_{act} and β_{act} . However, in the response characteristics of the state amounts γ_d and β_d of the model vehicle in this case, the attenuation properties of the state amounts γ_d and β_d will be higher than in the case where $k_2=1$, whereas the attenuation properties of the state amounts γ_d and β_d will be lower than the critical braking characteristic.

[0130] Further, in the model vehicle represented by

expression 01, if the traveling velocity $V_{act}(=V_d)$ is an extremely low velocity which is sufficiently lower than the critical braking velocity $V_{d_critical}$, then the responsiveness (the velocity responsiveness) of the state amounts γ_d and β_d of the model vehicle in response to a change in the steering angle θ_h (a change in the front wheel steering angle δ_d) tends to increase, compared with the actual vehicle 1. Therefore, the value of k_2 may be set to a value that is smaller than "1" in a situation wherein the traveling velocity V_{act} becomes an extremely low velocity (a traveling velocity which is not more than a predetermined value which is smaller than the critical braking velocity $V_{d_critical}$). In this case, however, the value of k_2 at an extremely low velocity is set to a value which is not less than the value of k_2 which turns the response characteristics of the state amounts γ_d and β_d of the model vehicle into the critical braking characteristics, thereby preventing the response characteristics of the state amounts γ_d and β_d of the model vehicle from becoming oscillatory characteristics. Setting the value of k_2 at an extremely low velocity as described above makes it possible to bring the responsiveness of the state amounts γ_d and β_d of the model vehicle in response to a change in the steering angle θ_h (the rising speed of β_d and γ_d in response to a change in the steering angle θ_h) close to the responsiveness of the actual state amounts γ_{act} and β_{act} .

[0131] Meanwhile, multiplying the second row of each term in the parenthesis of expression 01 by k_2 is equivalent to multiplying the inertia I of the model vehicle by $(1/k_2)$. Therefore, instead of using the characteristics adjusting matrix K , an inertia I' defined by $I'=I/k_2$ may be used to represent the dynamic characteristics of the model vehicle according to expression 103 given below.

[0132] [Mathematical Expression 2]

$$\frac{d}{dt} \begin{bmatrix} \beta d \\ \gamma d \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} \cdot \begin{bmatrix} \beta d \\ \gamma d \end{bmatrix} + \begin{bmatrix} b_1 \\ b_2 \end{bmatrix} \cdot \delta f_d + \begin{bmatrix} b_{11} & 0 \\ 0 & b_{22} \end{bmatrix} \cdot \begin{bmatrix} F_{vir} \\ M_{vir} \end{bmatrix} \dots\dots \text{Expression 103}$$

where

$$a_{11} = -\frac{2 \cdot (K_f + K_r)}{m \cdot V_d} \qquad a_{12} = -\frac{m \cdot V_d^2 + 2 \cdot (L_f \cdot K_f - L_r \cdot K_r)}{m \cdot V_d^2}$$

$$a_{21} = -\frac{2 \cdot (L_f \cdot K_f - L_r \cdot K_r)}{I'} \qquad a_{22} = -\frac{2 \cdot (L_f^2 \cdot K_f + L_r^2 \cdot K_r)}{I' \cdot V_d}$$

$$b_1 = \frac{2 \cdot K_f}{m \cdot V_d} \qquad b_2 = \frac{2 \cdot L_f \cdot K_f}{I'} \qquad b_{11} = \frac{1}{m \cdot V_d} \qquad b_{22} = \frac{1}{I'}$$

$$I' = \frac{I}{k_2}$$

[0133] In this case, the value of k_2 may be set according to the traveling velocity $V_{act}(=V_d)$, as described above. At this time, the inertia I' monotonously decreases as V_{act} increases in the situation wherein $V_{act} > V_{d_critical}$ holds.

[0134] Incidentally, the dynamic characteristics of the actual vehicle 1 in the present embodiment exhibit characteristics somewhere between the open characteristics of the actual vehicle 1 observed when the present

invention is not applied (the dynamic characteristics of the actual vehicle 1 observed when the actuator FB operation target value is steadily maintained at zero) and the dynamic characteristics of the reference dynamic characteristic model 16 when the virtual external forces M_{vir} and F_{vir} are steadily maintained at zero. For this reason, in general, the reference dynamic characteristic model 16 is desirably set to a model that exhibits dynamic characteristics considered more desirable for a driver than the open characteristics of the actual vehicle 1. To be more specific, the reference dynamic characteristic model 16 is desirably set to a model having a higher linearity than that of the actual vehicle 1. For example, the reference dynamic characteristic model 16 is desirably set such that the relationship between the side slip angle or the slip ratio of a wheel of the model vehicle and a road surface reaction force acting from a road surface to the wheel (a lateral force or a driving/braking force) is a linear relationship or a relationship close thereto. The reference dynamic characteristic model 16 representing the dynamic characteristics according to the aforesaid expression 01 is an example of the model that satisfies these requirements.

[0135]

[About the reference manipulated variable determiner]

The details of the processing by the reference

manipulated variable determiner 14 will now be described with reference to Fig. 6 and Fig. 7. Fig. 6 is a functional block diagram illustrating the details of the processing function of the reference manipulated variable determiner 14, and Fig. 7 is a graph for describing the processing by an excessive centrifugal force prevention limiter 14f provided in the reference manipulated variable determiner 14.

[0136] Referring to Fig. 6, the reference manipulated variable determiner 14 first determines, in a processor 14a, an unlimited front wheel steering angle δf_{unltd} by dividing a steering angle θ_h (a current time value) in the drive manipulation inputs, which are to be supplied, by an overall steering ratio "is". This unlimited front wheel steering angle δf_{unltd} has a meaning as a basic required value of a model front wheel steering angle δf_d based on the steering angle θ_h .

[0137] Here, the overall steering ratio "is" is the ratio between the steering angle θ_h and the steering angle of the front wheel W_f of the model vehicle, and it is set on the basis of, for example, the relationship between the steering angle θ_h of the actual vehicle 1 and the feedforward value of the steering angle of the front wheels W_1 and W_2 of the actual vehicle 1 associated therewith.

[0138] The overall steering ratio "is" may be variably set on the basis of the traveling velocity V_{act} of the

actual vehicle 1 detected or estimated by the sensor/estimator 12 rather than setting it at a constant value (a fixed value). In this case, it is desirable to set the "is" such that the overall steering ratio "is" increases as the traveling velocity V_{act} of the actual vehicle 1 increases.

[0139] Subsequently, the vehicle front wheel position side slip angle β_{f0} of the model vehicle on the reference dynamic characteristic model 16 is determined by a β_{f0} calculator 14b. The β_{f0} calculator 14b receives the last time values of the reference yaw rate γ_d and the reference vehicle center-of-gravity point side slip angle β_d determined by the reference dynamic characteristic model 16. From these values, the last time value of β_{f0} is determined by calculating the expression 02c (calculating the right side of the second equal sign of expression 02c). In this case, a last time value of the actual traveling velocity V_{act} is used as the value of V_d required for the calculation of expression 02c. Thus, β_{f0} calculated by the β_{f0} calculator 14b takes the value of the vehicle front wheel position side slip angle β_{f0} of the model vehicle at the last time control processing cycle.

[0140] Alternatively, the last time value of the front wheel side slip angle β_{f_d} of the model vehicle may be determined by the calculation of the expression 02a from the last time values of γ_d and β_d , the last time value of the model front wheel steering angle δ_{f_d} determined by

the reference manipulated variable determiner 14, and the last time value of the actual traveling velocity V_{act} , then the last time value of the model front wheel steering angle δf_d determined by the reference manipulated variable determiner 14 may be added to the determined βf_d (calculating the right side of the first equal sign of expression 02c) thereby to determine βf_0 . Alternatively, at each control processing cycle, the calculation of βf_0 may be carried out by the processing performed by the reference dynamic characteristic model 16, and the last time value of the calculated βf_0 may be input to the reference manipulated variable determiner 14. In this case, the arithmetic processing by the βf_0 calculator 14b in the reference manipulated variable determiner 14 is unnecessary.

[0141] Subsequently, the unlimited front wheel steering angle δf_{unltd} is subtracted by a subtracter 14c from the vehicle front wheel position side slip angle βf_0 determined as described above, thereby determining the unlimited front wheel side slip angle. The unlimited front wheel side slip angle means an instantaneous predicted value of the front wheel side slip angle βf_d of the model vehicle generated if it is assumed that the model front wheel steering angle δf_d of the model vehicle is instantaneously controlled to the unlimited front wheel steering angle δf_{unltd} (current time value) from the last time value.

[0142] Subsequently, the reference manipulated variable determiner 14 passes the unlimited front wheel side slip angle through a front wheel side slip angle limiter 14d to determine a limited front wheel side slip angle. Here, the graph of the front wheel side slip angle limiter 14d illustrated in the figure is a graph illustrating the relationship between an unlimited front wheel side slip angle and a limited front wheel side slip angle, the values in the direction of the axis of abscissas related to the graph indicating the values of the unlimited front wheel side slip angles while the values in the direction of the axis of ordinates indicating the values of the limited front wheel side slip angles.

[0143] The front wheel side slip angle limiter 14d is a limiter for restraining the magnitude of the front wheel side slip angle β_{f_d} of the model vehicle from becoming excessive (furthermore, for preventing the lateral forces of the front wheels W1 and W2 required for the actual vehicle 1 from becoming excessive).

[0144] In the present embodiment, the front wheel side slip angle limiter 14d sets the permissible range of the front wheel side slip angle β_{f_d} (more specifically, the upper limit value $\beta_{f_max}(>0)$ and the lower limit value $\beta_{f_min}(<0)$ of the permissible range) on the basis of the estimated friction coefficient μ_{estm} (current time value) and the actual traveling velocity V_{act} (current time value) input from the sensor/estimator 12 into the

reference manipulated variable determiner 14. In this case, basically, the permissible range is set such that the permissible range $[\beta_{f_min}, \beta_{f_max}]$ is narrower (β_{f_max} and β_{f_min} are brought more closely to zero) as the estimated friction coefficient μ_{estm} is smaller or the actual traveling velocity V_{act} is higher. At this time, the permissible range $[\beta_{f_min}, \beta_{f_max}]$ is set in the range of the values of side slip angle that maintains the relationship between, for example, the side slip angle and the lateral force of the front wheels W1 and W2 of the actual vehicle 1 or the cornering force at a substantially linear relationship (a proportional relationship).

[0145] The permissible range $[\beta_{f_min}, \beta_{f_max}]$ may be set on the basis of either μ_{estm} or V_{act} , or may be set to a pre-fixed permissible range independently of μ_{estm} and V_{act} .

[0146] And, if the value of the received unlimited front wheel side slip angle is within the permissible range $[\beta_{f_min}, \beta_{f_max}]$ set as described above (if $\beta_{f_min} \leq$ Unlimited front wheel side slip angle $\leq \beta_{f_max}$), then the front wheel side slip angle limiter 14d directly outputs the value of the unlimited front wheel side slip angle as the limited front wheel side slip angle. If the value of the received unlimited front wheel side slip angle deviates from the permissible range, then the front wheel side slip angle limiter 14d outputs the lower limit value β_{f_min} or the upper limit value β_{f_max} of the permissible

range $[\beta_{f_min}, \beta_{f_max}]$ as the limited front wheel side slip angle. To be more specific, if the unlimited front wheel side slip angle $> \beta_{f_max}$, then the β_{f_max} is output as the limited front wheel side slip angle. If the unlimited front wheel side slip angle $< \beta_{f_min}$, then the β_{f_min} is output as the limited front wheel side slip angle. Thus, the limited front wheel side slip angle is determined such that it agrees with an unlimited front wheel side slip angle or takes a value that is closest to the unlimited front wheel side slip angle within the permissible range $[\beta_{f_min}, \beta_{f_max}]$.

[0147] Subsequently, the limited front wheel side slip angle determined as described above is subtracted by a subtracter 14e from the vehicle front wheel position side slip angle β_{f0} determined by the β_{f0} calculator 14b thereby to determine a first limited front wheel steering angle δ_{f_ltd1} . The first limited front wheel steering angle δ_{f_ltd1} determined as described above has a meaning as a model front wheel steering angle δ_{f_d} obtained by restricting the unlimited front wheel steering angle δ_{f_unltd} such that the front wheel side slip angle β_{f_d} of the model vehicle does not deviate from the permissible range $[\beta_{f_min}, \beta_{f_max}]$.

[0148] Subsequently, the reference manipulated variable determiner 14 passes the first limited front wheel steering angle δ_{f_ltd1} through the excessive centrifugal force prevention limiter 14f to determine a second limited

front wheel steering angle δf_ltd2 . This δf_ltd2 is used as the value of the model front wheel steering angle δf_d to be input to the reference dynamic characteristic model 16. The graph of the excessive centrifugal force prevention limiter 14f illustrated in the figure is a graph illustrating the relationship between the first limited front wheel steering angle δf_ltd1 and the second limited front wheel steering angle δf_ltd2 , the values in the direction of the axis of abscissas related to the graph indicating the values of δf_ltd1 while the values in the direction of the axis of ordinates indicating the values of δf_ltd2 .

[0149] The excessive centrifugal force prevention limiter 14f is a limiter for restraining the centrifugal force generated in the model vehicle from becoming excessive (furthermore, for preventing the centrifugal force required for the actual vehicle 1 from becoming excessive).

[0150] In the present embodiment, the excessive centrifugal force prevention limiter 14f sets the permissible range of the model front wheel steering angle δf_d (more specifically, the upper limit value $\delta f_max(>0)$ and the lower limit value $\delta f_min(<0)$ of the permissible range) on the basis of the estimated friction coefficient μ_{estm} (current time value) and the actual traveling velocity V_{act} (current time value) input to the reference manipulated variable determiner 14. This permissible range $[\delta f_min, \delta f_max]$ is the permissible range of the

model front wheel steering angle δf_d that allows the model vehicle to make a normal circular turn without exceeding the limit of friction against a road surface when it is assumed that the virtual external forces M_{vir} and F_{vir} are steadily held at zero.

[0151] More specifically, first, a maximum yaw rate γ_{max} (>0) at a normal circular turn, which is a yaw rate that satisfies expression 05 given below, is determined on the basis of the values (current time values) of V_{act} and μ_{estm} input to the reference manipulated variable determiner 14.

[0152]

$$m \cdot \gamma_{max} \cdot V_{act} = C1 \cdot \mu_{estm} \cdot m \cdot g \quad \dots \quad \text{Expression 05}$$

where m in expression 05 denotes the total mass of the model vehicle, as described above. Further, g denotes a gravitational acceleration and $C1$ denotes a positive coefficient of 1 or less. The left side of this expression 05 means a centrifugal force generated in the model vehicle (more specifically, a predicted convergence value of the centrifugal force) when the normal circular turn of the model vehicle is made while holding the yaw rate γ_d and the traveling velocity V_d of the model vehicle at γ_{max} and V_{act} , respectively. Further, the value of the computation result of the right side of expression 05 indicates a road surface reaction force determined on the basis of μ_{estm} (more specifically, the value obtained by

multiplying the limit value of the magnitude of a total frictional force that can be applied to the model vehicle from a road surface through the intermediary of the wheels W_f and W_r (the total sum of the translational force horizontal components of a road surface reaction force) by the coefficient C_1 (\leq the limit value). Hence, the maximum yaw rate γ_{max} at a normal circular turn is determined such that the centrifugal force generated in the model vehicle when the normal circular turn of the model vehicle is made while holding the virtual external forces M_{vir} and F_{vir} to be applied to the model vehicle at zero and the yaw rate γ_d and the traveling velocity V_d of the model vehicle at γ_{max} and V_{act} , respectively, does not exceed the limit value of the total frictional force (the total sum of the translational force horizontal components of a road surface reaction force) which can be applied to the model vehicle on the basis of the estimated friction coefficient μ_{estm} .

[0153] Incidentally, the value of the coefficient C_1 of expression 05 may be variably set on the basis of the value of at least either one of μ_{estm} and V_{act} . In this case, preferably, the value of C_1 is set to be smaller as μ_{estm} is smaller or as V_{act} is higher.

[0154] Subsequently, the value of the model front wheel steering angle δf_d associated with γ_{max} at the normal circular turn of the model vehicle is determined as a limit steering angle at normal circular turn $\delta f_{max_c}(>0)$.

Here, in the reference dynamic characteristic model 16 represented by the expression 01, the relationship of expression 06 given below holds between the yaw rate γ_d of the model vehicle at the normal circular turn and the model front wheel steering angle δf_d .

[0155] [Mathematical expression 3]

$$\gamma_d = \frac{1}{1 - \frac{m}{2 \cdot L^2} \cdot \frac{L_f \cdot K_f - L_r \cdot K_r}{K_f \cdot K_r} \cdot V_d^2} \cdot \frac{V_d}{L} \cdot \delta f_d \quad \text{..... Expression 06}$$

where $L = L_f + L_r$

[0156] If V_d is sufficiently small, then expression 06 can be approximately rewritten to the following expression 07.

[0157]

$$\gamma_d = (V_d/L) \cdot \delta f_d \quad \text{..... Expression 07}$$

Hence, in the present embodiment, the limit steering angle δf_{\max_c} at normal circular turn associated with γ_{\max} is determined by making a solution on δf_d , denoting the values of γ_d and V_d , respectively, in expression 06 or expression 07 as γ_{\max} and V_{act} .

[0158] The permissible range $[\delta f_{\min}, \delta f_{\max}]$ of the model front wheel steering angle δf_d for preventing a centrifugal force generated in the model vehicle from becoming excessive may be basically set to a permissible range $[-\delta f_{\max_c}, \delta f_{\max_c}]$. In that case, however, the

model front wheel steering angle δf_d may be subjected to unwanted restriction in a countersteering state of the actual vehicle 1 (a state wherein the front wheels W1 and W2 are steered in the direction of the opposite polarity from the polarity of the yaw rate of the actual vehicle 1).

[0159] In the present embodiment, therefore, δf_{max_c} and $-\delta f_{max_c}$ are corrected according to expressions 08a and 08b given below on the basis of the yaw rates γ_d and γ_{max} of the model vehicle thereby to set the upper limit value δf_{max} and the lower limit value δf_{min} of the permissible range of the model front wheel steering angle δf_d .

[0160]

$$\delta f_{max} = \delta f_{max_c} + fe(\gamma_d, \gamma_{max}) \dots\dots \text{Expression 08a}$$

$$\delta f_{min} = -\delta f_{max_c} - fe(-\gamma_d, -\gamma_{max}) \dots\dots \text{Expression}$$

08b

$fe(\gamma_d, \gamma_{max})$ and $fe(-\gamma_d, -\gamma_{max})$ in expressions 08a and 08b are functions of γ_d and γ_{max} , and the function values thereof are, for example, functions that vary according to the values of γ_d and γ_{max} , as illustrated in the graphs of Figs. 7(a) and (b). In this example, the value of the function $fe(\gamma_d, \gamma_{max})$ takes a positive fixed value fex if γ_d takes a value of a predetermined value γ_1 , which is slightly larger than zero, or less (including a case where $\gamma_d < 0$), as illustrated in the graph of Fig. 7(a). And, the value of $fe(\gamma_d, \gamma_{max})$ monotonously decreases as γ_d increases if $\gamma_d > \gamma_1$ and reaches zero by the time γ_d reaches

$\gamma_2 (> \gamma_1)$, which is a predetermined value of γ_{\max} or less. Further, the value of $f_e(\gamma_d, \gamma_{\max})$ is maintained at zero if $\gamma_d > \gamma_2$ (including the case where $\gamma_d \geq \gamma_{\max}$).

[0161] Further, a function $f_e(-\gamma_d, -\gamma_{\max})$ is a function obtained by reversing the polarities of the variables γ_d and γ_{\max} of the function $f_e(\gamma_d, \gamma_{\max})$, so that the value of the function $f_e(-\gamma_d, -\gamma_{\max})$ varies in relation to γ_d , as illustrated in the graph of Fig. 7(b). More specifically, if γ_d takes a value of a predetermined negative value $-\gamma_1$, which is slightly smaller than zero, or more (including the case where $\gamma_d > 0$), then the function takes a positive fixed value f_{ex} . And, the value of $f_e(-\gamma_d, -\gamma_{\max})$ monotonously decreases as γ_d decreases if $\gamma_d < -\gamma_1$ and reaches zero by the time when γ_d reaches $-\gamma_2$, which is a predetermined value of $-\gamma_{\max}$ or more. Further, the value of $f_e(-\gamma_d, -\gamma_{\max})$ is maintained at zero if $\gamma_d < -\gamma_2$ (including the case where $\gamma_d \leq -\gamma_{\max}$).

[0162] As the value of γ_d required for determining the values of the functions $f_e(\gamma_d, \gamma_{\max})$ and $f_e(-\gamma_d, -\gamma_{\max})$, the last time value of the reference yaw rate γ_d determined by the reference dynamic characteristic model 16 may be used.

[0163] Further, the values γ_1 and γ_2 of γ_d at breakpoints of the graph of the function $f_e(\gamma_d, \gamma_{\max})$ or the aforesaid positive fixed value f_{ex} may be variably changed according to the estimated friction coefficient μ_{estm} or the actual traveling velocity V_{act} .

[0164] The permissible range of the model front wheel steering angle δf_d [δf_{\min} , δf_{\max}] is set by correcting δf_{\max_c} on the basis of the value of the function f_e as described above, so that the magnitude (the absolute value) of the limit value δf_{\max} or δf_{\min} of the model front wheel steering angle δf_d in the direction opposite from the direction of γ_d is set to be larger than the limit steering angle δf_{\max_c} at a normal circular turn associated with the limit of a centrifugal force generated in the model vehicle. This makes it possible to prevent the model front wheel steering angle δf_d from being subjected to unwanted restriction in the countersteering state of the actual vehicle 1. Incidentally, the permissible range $[-\delta f_{\min}$, δf_{\max}] narrows as the actual traveling velocity V_{act} increases or as the estimated friction coefficient μ_{estm} decreases.

[0165] After setting the permissible range of the model front wheel steering angle δf_d as described above, the excessive centrifugal force prevention limiter 14f directly outputs the value of δf_{ltd1} as the second limited front wheel steering angle δf_{ltd2} (= the model front wheel steering angle δf_d to be input to the reference dynamic characteristic model 16) if the received first limited front wheel steering angle δf_{ltd1} takes a value within the permissible range [δf_{\min} , δf_{\max}] (if $\delta f_{\min} \leq \delta f_{ltd1} \leq \delta f_{\max}$). Further, if the value of the received δf_{ltd1} deviates from the permissible range

$[\delta f_{\min}, \delta f_{\max}]$, then the excessive centrifugal force prevention limiter 14f outputs a value obtained by forcibly restricting the input value as the second limited front wheel steering angle $\delta f_{\text{ltd}2}$. To be more specific, if $\delta f_{\text{ltd}1} > \delta f_{\max}$, then δf_{\max} is output as the second limited front wheel steering angle $\delta f_{\text{ltd}2}$, and if $\delta f_{\text{ltd}1} < \delta f_{\min}$, then δf_{\min} is output as the second limited front wheel steering angle $\delta f_{\text{ltd}2}$. Thus, $\delta f_{\text{ltd}2}$ is determined such that it agrees with the first limited front wheel steering angle $\delta f_{\text{ltd}1}$ or takes a value that is closest to the first limited front wheel steering angle $\delta f_{\text{ltd}1}$ within the permissible range $[\delta f_{\min}, \delta f_{\max}]$.

[0166] In the reference dynamic characteristic model 16 represented by the expression 01, the relationship of expression 09 given below holds between β_d and γ_d at a normal circular turn of the model vehicle.

[0167] [Mathematical expression 4]

$$\beta_d = \left(1 - \frac{m}{2L} \cdot \frac{L_f}{L_r \cdot K_r} \cdot V_d^2 \right) \cdot \frac{L_r}{V_d} \cdot \gamma_d \quad \dots \text{Expression 09}$$

[0168] If V_d is sufficiently small, then expression 09 can be approximately rewritten to the following expression 10.

[0169]

$$\beta_d = (L_r/V_d) \cdot \gamma_d \quad \dots \text{Expression 10}$$

Hence, the value of γ_d or γ_{\max} at the normal

circular turn of the model vehicle can be converted into a value of β_d (provided $V_d=V_{act}$) according to expression 09 or expression 10. Therefore, the permissible range of the model front wheel steering angle δf_d may be set on the basis of the value of the vehicle center-of-gravity point side slip angle β_d associated with the yaw rates γ_d and γ_{max} instead of setting the permissible range of the model front wheel steering angle δf_d on the basis of the values of the yaw rates γ_d and γ_{max} as described above.

[0170] The above has presented the details of the processing by the reference manipulated variable determiner 14.

[0171] The processing by the reference manipulated variable determiner 14 described above determines, at each control processing cycle, the second limited front wheel steering angle δf_{ltd2} as the model front wheel steering angle δf_d to be input to the reference dynamic characteristic model 16 on the basis of the steering angle θ_h among drive manipulation inputs such that an instantaneous value of the front wheel side slip angle β_f_d of the model vehicle on the reference dynamic characteristic model 16 does not become excessive and the centrifugal force generated in the model vehicle does not become excessive.

[0172] Supplementally, in the excessive centrifugal force prevention limiter 14f, limiting the model front wheel steering angle δf_d to be input to the reference dynamic

characteristic model 16 as described above to prevent the centrifugal force generated in the model vehicle from becoming excessive is equivalent to limiting the model front wheel steering angle δf_d to prevent the vehicle center-of-gravity point side slip angle βd (or the rear wheel side slip angle βr_d) of the model vehicle from becoming excessive. Further, in general, a centrifugal force in the vehicle or a vehicle center-of-gravity point side slip angle (or a rear wheel side slip angle) is generated with a delay from a steering operation, so that the processing for limiting the model front wheel steering angle δf_d performed by the excessive centrifugal force prevention limiter 14f may be said to be the processing for limiting the model front wheel steering angle δf_d on the basis of a predicted convergence values of a centrifugal force of the vehicle or a vehicle center-of-gravity point side slip angle (or a rear wheel side slip angle). In contrast to this, the limiting processing by the front wheel side slip angle limiter 14d may be said to be the processing for limiting the model front wheel steering angle δf_d to prevent an instantaneous value of the front wheel side slip angle βf_d of the model vehicle from becoming excessive.

[0173] In the present embodiment, the function f_e used to set the permissible range $[\delta f_min, \delta f_max]$ by the excessive centrifugal force prevention limiter 14f has been set as illustrated in Figs. 7(a) and (b) described

above; however, the method for setting the function f_e it is not limited thereto.

[0174] For instance, the function $f_e(\gamma_d, \gamma_{max})$ may be set as shown by the solid-line graph in Fig. 8. In this example, the value of $f_e(\gamma_d, \gamma_{max})$ monotonously decreases as the value of γ_d increases (increases from a value on the negative side to a value on the positive side) and becomes zero when $\gamma_d = \gamma_{max}$. At this time, the function $f_e(-\gamma_d, -\gamma_{max})$ will be as indicated by the dashed-line graph in Fig. 8. In this case, the upper limit value δf_{max} of the permissible range of the model front wheel steering angle δf_d determined by the expression 08a will be closer to zero than the limit steering angle δf_{max_c} at normal circular turn as γ_d increases when γ_d exceeds γ_{max} . Similarly, the lower limit value δf_{min} of the permissible range of the model front wheel steering angle δf_d determined by the expression 08b will be closer to zero than $-\delta f_{max}$ as γ_d decreases (as the magnitude increases) when γ_d exceeds $-\gamma_{max}$ onto the negative side.

[0175] Further, instead of the expressions 08a and 08b, the following expressions 11a and 11b may be used to set the upper limit value δf_{max} and the lower limit value δf_{min} of the permissible range of δf_d , and the functions $f_e(\gamma_d, \gamma_{max})$ and $f_e(-\gamma_d, -\gamma_{max})$ may be set as indicated by, for example, the solid-line and dashed-line graphs in Fig. 9.

[0176]

$\delta f_{\max} = \delta f_{\max_c} \cdot fe(\gamma_d, \gamma_{\max})$ Expression 11a

$\delta f_{\min} = -\delta f_{\max_c} \cdot fe(-\gamma_d, -\gamma_{\max})$ Expression

11b

In this example, the values of $fe(\gamma_d, \gamma_{\max})$ and $fe(-\gamma_d, -\gamma_{\max})$ are always 1 or more and change with γ_d in the same manner as those illustrated in Figs. 7(a) and (b). Then, δf_{\max_c} and δf_{\min_c} are multiplied by these values of $fe(\gamma_d, \gamma_{\max})$ and $fe(-\gamma_d, -\gamma_{\max})$, respectively, to set the upper limit value δf_{\max} and the lower limit value δf_{\min} .

[0177] Further, the second limited front wheel steering angle $\delta f_{\text{ltd}2}$ may be determined by, for example, the processing described below in place of setting the permissible range $[\delta f_{\min}, \delta f_{\max}]$ of the model front wheel steering angle δf_d by correcting δf_{\max_c} on the basis of a value of the function fe . Fig. 10 is a functional block diagram for explaining the processing function.

[0178] A front wheel steering angle correction $\Delta\delta f$ for correcting the first limited front wheel steering angle $\delta f_{\text{ltd}1}$ calculated by the subtracter 14e (refer to Fig. 6) is determined on the basis of the yaw rate γ_d (last time value) of the model vehicle in a processor 14g. At this time, $\Delta\delta f$ is basically determined such that the value of $\Delta\delta f$ monotonously increases on the positive side as γ_d increases on the positive side, while the value of $\Delta\delta f$

monotonously decreases on the negative side as γ_d decreases on the negative side, as illustrated by the graph in the processor 14g. In the graph in the processor 14g, the value of $\Delta\delta f$ is provided with an upper limit value (>0) and a lower limit value (<0). In this case, the upper limit value and the lower limit value are set such that, for example, the absolute values thereof are the same values as the fixed values f_{ex} illustrated in Figs. 7(a) and (b) described above.

[0179] Subsequently, the front wheel steering angle correction $\Delta\delta f$ determined as described above is added by an adder 14h to the first limited front wheel steering angle δf_{ltd1} calculated by the subtracter 14e (refer to Fig. 6) thereby to determine a first limited front wheel steering angle with input correction. In this case, if the direction of δf_{ltd1} and the direction of γ_d are opposite from each other, then the magnitude of the first limited front wheel steering angle with input correction will be smaller than the magnitude of δf_{ltd1} . However, if the direction of δf_{ltd1} and the direction of γ_d are the same, then the magnitude of the first limited front wheel steering angle with input correction will be larger than the magnitude of δf_{ltd1} .

[0180] Subsequently, the first limited front wheel steering angle with input correction is passed through the excessive centrifugal force prevention limiter 14f to determine a second limited front wheel steering angle with

input correction obtained by restricting the first limited front wheel steering angle with input correction to a value within the permissible range $[\delta f_{\min}, \delta f_{\max}]$ of the model front wheel steering angle δf_d . In other words, if the first limited front wheel steering angle with input correction has a value within the permissible range, then the first limited front wheel steering angle with input correction is directly determined as the second limited front wheel steering angle with input correction. Further, if the first limited front wheel steering angle with input correction deviates from the permissible range, then either one of δf_{\max} and δf_{\min} which has a value closer to the first limited front wheel steering angle with input correction is determined as the second limited front wheel steering angle with input correction.

[0181] In this case, the upper limit value $\delta f_{\max}(>0)$ of the permissible range of the model front wheel steering angle δf_d in the excessive centrifugal force prevention limiter 14f is set to a value that is slightly larger than the steering angle limit value at normal circular turn δf_{\max_c} (e.g., $\delta f_{\max_c} + f_{ex}$), taking into account the correction of δf_{ltd1} when the direction of δf_{ltd1} and the direction of γ_d are the same. Similarly, the lower limit value $\delta f_{\min}(<0)$ of the permissible range of the model front wheel steering angle δf_d is set such that the absolute value thereof will be a value that is slightly larger than δf_{\max_c} (e.g., $-\delta f_{\max_c} - f_{ex}$).

[0182] Subsequently, the front wheel steering angle correction $\Delta\delta f$ is subtracted by a subtracter 14i from the second limited front wheel steering angle with input correction determined as described above, thereby determining the second limited front wheel steering angle δf_{ltd2} .

[0183] The model front wheel steering angle $\delta f_d (= \delta f_{ltd2})$ to be input to the reference dynamic characteristic model 16 can be determined while preventing the centrifugal force generated in the model vehicle from becoming excessive and also preventing unwanted restriction from being placed in the countersteering state of the actual vehicle 1 even when the second limited front wheel steering angle δf_{ltd2} is determined as described above.

[0184] In the present embodiment, the processing by the front wheel side slip angle limiter 14d and the excessive centrifugal force prevention limiter 14f has been carried out to determine the model front wheel steering angle δf_d to be input to the reference dynamic characteristic model 16; however, the processing by one or both of them may be omitted. More specifically, the unlimited front wheel steering angle δf_{unltd} determined by the processor 14a or a value obtained by supplying the δf_{unltd} to the excessive centrifugal force prevention limiter 14f or the first limited front wheel steering angle δf_{ltd1} determined by the subtracter 14e may be determined as the

model front wheel steering angle δf_d to be input to the reference dynamic characteristic model 16.

[0185] The current time value of the model front wheel steering angle δf_d (= the current time value of δf_ltd2) determined by the reference manipulated variable determiner 14 as described above is input to the reference dynamic characteristic model 16, and the current time values of the reference yaw rate γd and the reference vehicle center-of-gravity point side slip angle βd are newly determined by the reference dynamic characteristic model 16 (according to the expression 01 or expression 103) from the above input value and the virtual external forces F_{vir} and M_{vir} (last time values) determined by the FB distribution law 20, as will be discussed later. This processing is actually carried out according to an expression obtained by representing expression 01 in terms of a discrete-time system, so that the last time values of γd and βd are also used to determine the current time values of γd and βd . Further, the value of the model characteristics adjusting parameter $k2$ of the characteristics adjusting matrix K in expression 01 or the value of inertia I' in expression 103 is set on the basis of the traveling velocity $Vd(=Vact)$, as described above.

[0186] In this case, the model front wheel steering angle δf_d input to the reference dynamic characteristic model 16 is restricted by the reference manipulated variable determiner 14 as previously described, thus preventing the

occurrence of a spin or an extreme side slip of the model vehicle.

[0187]

[About the FB distribution law]

The details of the processing by the FB distribution law 20 will now be described with reference to Fig. 11 to Fig. 18.

[0188] Fig. 11 is a functional block diagram illustrating the processing function of the FB distribution law 20. As illustrated in the figure, the processing function of the FB distribution law 20 is roughly constituted of a virtual external force determiner 20a which carried out the processing for determining the virtual external forces M_{vir} and F_{vir} and an actuator operation FB target value determiner 20b which carries out the processing for determining an actuator operation FB target value.

[0189] First, the virtual external force determiner 20a will be described with reference to Fig. 11. The processing function of the virtual external force determiner 20a is roughly divided into a virtual external force temporary value determiner 201 and a $\gamma\beta$ limiter 202.

[0190] In the processing by the virtual external force determiner 20a, first, temporary values M_{virtmp} and F_{virtmp} of virtual external forces are determined by the virtual external force temporary value determiner 201 on the basis of state amount errors $\gamma_{err}(= \gamma_{act}-\gamma_d)$, $\beta_{err}(=\beta_{act}-\beta_d)$ input from the subtracter 18. M_{virtmp} of

the temporary values M_{virtmp} and F_{virtmp} means a moment (a moment in the yaw direction) to be additionally generated about the center-of-gravity point G_d of the model vehicle of the reference dynamic characteristic model 16 in order to approximate the state amount errors γ_{err} and β_{err} to zero, and F_{virtmp} means a translational force (a lateral translational force of the model vehicle) to be additionally applied to the center-of-gravity point G_d of the model vehicle of the reference dynamic characteristic model 16 in order to approximate the state amount errors γ_{err} and β_{err} to zero.

[0191] To be specific, as shown by expression 15 given below, a vector composed of the input state amount errors γ_{err} and β_{err} ($\gamma_{err}, \beta_{err}$)^T (the superscript T means transposition) is multiplied by a predetermined gain matrix K_{fvir} thereby to determine the temporary values M_{virtmp} and F_{virtmp} of the virtual external force (hereinafter referred to as the virtual external force temporary values M_{virtmp} and F_{virtmp}).

[0192] [Mathematical expression 5]

$$\begin{bmatrix} F_{virtmp} \\ M_{virtmp} \end{bmatrix} = K_{fvir} \cdot \begin{bmatrix} \beta_{err} \\ \gamma_{err} \end{bmatrix} \quad \text{..... Expression 15}$$

where

$$K_{fvir} \equiv \begin{bmatrix} K_{fvir11} & K_{fvir12} \\ K_{fvir21} & K_{fvir22} \end{bmatrix}$$

[0193] According to the expression 15, the virtual external force temporary values M_{virtmp} and F_{virtmp} are determined as the temporary values of control inputs to be

fed back to the reference dynamic characteristic model 16 to approximate the state amount errors γ_{err} and β_{err} to zero.

[0194] If it is required that the $\gamma\beta$ limiter 202, which will be described in detail below, generates an intense action for bringing β_d or β_{act} back to a predetermined permissible range only if the vehicle center-of-gravity point side slip angle β_d of the model vehicle or the actual vehicle center-of-gravity point side slip angle β_{act} of the actual vehicle 1 is about to exceed or has exceeded the permissible range, then β_{err} is desirably converged to zero by a characteristic close to a primary delay characteristic with a small time constant. For this purpose, for example, K_{fvir12} among gain matrix K_{fvir} components may be set to zero and K_{fvir11} may be set such that the absolute value thereof increases.

[0195] Subsequently, the $\gamma\beta$ limiter 202 carries out the processing for correcting the virtual external force temporary values M_{virtmp} and F_{virtmp} so as to restrain the yaw rate γ_d and the vehicle center-of-gravity point side slip angle β_d of the model vehicle on the reference dynamic characteristic model 16 from deviating from the respective predetermined permissible ranges thereof.

[0196] More specifically, the $\gamma\beta$ limiter 202 first carries out the processing by a prediction calculator 203. The prediction calculator 203 predicts the yaw rate γ_d and the vehicle center-of-gravity point side slip angle β_d of the

model vehicle after predetermined time (after the time equivalent to a predetermined number of one or more control processing cycles), and outputs those predicted values as the predicted yaw rate γ_{da} and a predicted vehicle center-of-gravity point side slip angle β_{da} .

[0197] At this time, the prediction calculator 203 receives the reference yaw rate γ_d (current time value) and the reference vehicle center-of-gravity point side slip angle β_d (current time value) determined by the reference dynamic characteristic model 16, the actual traveling velocity V_{act} (current time value) detected or estimated by the sensor/estimator 12, the second limited front wheel steering angle δf_{ltd2} (current time value) determined by the reference manipulated variable determiner 14, and the virtual external force temporary values M_{virtmp} and F_{virtmp} (current time values) determined as described above by the virtual external force temporary value determiner 201. Then, the prediction calculator 203 calculates the predicted yaw rate γ_{da} and the predicted vehicle center-of-gravity point side slip angle β_{da} on the basis of expression 01 or expression 103 described above on the assumption that the model front wheel steering angle δf_d is held at the input δf_{ltd2} , the virtual external forces M_{vir} and F_{vir} to be applied to the model vehicle are held at the input M_{virtmp} and F_{virtmp} , and the traveling velocity V_d of the model vehicle is held at the input V_{act} .

[0198] Subsequently, the $\gamma\beta$ limiter 202 passes the γ_{da} and β_{da} calculated by the prediction calculator 203 as described above through a γ dead-zone processor 204 and a β dead-zone processor 205, respectively, to determine the amounts of deviation γ_{over} and β_{over} from predetermined permissible ranges of γ_{da} and β_{da} , respectively. The graph of the γ dead-zone processor 204 illustrated in the figure is a graph illustrating the relationship between γ_{da} and γ_{over} , the values in the direction of the axis of abscissas related to the graph indicating the values of γ_{da} , while the values in the direction of the axis of ordinates indicating the values of γ_{over} . Similarly, the graph of the β dead-zone processor 205 illustrated in the figure is a graph illustrating the relationship between β_{da} and β_{over} , the values in the direction of the axis of abscissas related to the graph indicating the values of β_{da} , while the values in the direction of the axis of ordinates indicating the values of β_{over} .

[0199] The permissible range in the γ dead-zone processor 204 is a permissible range (a permissible range of the yaw rate γ_d) having the lower limit value and the upper limit value thereof set to $\gamma_{damin}(<0)$ and $\gamma_{damax}(>0)$, respectively, and the permissible range in the β dead-zone processor 205 is a permissible range (a permissible range of the vehicle center-of-gravity point side slip angle β_d) having the lower limit value and the upper limit value thereof set to $\beta_{damin}(<0)$ and $\beta_{damax}(>0)$, respectively.

[0200] In the present embodiment, the permissible range $[\gamma_{damin}, \gamma_{damax}]$ related to the yaw rate γ_d is set such that, for example, the centrifugal force generated in the model vehicle when a normal circular turn is made while holding the traveling velocity V_d of the model vehicle at V_{act} (current time value) and also holding the yaw rate γ_d of the model vehicle at γ_{damin} or γ_{damax} does not exceed a limit value of a frictional force based on the estimated friction coefficient μ_{estm} (current time value). In other words, γ_{damax} and γ_{damin} are set on the basis of V_{act} (current time value) and μ_{estm} (current time value) such that expressions 16a and 16b shown below are satisfied.

[0201]

$$m \cdot V_{act} \cdot \gamma_{damax} < \mu_{estm} \cdot m \cdot g \quad \dots \quad \text{Expression 16a}$$

$$m \cdot V_{act} \cdot \gamma_{damin} > -\mu_{estm} \cdot m \cdot g \quad \dots \quad \text{Expression 16b}$$

γ_{damax} , γ_{damin} may be set such that, for example, the absolute value of each thereof will be the same value as the maximum yaw rate γ_{max} at a normal circular turn determined according to the expression 05 (provided $\gamma_{damax} = \gamma_{max}$ and $\gamma_{damin} = -\gamma_{max}$). Alternatively, however, the γ_{damax} and γ_{damin} may be set such that the absolute values thereof are different values from γ_{max} (e.g., values that are smaller than γ_{max}).

[0202] Further, the permissible range $[\beta_{damin}, \beta_{damax}]$ related to the vehicle center-of-gravity point side slip angle β_d is set, for example, within a range of a vehicle

center-of-gravity point side slip angle that maintains the relationship between the vehicle center-of-gravity point side slip angle of the actual vehicle 1 and the translational force in the lateral direction applied to the center-of-gravity point of the actual vehicle 1 to be a substantially linear relationship (proportional relationship). In this case, β_{damin} and β_{damax} are desirably set on the basis of at least one of V_{act} (current time value) and μ_{estm} (current time value).

[0203] Further, specifically, the processing by the γ dead-zone processor 204 sets $\gamma_{over}=0$ if an input γ_{da} is a value within a predetermined permissible range $[\gamma_{damin}, \gamma_{damax}]$ (if $\gamma_{damin} \leq \gamma_{da} \leq \gamma_{damax}$), or sets $\gamma_{over} = \gamma_{da} - \gamma_{damin}$ if $\gamma_{da} < \gamma_{damin}$, or sets $\gamma_{over} = \gamma_{da} - \gamma_{damax}$ if $\gamma_{da} > \gamma_{damax}$. Thus, the amount of deviation γ_{over} of the predicted yaw rate γ_{da} from the permissible range $[\gamma_{damin}, \gamma_{damax}]$ is determined.

[0204] Similarly, the processing by the β dead-zone processor 205 sets $\beta_{over}=0$ if the value of an input β_{da} is a value within a predetermined permissible range $[\beta_{damin}, \beta_{damax}]$ (if $\beta_{damin} \leq \beta_{da} \leq \beta_{damax}$), or sets $\beta_{over} = \beta_{da} - \beta_{damin}$ if $\beta_{da} < \beta_{damin}$, or sets $\beta_{over} = \beta_{da} - \beta_{damax}$ if $\beta_{da} > \beta_{damax}$. Thus, the amount of deviation β_{over} of the predicted vehicle center-of-gravity point side slip angle β_{da} from the permissible range $[\beta_{damin}, \beta_{damax}]$ is determined.

[0205] Subsequently, the $\gamma\beta$ limiter 202 calculates, by a processor 206, the temporary value manipulated variables

Mvir_over and Fvir_over, which are the correction amounts of the virtual external force temporary values Mvirtmp and Fvirtmp, such that these amounts of deviation γ_{over} and β_{over} are approximated to zero.

[0206] To be more specific, as indicated by expression 17 given below, a vector $(\gamma_{over}, \beta_{over})^T$ composed of γ_{over} and β_{over} is multiplied by a predetermined gain matrix Kfov to determine Mvir_over and Fvir_over.

[0207] [Mathematical expression 6]

$$\begin{bmatrix} Fvir_over \\ Mvir_over \end{bmatrix} = Kfov \cdot \begin{bmatrix} \beta_{over} \\ \gamma_{over} \end{bmatrix} \quad \dots\dots \text{Expression 17}$$

where

$$Kfov \equiv \begin{bmatrix} Kfov11 & Kfov12 \\ Kfov21 & Kfov22 \end{bmatrix}$$

[0208] Subsequently, the $\gamma\beta$ limiter 202 subtracts the temporary value manipulated variables Mvir_over and Fvir_over from the virtual external force temporary values Mvirtmp and Fvirtmp by a subtracter 207 to determine the current time values of the virtual external forces Mvir and Fvir. In other words, the virtual external forces Mvir and Fvir are determined according to the following expressions 18a and 18b.

[0209]

$$Mvir = Mvirtmp - Mvir_over \quad \dots\dots \text{Expression 18a}$$

18a

$$Fvir = Fvirtmp - Fvir_over \quad \dots\dots \text{Expression 18b}$$

The processing by the virtual external force determiner 20a is carried out as described above thereby to determine the virtual external forces M_{vir} and F_{vir} such that the state amount errors γ_{err} and β_{err} are approximated to zero, while restraining the predicted yaw rate γ_{da} and the predicted vehicle center-of-gravity point side slip angle β_{da} from deviating from the permissible ranges $[\gamma_{damin}, \gamma_{damax}]$ and $[\beta_{damin}, \beta_{damax}]$, respectively. [0210] The $\gamma\beta$ limiter 202 of the virtual external force determiner 20a described above determines the virtual external forces M_{vir} and F_{vir} by correcting the virtual external force temporary values M_{virtmp} and F_{virtmp} on the basis of the temporary value manipulated variables M_{vir_over} and F_{vir_over} (more generally speaking, M_{vir} and F_{vir} are determined by the linear coupling of M_{vir_over} and M_{virtmp} and the linear coupling of F_{vir_over} and F_{virtmp} , respectively). Alternatively, however, the virtual external forces M_{vir} and F_{vir} may be determined as described below. Fig. 12 is a functional block diagram for explaining the processing.

[0211] Referring to the figure, in this example, the processing by the virtual external force temporary value determiner 201, the prediction calculator 203, the γ dead-zone processor 204, the β dead-zone processor 205, and a processor 206 is the same as that illustrated in Fig. 11. Meanwhile, in the present example, the temporary value manipulated variables F_{vir_over} and M_{vir_over} determined

by the processor 206 are input to processors 208 and 209, respectively, and correction coefficients $Katt1(\geq 0)$ and $Katt2(\geq 0)$ for correcting the virtual external force temporary values $Mvirtmp$ and $Fvirtmp$, respectively, are determined in the processors 208 and 209. These correction coefficients $Katt1$ and $Katt2$ are correction coefficients serving as multipliers for the virtual external force temporary values $Mvirtmp$ and $Fvirtmp$, respectively. The graph related to the processor 208 illustrated in the figure is a graph illustrating the relationship between $Mvir_over$ and $Katt1$, the values in the direction of the axis of abscissas related to the graph indicating the values of $Mvir_over$ and the values in the direction of the axis of ordinates indicating the values of $Katt1$. Similarly, the graph related to the processor 209 illustrated in the figure is a graph illustrating the relationship between $Fvir_over$ and $Katt2$, the values in the direction of the axis of abscissas related to the graph indicating the values of $Fvir_over$ and the values in the direction of the axis of ordinates indicating the values of $Katt2$.

[0212] The processing by the processor 208 sets $Katt1=1$ if $Mvir_over$ is zero and sets the value of $Katt1$ such that the value of $Katt1$ monotonously decreases from 1 to 0 as the absolute value of $Mvir_over$ increases from zero, as illustrated by the graph in the figure. Further, the value of $Katt1$ is maintained at zero if the absolute value

of M_{vir_over} exceeds a predetermined value (a value at which K_{att1} reaches zero).

[0213] Similarly, the processing by the processor 209 sets $K_{att2}=1$ if F_{vir_over} is zero and sets the value of K_{att2} such that the value of K_{att2} monotonously decreases from 1 to 0 as the absolute value of F_{vir_over} increases from zero, as illustrated by the graph in the figure.

Further, the value of K_{att2} is maintained at zero if the absolute value of F_{vir_over} exceeds a predetermined value (a value at which K_{att2} reaches zero).

[0214] Subsequently, the correction coefficients K_{att1} and K_{att2} determined as described above are multiplied by the virtual external force temporary values M_{virtmp} and F_{virtmp} by multipliers 210 and 211, respectively, thereby determining the current time values of the virtual external forces M_{vir} and F_{vir} .

[0215] Thus, in the example illustrated in Fig. 12, the virtual external force M_{vir} is determined such that the magnitude of the virtual external force M_{vir} is narrowed (approximated to zero) relative to the virtual external force temporary value M_{virtmp} as the absolute value of the amount of deviation M_{vir_over} increases. Similarly, the virtual external force F_{vir} is determined such that the magnitude of the virtual external force M_{vir} is narrowed (approximated to zero) relative to the virtual external force temporary value M_{virtmp} as the absolute value of the amount of deviation F_{vir_over} increases. Thus,

determining the virtual external forces M_{vir} and F_{vir} means to regard that the deviation of γ_{da} and β_{da} from their permissible ranges is attributable to the virtual external forces M_{vir} and F_{vir} and to determine the virtual external forces M_{vir} and F_{vir} such that the state amount errors γ_{err} and β_{err} are approximated to zero while restraining the deviation of γ_{da} and β_{da} from their permissible ranges $[\gamma_{damin}, \gamma_{damax}]$ and $[\beta_{damin}, \beta_{damax}]$. In this case, desirably, in the reference manipulated variable determiner 14, the model front wheel steering angle δf_d to be input to the reference dynamic characteristic model 16 is limited, as described above.

[0216] Further, in the $\gamma\beta$ limiter 202 described above, the predicted yaw rate γ_{da} and the predicted vehicle center-of-gravity point side slip angle β_{da} determined using expression 01 or expression 103 as described above by the prediction calculator 203 have been input to the γ dead-zone processor 204 and the β dead-zone processor 205 to determine the deviation amounts γ_{over} and β_{over} . At this time, however, in place of γ_{da} and β_{da} , the current time values of the reference yaw rate γ_d and the reference vehicle center-of-gravity point side slip angle β_d , or the current time values of the actual yaw rate γ_{act} and the actual vehicle center-of-gravity point side slip angle β_{act} , or the values obtained by filtering these values may be used.

[0217] For example, at each control processing cycle, the

current time value of γ_d in place of γ_{da} may be input to the γ dead-zone processor 204, and a value obtained by filtering, in which a transfer function is represented in the form of $(1+T1 \cdot s)/(1+T2 \cdot s)$, the β_d sequentially calculated by the reference dynamic characteristic model 16 ($T1$ and $T2$ denoting certain time constants and s denoting a Laplace operator) may be input in place of β_{da} into the β dead-zone processor 205. In this case, if the time constants $T1$ and $T2$ are set such that, for example, $T1 > T2$, then the filtering processing functions as a so-called phase advancing compensation element. At this time, advancing the phase of a frequency component of β_d in a frequency band which is high to a certain degree and enhancing a gain relative to the frequency component make it possible to limit the virtual external forces M_{vir} and F_{vir} on the basis of β_{over} before the value itself of β_d determined at each control processing cycle deviates from the permissible range $[\beta_{damin}, \beta_{damax}]$.

[0218] Further, in the prediction calculator 203, as indicated by the following expressions 19a and 19b, an appropriate coefficient c_{ij} may be used to determine, as γ_{da} and β_{da} , the values obtained by linearly coupling the current time values of γ_d and β_d .

[0219]

$$\gamma_{da} = c_{11} \cdot \gamma_d + c_{12} \cdot \beta_d \dots\dots \text{Expression 19a}$$

$$\beta_{da} = c_{21} \cdot \gamma_d + c_{22} \cdot \beta_d \dots\dots \text{Expression 19b}$$

Alternatively, as indicated by the following expressions 20a and 20b, an appropriate coefficient c_{ij} may be used to determine, as γ_{da} and β_{da} , the values obtained by linearly coupling the current time values of γ_d , β_d , M_{virtmp} , F_{virtmp} , and δf_{ltd2} .

[0220]

$$\gamma_{da} = c_{11} \cdot \gamma_d + c_{12} \cdot \beta_d + c_{13} \cdot M_{virtmp} + c_{14} \cdot F_{virtmp} + c_{15} \cdot \delta f_{ltd2} \dots\dots 20a$$

$$\beta_{da} = c_{21} \cdot \gamma_d + c_{22} \cdot \beta_d + c_{23} \cdot M_{virtmp} + c_{24} \cdot F_{virtmp} + c_{25} \cdot \delta f_{ltd2} \dots\dots 20b$$

These expressions 20a and 20b present more generalized representation of the processing by the prediction calculator 203 described above.

[0221] Alternatively, as shown by the following expressions 21a and 21b, an appropriate coefficient c_{ij} may be used to determine, as γ_{da} and β_{da} , the values obtained by linearly coupling the current time values of γ_{act} and β_{act} .

[0222]

$$\gamma_{da} = c_{11} \cdot \gamma_{act} + c_{12} \cdot \beta_{act} \dots\dots \text{Expression 21a}$$

$$\beta_{da} = c_{21} \cdot \gamma_{act} + c_{22} \cdot \beta_{act} \dots\dots \text{Expression 21b}$$

Alternatively, as shown by the following expressions 22a and 22b, an appropriate coefficient c_{ij} may be used to determine, as γ_{da} and β_{da} , the values obtained by linearly coupling the current time values of γ_d , β_d and a temporal

differential value $d\beta_d/dt$ of β_d , γ_{act} , β_{act} and a temporal differential value $d\beta_{act}/dt$ of β_{act} , M_{virtmp} , F_{virtmp} , and δf_{ltd2} .

[0223]

$$\begin{aligned} \gamma_{da} = & c11 \cdot \gamma_d + c12 \cdot \beta_d + c13 \cdot d\beta_d/dt \\ & + c14 \cdot \gamma_{act} + c15 \cdot \beta_{act} + c16 \cdot d\beta_{act}/dt \\ & + c17 \cdot M_{virtmp} + c18 \cdot F_{virtmp} + c19 \cdot \delta f_{ltd2} \quad \dots\dots 22a \end{aligned}$$

$$\begin{aligned} \beta_{da} = & c21 \cdot \gamma_d + c22 \cdot \beta_d + c23 \cdot d\beta_d/dt \\ & + c24 \cdot \gamma_{act} + c25 \cdot \beta_{act} + c26 \cdot d\beta_{act}/dt \\ & + c27 \cdot M_{virtmp} + c28 \cdot F_{virtmp} + c29 \cdot \delta f_{ltd2} \quad \dots\dots 22b \end{aligned}$$

Alternatively, the weighted mean value of the value of the computation result of the right side of expression 20a and the value of the computation result of the right side of expression 21a and the weighted mean value of the value of the computation result of the right side of expression 20b and the value of the computation result of the right side of expression 21b may be determined as γ_{da} and β_{da} , respectively. This is an example of the case where γ_{da} and β_{da} are determined according to expression 22a and expression 22b. The terms of M_{virtmp} and F_{virtmp} in expression 20a and expression 20b or expression 22a and expression 22b may be omitted.

[0224] Alternatively, the predicted values of γ_d and β_d at each control processing cycle until after predetermined time may be determined according to the expression 01 or expression 103 and the peak values of the determined γ_d

and β_d may be determined as γ_{da} and β_{da} .

[0225] Further, even in the case where γ_{da} and β_{da} are determined using any of expression 20a and expression 20b, or expression 21a and expression 21b, or expression 22a and expression 22b, the coefficient c_{ij} of these expressions may be provided with a frequency characteristic (in other words, the value of a variable to be multiplied by c_{ij} may be subjected to filtering by a low-pass filter or the like). Alternatively, the limitation of a temporal change rate of the variable may be placed on the value of the variable to be multiplied by the coefficient c_{ij} .

[0226] Supplementally, if γ_{da} and β_{da} are determined by expression 21a and expression 21b or expression 22a and expression 22b described above, then each coefficient c_{ij} is desirably set such that the γ_{da} and β_{da} bear meanings as the predicted values of the actual yaw rate γ_{act} and the actual vehicle center-of-gravity point side slip angle β_{act} of the actual vehicle 1 after predetermined time.

[0227] If the reference dynamic characteristic model 16 is a linear model as represented by the expression 01 or expression 103, then γ_{da} and β_{da} can be properly determined as the predicted values of a yaw rate and a vehicle center-of-gravity point side slip angle of the actual vehicle 1 or the model vehicle after predetermined time by using any of expression 20a and expression 20b, or expression 21a and expression 21b, or expression 22a and

expression 22b.

[0228] If the current time values of γ_{act} and β_{act} or the values obtained by filtering γ_{act} and β_{act} are used in place of γ_{da} and β_{da} , or if γ_{da} and β_{da} are determined by expression 21a and expression 21b or expression 22a and expression 22b described above, then the virtual external forces M_{vir} and F_{vir} will be determined such that the state amount errors γ_{err} and β_{err} are approximated to zero while restraining the current time values or filtered values or predicted values of the actual yaw rate γ_{act} and the actual vehicle center-of-gravity point side slip angle β_{act} of the actual vehicle 1 from deviating from the permissible ranges $[\gamma_{damin}, \gamma_{damax}]$ and $[\beta_{damin}, \beta_{damax}]$, respectively.

[0229] Supplementally, more generally, the processing by the virtual external force determiner 20a may determine the virtual external forces M_{vir} and F_{vir} according to expression 200 given below.

[0230] [Mathematical expression 7]

$$\begin{bmatrix} F_{vir} \\ M_{vir} \end{bmatrix} = \begin{bmatrix} K_{fb11} & K_{fb12} & K_{fb13} & K_{fb14} & K_{fb15} & K_{fb16} \\ K_{fb21} & K_{fb22} & K_{fb23} & K_{fb24} & K_{fb25} & K_{fb26} \end{bmatrix} \cdot \begin{bmatrix} \beta_d \\ \gamma_d \\ \beta_{act} \\ \gamma_{act} \\ \beta_{over} \\ \gamma_{over} \end{bmatrix} + \begin{bmatrix} K_{fb_d1} \\ K_{fb_d2} \end{bmatrix} \cdot \delta f_{ltd2} \quad \dots \text{Expression 200}$$

[0231] Further, in the γ dead-zone processor 204 and the β dead-zone processor 205 of the $\gamma\beta$ limiter 202, the amounts

of deviation γ_{over} and β_{over} have been determined by separately setting the permissible ranges $[\gamma_{damin}, \gamma_{damax}]$ and $[\beta_{damin}, \beta_{damax}]$ of γ_{da} and β_{da} , respectively; alternatively, however, a permissible range (permissible area) for a pair of γ_{da} and β_{da} may be set, considering the correlativity between γ_{da} and β_{da} , to determine the amounts of deviation γ_{over} and β_{over} .

[0232] For example, as illustrated in Fig. 13, an area A (a parallelogram area) enclosed by straight lines 1 to 4 on a coordinate plane having γ_{da} on the axis of abscissa and β_{da} on the axis of ordinates is set as a permissible area A for a pair of γ_{da} and β_{da} . In this case, the straight lines 1 and 3 are the straight lines that define a lower limit value and an upper limit value, respectively, of γ_{da} . The lower limit value and the upper limit value are set, for example, in the same manner as that for the lower limit value γ_{damin} and the upper limit value γ_{damax} of the permissible range $[\gamma_{damin}, \gamma_{damax}]$ in the γ dead-zone processor 204. The straight lines 2 and 4 are the straight lines that define a lower limit value and an upper limit value, respectively, of β_{da} . In this example, the setting is made such that the lower limit value and the upper limit value, respectively, linearly change according to γ_{da} . Further, the amounts of deviation γ_{over} and β_{over} are determined, for example, as follows. If the pair of γ_{da} and β_{da} exists within the permissible area A, as indicated by a point P1 in Fig. 13, then $\gamma_{over}=\beta_{over}=0$.

On the other hand, if the pair of γ_{da} and β_{da} deviates from the permissible area A, as indicated by, for example, a point P2 in Fig. 13, then a point P3 on the boundary of the permissible area A that is closest to the point P2 among the points on the straight line 5 which passes the point P2 and has a predetermined inclination (a point P3 closest to P2 among the points existing on a straight line 5 in the permissible area A) is determined. Then, the difference between the value of γ_{da} at the point P2 and the value of γ_{da} at the point P3 is determined as the amount of deviation γ_{over} , and the difference between the value of β_{da} at the point P2 and the value of β_{da} at the point P3 is determined as the amount of deviation β_{over} .

If a point associated with the pair of γ_{da} and β_{da} is, for example, a point P4 illustrated in Fig. 13, i.e., if a straight line 6 having a predetermined inclination (the same inclination as that of the straight line 5) to pass the point P4 associated with the pair of γ_{da} and β_{da} does not intersect with the permissible area A (if no point exists on the straight line 6 in the permissible range A), then the difference between the value of γ_{da} at the point P4 and the value of γ_{da} at the point P5, which is closest to the straight line 6 among the points in the permissible range A, may be determined as the amount of deviation γ_{over} , and the difference between the value of β_{da} at the point P4 and the value of β_{da} at the point P5 may be determined as the amount of deviation β_{over} .

[0233] Supplementally, the permissible area of the pair of γ_{da} and β_{da} does not have to be a parallelogram area, and it may alternatively be, for example, an area A' having smoothly shaped boundary portions (shaped with no angular portions of acute angles), as indicated by the dashed line in Fig. 13.

[0234] Further, in the $\gamma\beta$ limiter 202, the amounts of deviation γ_{over} and β_{over} from $[\gamma_{damin}, \gamma_{damax}]$ and $[\beta_{damin}, \beta_{damax}]$ have been determined on both γ_{da} and β_{da} , then the temporary values M_{virtmp} and F_{virtmp} have been corrected on the basis thereof; alternatively, however, the temporary values M_{virtmp} and F_{virtmp} may be corrected on the basis of only one of γ_{over} and β_{over} . In this case, the processing by the processor 206 may determine the temporary value manipulated variables M_{vir_over} and F_{vir_over} by fixing the value of either one of γ_{over} and β_{over} to zero.

[0235]

Next, the processing by the actuator operation FB target value determiner 20b will be described with reference to Fig. 14 to Fig. 16. In the following explanation, the wheels $W1$ to $W4$ may be referred to as an n -th wheel W_n ($n=1, 2, 3, 4$).

[0236] Fig. 14 is a functional block diagram illustrating the processing by the actuator operation FB target value determiner 20b. Referring to the figure, the actuator operation FB target value determiner 20b first determines

in a processor 220 a feedback yaw moment basic required value M_{fbdmd} , which is a basic required value of a moment in the yaw direction to be generated about the center-of-gravity point G of the actual vehicle 1 in order to bring the state amount errors γ_{err} and β_{err} close to zero on the basis of received state amount errors γ_{err} and β_{err} , as the basic required value of a feedback control input to the actuator device 3 of the actual vehicle 1.

[0237] To be more specific, as indicated by expression 23 given below, a vector $(\beta_{err}, \gamma_{err})^T$ composed of β_{err} and γ_{err} is multiplied by a predetermined gain matrix K_{fbdmd} (by linearly coupling β_{err} and γ_{err}), thereby determining M_{fbdmd} .

[0238] [Mathematical expression 8]

$$M_{fbdmd} = K_{fbdmd} \cdot \begin{bmatrix} \beta_{err} \\ \gamma_{err} \end{bmatrix} \quad \dots\dots \text{Expression 23}$$

where

$$K_{fbdmd} \equiv \begin{bmatrix} K_{fbdmd1} & K_{fbdmd2} \end{bmatrix}$$

[0239] Alternatively, M_{fbdmd} may be determined on the basis of β_{err} , γ_{err} and a first-order differential value $d\beta_{err}/dt$ of β_{err} . For example, a vector composed of β_{err} , γ_{err} and $d\beta_{err}/dt$ may be multiplied by an appropriate gain matrix (by linearly coupling β_{err} , γ_{err} , and $d\beta_{err}/dt$ by an appropriate coefficient) so as to determine M_{fbdmd} .

[0240] Alternatively, at least one of elements K_{fbdmd1} and K_{fbdmd2} of the gain matrix K_{fbdmd} may be multiplied by a phase compensating element whose transfer function is

expressed by $(1+Tc1 \cdot s)/(1+Tc2 \cdot s)$. For instance, $Kfbdmd1$, which is a multiplier for β_{err} , may be multiplied by the phase compensating element, and the values of time constants $Tc1$ and $Tc2$ may be set such that $Tc1 > Tc2$. In such a case, the term obtained by multiplying $Kfbdmd1$ by β_{err} will be equivalent to the result obtained by passing β_{err} and a differential value thereof, which have been linearly coupled, through a high-cut filter.

[0241] Subsequently, the actuator operation FB target value determiner 20b passes the $Mfbdmd$ through a dead-zone processor 221 to determine a dead zone excess feedback yaw moment required value $Mfbdmd_a$. The graph of the dead zone processor 221 in the figure is a graph illustrating the relationship between $Mfbdmd$ and $Mfbdmd_a$, the values in the direction of the axis of abscissas related to the graph indicating the values of $Mfbdmd$, while the values in the direction of the axis of ordinates indicating the values of $Mfbdmd_a$.

[0242] According to the present embodiment, in the feedback control of the actuator devices 3 of the actual vehicle 1, mainly the braking device of the driving/braking device 3A among the actuator devices 3 is operated to approximate the state amount errors y_{err} and β_{err} to zero. In this case, if the braking device is operated on the basis of $Mfbdmd$ determined as described above, there is a danger that the braking device will be frequently operated. To prevent this, according to the

present embodiment, the braking device is operated on the basis of the dead zone excess feedback yaw moment required value M_{fbdmd_a} obtained by passing M_{fbdmd} through the dead zone processor 221.

[0243] To be more specific, the processing by the dead zone processor 221 is carried out as follows. The dead zone processor 221 sets $M_{fbdmd_a}=0$ if the value of M_{fbdmd} exists in a predetermined dead zone established in the vicinity of zero. The dead zone processor 221 sets $M_{fbdmd_a}=M_{fbdmd}$ - upper limit value if M_{fbdmd} is larger than an upper limit value (>0) of the dead zone, while the dead zone processor 221 sets $M_{fbdmd_a}=M_{fbdmd}$ - lower limit value if M_{fbdmd} is smaller than a lower limit value (<0) of the dead zone. In other words, an excess from the dead zone of M_{fbdmd} is determined as M_{fbdmd_a} . Operating the braking device of the driving/braking device 3A on the basis of M_{fbdmd_a} determined as described above makes it possible to restrain frequent operation of the braking device on the basis of the state amount errors γ_{err} and β_{err} .

[0244] Subsequently, an actuator operation FB target value distribution processor 222 carries out processing for determining the actuator operation FB target value (a feedback control input to an actuator device 3) on the basis of the dead zone excess feedback yaw moment required value M_{fbdmd_a} .

[0245] The processing by the actuator operation FB target

value distribution processor 222 will be schematically described. The actuator operation FB target value distribution processor 222 determines an FB target n-th wheel brake driving/braking force $F_{x\text{fbdmd}_n}$ ($n=1, 2, 3, 4$), which is a feedback target value of the driving/braking force of the wheels W1 to W4 by an operation of the braking device of the driving/braking device 3A (a feedback control input to the braking device to approximate γ_{err} and β_{err} to zero), such that M_{fbdmd_a} is generated about the center-of-gravity point of the actual vehicle 1 (consequently to approximate γ_{err} and β_{err} to zero). Alternatively, in addition to $F_{x\text{fbdmd}_n}$ ($n=1, 2, 3, 4$), an active steering FB target lateral force $F_{y\text{fbdmd}_f}$, which is a feedback target value of the lateral forces of the front wheels W1 and W2 by an operation of the steering device 3B, is determined.

[0246] In this case, according to the present embodiment, if the dead zone excess feedback yaw moment required value M_{fbdmd_a} indicates a moment in the positive direction (a moment in the counterclockwise direction as observed from above the actual vehicle 1), then basically, the driving/braking force of the left wheels W1 and W3 of the actual vehicle 1 is increased in the braking direction thereby to determine the FB target n-th wheel brake driving/braking force $F_{x\text{fbdmd}_n}$ ($n=1, 2, 3, 4$) such that M_{fbdmd_a} is generated about the center-of-gravity point G of the actual vehicle 1. If M_{fbdmd_a} is a moment in the

negative direction (a moment in the clockwise direction as observed from above the actual vehicle 1), then basically, the FB target n-th wheel brake driving/braking force $F_{x\text{fbdmd}_n}$ ($n=1, 2, 3, 4$) is determined such that the driving/braking force of the right wheels W1 and W3 of the actual vehicle 1 is increased in the braking direction thereby to generate M_{fbdmd_a} about the center-of-gravity point G of the actual vehicle 1.

[0247] In the following explanation, as illustrated in Fig. 15, the interval between the front wheels W1 and W2 (i.e., the tread of the front wheels W1 and W2) of the actual vehicle 1 is denoted by d_f , and the interval between the rear wheels W3 and W4 (i.e., the tread of the rear wheels W3 and W4) is denoted by d_r , and the actual steering angle of the front wheels W1 and W2 (the actual front wheel steering angle) is denoted by δf_{act} . The distance between an n-th wheel W_n and the center-of-gravity point G of the actual vehicle 1 in the direction orthogonal to the longitudinal direction of the n-th wheel W_n (in the direction orthogonal on a horizontal plane) when the actual vehicle 1 is observed from above is denoted by L_n ($n=1, 2, 3, 4$). In the present embodiment, although the rear wheels W3 and W4 are not shown because they are non-steering control wheels, the actual steering angle of the rear wheels W3 and W4 (actual rear wheel steering angle) is denoted by δr_{act} . In the present embodiment, $\delta r_{\text{act}}=0$ and $L_3=L_4=d_r/2$.

[0248] L_f in Fig. 15 denotes the distance in the longitudinal direction between the center-of-gravity point G of the actual vehicle 1 and the axle of the front wheels W_1 and W_2 , and L_r denotes the distance in the longitudinal direction between the center-of-gravity point G of the actual vehicle 1 and the axle of the rear wheels W_3 and W_4 . The values of these L_f and L_r are the same as the values of L_f and L_r related to the model vehicle illustrated in Fig. 3 described above.

[0249] The processing by the actuator operation FB target value distribution processor 222 will be specifically described below. First, it is assumed that the actual vehicle 1 is in a traveling-straight state (a traveling state in which $\delta f_{act}=0$), and an n -th wheel driving/braking force full required value $F_{xfullfbdmd_n}$, which is the driving/braking force of the n -th wheel W_n ($n=1, 2, 3, 4$) required to generate a moment in the yaw direction that is equal to M_{fbdmd_a} about the center-of-gravity point G of the actual vehicle 1 in the traveling-straight state is respectively determined by a processor 222a $_n$ ($n=1, 2, 3, 4$).

[0250] To be more specific, $F_{xfullfbdmd_n}$ ($n=1, 2, 3, 4$) is determined in each processor 222a $_n$ by the multiplication calculation of the following expressions 24a to 24d.

[0251]

$$F_{xfullfbdmd_1} = -(2/df) \cdot M_{fbdmd_a} \quad \dots \text{Expression}$$

24a

$$F_{xfullfbdmd_2} = (2/df) \cdot M_{fbdmd_a} \quad \dots \text{Expression}$$

24b

$$F_{xfullfbdmd_3} = -(2/dr) \cdot M_{fbdmd_a} \quad \dots \text{Expression}$$

24c

$$F_{xfullfbdmd_4} = (2/dr) \cdot M_{fbdmd_a} \quad \dots \text{Expression}$$

24d

Subsequently, the actuator operation FB target value distribution processor 222 determines a first wheel distribution ratio correction value $K1_str$ and a second wheel distribution ratio correction value $K2_str$ in processors 222b_1 and 222b_2, respectively, on the basis of the actual front wheel steering angle δf_act , and also determines a third wheel distribution ratio correction value $K3_str$ and a fourth wheel distribution ratio correction value $K4_str$ in processors 222b_3 and 222b_4, respectively, on the basis of the actual rear wheel steering angle δr_act . These respective n-th wheel distribution ratio correction values Kn_str ($n=1, 2, 3, 4$) are correction coefficients whereby $F_{xfullfbdmd_n}$ is multiplied.

[0252] Here, as the actual front wheel steering angle δf_act changes from zero, the driving/braking forces of the first wheel $W1$ and the second wheel $W2$ that generate a moment in the yaw direction equivalent to M_{fbdmd_a} about the center-of-gravity point G of the actual vehicle 1

change from $F_{xfullfbdmd_1}$ and $F_{xfullfbdmd_2}$ determined according to the aforesaid expressions 24a and 24b, respectively. Similarly, if the rear wheels W3 and W4 are steering control wheels, then as the actual rear wheel steering angle δr_{act} changes from zero, the driving/braking forces of the third wheel W3 and the fourth wheel W4 that generate a moment in the yaw direction equivalent to M_{fbdmd_a} about the center-of-gravity point G of the actual vehicle 1 change from $F_{xfullfbdmd_3}$ and $F_{xfullfbdmd_4}$ determined according to the expressions 24c and 24d, respectively. The n-th wheel distribution ratio correction value K_{n_str} is basically a correction coefficient for determining the driving/braking force of the n-th wheel W_n that generates a moment in the yaw direction equal or close to M_{fbdmd_a} about the center-of-gravity point G of the actual vehicle 1 by correcting $F_{xfullfbdmd_n}$ ($n= 1, 2, 3, 4$), taking such influences of a steering angle into account.

[0253] In the present embodiment, however, the rear wheels W3 and W4 are non-steering control wheels, so that δr_{act} is always zero. Hence, K_{3_str} and K_{4_str} are in fact always set to "1." Therefore, the processors 222b_3 and 222b_4 may be omitted.

[0254] Meanwhile, K_{1_str} and K_{2_str} related to the front wheels W1 and W2 are determined as described below by the processors 222b_1 and 222b_2, respectively. First, the values of L1 and L2 shown in Fig. 15 are calculated by the

geometric calculation of expressions 25a and 25b shown below from values of df and Lf , which are set beforehand, and a value of δf_{act} . As the value of δf_{act} in the calculation, a value (current time value) detected or estimated by the sensor/estimator 12 may be used, or alternatively, a last time value of a target value (a target value finally determined at each control processing cycle) of a steering angle of the front wheels W1 and W2 of the actual vehicle 1 may be used. Further, if the steering device 3B is a mechanical steering device, then the value may be determined from an overall steering ratio of the mechanical steering device and the steering angle θ_h in the drive manipulation inputs. Alternatively, a current time value of the unlimited front wheel steering angle δf_{unltd} determined by the processor 14a of the reference manipulated variable determiner 14 may be used.

[0255]

$$L1 = (df/2) \cdot \cos \delta f_{act} - Lf \cdot \sin \delta f_{act} \quad \dots\dots \text{Expression 25a}$$

$$L2 = (df/2) \cdot \cos \delta f_{act} + Lf \cdot \sin \delta f_{act} \quad \dots\dots \text{Expression 25b}$$

Here, the result obtained by multiplying the driving/braking force of each of the front wheels W1 and W2 by L1 and L2, respectively, provides the moment in the yaw direction generated about the center-of-gravity point G of the actual vehicle 1. Therefore, basically, the

driving/braking forces of the front wheels W1 and W2 for generating a moment in the yaw direction that is equal to M_{fbdmd_a} about the center-of-gravity point G can be determined by multiplying $F_{xfullfbdmd_1}$ and $F_{xfullfbdmd_2}$ by $K1_str=(df/2)/L1$ and $K2_str=(df/2)/L2$, respectively.

[0256] Doing as described above, however, tends to cause $K1_str$ or $K2_str$ to become excessive when $L1$ or $L2$ is small and to cause the overall feedback loop gain of the actual vehicle 1 based on the state amount errors γ_{err} and β_{err} to become excessive, frequently resulting in an oscillation of a control system.

[0257] In the present embodiment, therefore, $K1_str$ and $K2_str$ are determined according to the following expressions 26a and 26b.

[0258]

$$K1_str=(df/2)/\max(L1, Lmin) \dots\dots \text{Expression 26a}$$

$$K2_str=(df/2)/\max(L2, Lmin) \dots\dots \text{Expression 26b}$$

Here, in expression 26a and expression 26b, $\max(a,b)$ (a and b denote general variables) denotes a function for outputting a value of the variable a or b, whichever is larger, and $Lmin$ denotes a positive constant that is smaller than $df/2$. This has prevented $K1_str$ and $K2_str$ from becoming excessive. In other words, according to the present embodiment, $(df/2)/Lmin(>1)$ is defined as the upper limit value of $K1_str$ and $K2_str$, and $K1_str$ and $K2_str$ are set at the upper limit value or less on the

basis of the actual front wheel steering angle δf_{act} .

[0259] In the present embodiment, since the rear wheels W3 and W4 are non-steering control wheels, $K3_{str}=K4_{str}=1$, as described above. If, however, the rear wheels W3 and W4 are steering control wheels, then $K3_{str}$ and $K4_{str}$ are desirably set on the basis of the actual rear wheel steering angle δr_{act} in the same manner as that for setting $K1_{str}$ and $K2_{str}$ on the basis of the actual front wheel steering angle δf_{act} as described above.

[0260] Subsequently, the actuator operation FB target value distribution processor 222 determines the n-th wheel distribution gain K_n in the processor $222c_n$ ($n=1, 2, 3, 4$) on the basis of the actual front wheel side slip angle βf_{act} (current time value) or the actual rear wheel side slip angle βr_{act} (current time value). This K_n is a correction coefficient (a positive value that is smaller than 1) for correcting $F_{xfullfbdmd_n}$ by multiplying the n-th wheel driving/braking force full required value $F_{xfullfbdmd_n}$ by K_n .

[0261] In this case, the n-th wheel distribution gain K_n is determined as described below in each processor $222c_n$.

[0262] A first wheel distribution gain $K1$ and a third wheel distribution gain $K3$ related to the first wheel W1 and the third wheel W3, which are longitudinally disposed on the left side of the actual vehicle 1, are determined such that the gains virtually continuously change on the basis of βf_{act} and βr_{act} , as shown by the solid-line

graphs in Figs. 16(a) and (b), respectively. A second wheel distribution gain K_2 and a fourth wheel distribution gain K_4 related to the second wheel W_2 and the fourth wheel W_4 , which are longitudinally disposed on the right side of the actual vehicle 1, are determined such that the gains virtually continuously change on the basis of βf_{act} and βr_{act} , as shown by the dashed-line graphs in Figs. 16(a) and (b), respectively. Incidentally, any one value of K_n is a positive value that is smaller than 1. Further, "virtually continuously" means that a jump (quantization) of a value that inevitably occurs when an analog quantity is expressed in terms of a discrete system does not impair the continuity of the analog quantity.

[0263] In this case, more specifically, regarding the first wheel distribution gain K_1 and the third wheel distribution gain K_3 , K_1 is determined on the basis of a value of βf_{act} such that it monotonously increases from a predetermined lower limit value to a predetermined upper limit value as βf_{act} increases from a negative value to a positive value, as shown by the solid-line graph in Fig. 16(a). Hence, K_1 is determined such that, when βf_{act} takes a positive value, it takes a larger value than that when βf_{act} takes a negative value.

[0264] Meanwhile, K_3 is determined on the basis of a value of βr_{act} such that it monotonously decreases from a predetermined upper limit value to a predetermined lower limit value as βr_{act} increases from a negative value to a

positive value, as shown by the solid-line graph in Fig. 16(b). Hence, $K3$ is determined such that, when β_{r_act} takes a negative value, $K3$ takes a larger value than that when β_{r_act} takes a positive value.

[0265] The solid-line graphs in Figs. 16(a) and (b) are set such that the sum of the values of $K1$ and $K3$ corresponding to β_{f_act} and β_{r_act} becomes substantially one when β_{f_act} and β_{r_act} agree or substantially agree with each other.

[0266] Further, regarding the second wheel distribution gain $K2$ and the fourth wheel distribution gain $K4$, $K2$ is determined on the basis of a value of β_{f_act} such that it monotonously decreases from a predetermined upper limit value to a predetermined lower limit value as β_{f_act} increases from a negative value to a positive value, as shown by the dashed-line graph in Fig. 16(a). In this case, the dashed-line graph indicating a relationship between $K2$ and β_{f_act} is identical to the graph obtained by laterally reversing the solid-line graph indicating a relationship between $K1$ and β_{f_act} around the axis of ordinates (the line of $\beta_{f_act}=0$). Hence, the value of $K2$ at each value of β_{f_act} is determined such that it is equal to the value of $K1$ at the value obtained by reversing the positive/negative of β_{f_act} .

[0267] Further, $K4$ is determined on the basis of a value of β_{r_act} such that it monotonously increases from a predetermined lower limit value to a predetermined upper

limit value as β_{r_act} increases from a negative value to a positive value, as shown by the dashed-line graph in Fig. 16(b). In this case, the dashed-line graph indicating the relationship between K_4 and β_{r_act} is identical to a graph obtained by laterally reversing the solid-line graph indicating the relationship between K_3 and β_{r_act} around the axis of ordinates (the line of $\beta_{r_act}=0$). Hence, the value of K_4 at each value of β_{r_act} is determined such that it is equal to the value of K_3 at the value obtained by reversing the positive/negative of β_{r_act} .

[0268] By determining the n-th wheel distribution gain K_n ($n=1, 2, 3, 4$) as described above, in a situation wherein β_{f_act} and β_{r_act} take virtually the same value, such as when the actual vehicle 1 is in a normal traveling mode, the ratio of the first wheel distribution gain K_1 corresponding to the front wheel W_1 to the third wheel distribution gain K_2 corresponding to the rear wheel W_3 immediately behind the front wheel W_1 will monotonously change as β_{f_act} and β_{r_act} change while maintaining the sum of K_1 and K_3 to be substantially constant. Similarly, the ratio of the second wheel distribution gain K_2 corresponding to the front wheel W_2 to the fourth wheel distribution gain K_4 corresponding to the rear wheel W_4 immediately behind the front wheel W_2 will monotonously change as β_{f_act} and β_{r_act} change while maintaining the sum of K_2 and K_4 to be substantially constant.

[0269] The reason for determining the n-th wheel

distribution gain K_n ($n=1, 2, 3, 4$) on the basis of β_{f_act} and β_{r_act} as described above will be discussed later.

[0270] After determining K_{n_str} and K_n ($n=1, 2, 3, 4$) as described above, the actuator operation FB target value distribution processor 222 multiplies each n -th wheel driving/braking force full required value $F_{xfullfbdmd_n}$ ($n=1, 2, 3, 4$) by K_{n_str} and K_n by the processors 222b $_n$ and 222c $_n$, respectively, thereby determining the n -th wheel distribution driving/braking force basic value F_{xfb_n} . In other words, the n -th wheel distribution driving/braking force basic values F_{xfb_n} ($n=1, 2, 3, 4$) are determined according to the following expressions 27a to 27d.

[0271]

$$F_{xfb_1} = F_{xfullfbdmd_1} \cdot K_{1_str} \cdot K_1 \quad \dots\dots$$

Expression 27a

$$F_{xfb_2} = F_{xfullfbdmd_2} \cdot K_{2_str} \cdot K_2 \quad \dots\dots$$

Expression 27b

$$F_{xfb_3} = F_{xfullfbdmd_3} \cdot K_{3_str} \cdot K_3 \quad \dots\dots$$

Expression 27c

$$F_{xfb_4} = F_{xfullfbdmd_4} \cdot K_{4_str} \cdot K_4 \quad \dots\dots$$

Expression 27d

When F_{xfb_n} ($n=1, 2, 3, 4$) is determined as described above, if $M_{fbdmd_a} > 0$, then F_{xfb_1} and F_{xfb_3} associated with the left wheels $W1$ and $W3$ provide a driving/braking force in a braking direction (a negative

driving/braking force), while F_{xfb_2} and F_{xfb_4} associated with the right wheels W2 and W4 provide a driving/braking force in a driving direction (a positive driving/braking force). Further, if $M_{fbdmd_a} < 0$, then F_{xfb_1} and F_{xfb_3} associated with the left wheels W1 and W3 provide a driving/braking force in the driving direction (a positive driving/braking force), while F_{xfb_2} and F_{xfb_4} associated with the right wheels W2 and W4 provide a driving/braking force in the braking direction (a negative driving/braking force).

[0272] Subsequently, the actuator operation FB target value distribution processor 222 passes the n-th wheel distribution driving/braking force basic value F_{xfb_n} ($n=1, 2, 3, 4$), which has been determined as described above, through a limiter 222d_n associated with each n-th wheel W_n thereby to determine respective FB target n-th wheel brake driving/braking force F_{fbdmd_n} , which is the feedback target value of the driving/braking force of the n-th wheel W_n by an operation of the braking device of the driving/braking device 3A.

[0273] Here, the graphs of the limiters 222d_n ($n=1, 2, 3, 4$) in Fig. 14 are graphs illustrating the relationships between F_{xfb_n} and F_{fbdmd_n} , the values in the direction of the axis of abscissas related to the graphs indicating the values of F_{xfb_n} , while the values in the direction of the axis of ordinates indicating the values of F_{fbdmd_n} .

[0274] The limiter 222d_n outputs F_{xfb_n} directly as

Fxkbdmd_n without processing it only if the value of Fxkb_n input thereto is zero or a negative value, and if Fxkb_n takes a positive value, then the value of Fxkbdmd_n to be output is set to zero independently of the value of Fxkb_n. In other words, Fxkbdmd_n is determined by limiting Fxkb_n with zero being an upper limit value.

[0275] Determining the FB target n-th wheel brake driving/braking force Fxkbdmd_n, respectively, as described above determines the FB target n-th wheel brake driving/braking force Fxkbdmd_n (n=1, 2, 3, 4) such that the driving/braking forces of the left wheels W1 and W3 of the actual vehicle 1 are increased in the braking direction (to set Fxkbdmd₁<0 and Fxkbdmd₃<0) if Mfbmd_a>0, as described above, thereby to generate Mfbmd_a about the center-of-gravity point G of the actual vehicle 1. In this case, for the right wheels W2 and W4, Fxkbdmd₂=Fxkbdmd₄=0 in the present embodiment.

[0276] Further, the FB target n-th wheel brake driving/braking force Fxkbdmd_n (n=1, 2, 3, 4) is determined such that the driving/braking forces of the right wheels W2 and W4 of the actual vehicle 1 are increased in the braking direction (to set Fxkbdmd₂<0 and Fxkbdmd₄<0) if Mfbmd_a<0, thereby generating Mfbmd_a about the center-of-gravity point G of the actual vehicle 1. In this case, for the left wheels W1 and W3, Fxkbdmd₁=Fxkbdmd₃=0 in the present embodiment.

[0277] And, in either case, the n-th wheel distribution

gain K_n ($n=1, 2, 3, 4$) is determined such that it virtually continuously changes according to β_{f_act} or β_{r_act} , thus preventing a situation wherein $F_{x_fb_dmd_n}$ discontinuously changes.

[0278] Here, the following will describe the reason for determining the n -th wheel distribution gain K_n ($n=1, 2, 3, 4$) on the basis of β_{f_act} and β_{r_act} in the tendency described above.

[0279] First, if $M_{fb_dmd_a} > 0$, then the FB target n -th wheel brake driving/braking force $F_{x_fb_dmd_n}$ is determined such that the driving/braking forces of the first wheel $W1$ and the third wheel $W3$, which are the left wheels of the actual vehicle 1, are increased in the braking direction, as described above.

[0280] In this case, a situation wherein $\beta_{f_act} < 0$ and $\beta_{r_act} < 0$ is assumed. In such a situation, if it is assumed that $K1$ is set to a slightly larger value (to cause $F_{x_fb_dmd_1}$ to increase in the braking direction) and $K3$ is set to a slightly smaller value (to restrain $F_{x_fb_dmd_3}$ from increasing in the braking direction), then the lateral force of the first wheel $W1$ (this functions to generate a moment in the same direction as $M_{fb_dmd_a}$ about the center-of-gravity point of the actual vehicle 1) decreases, whereas the lateral force of the third wheel $W3$ (this functions to generate a moment in the opposite direction from $M_{fb_dmd_a}$ about the center-of-gravity point of the actual vehicle 1) slightly increases. For this

reason, there is a danger that it becomes difficult to adequately generate a moment in the positive direction (a moment about the yaw axis) required by M_{fbdmd_a} about the center-of-gravity point G of the actual vehicle 1. Hence, it has been decided to determine the first wheel distribution gain $K1$ to be a slightly smaller value and to determine the third wheel distribution gain $K3$ to be a slightly larger value in the situation wherein $\beta_{f_act} < 0$ and $\beta_{r_act} < 0$.

[0281] Another situation wherein $\beta_{f_act} > 0$ and $\beta_{r_act} > 0$ when $M_{fbdmd_a} > 0$ will be assumed. In such a situation, if $K1$ is set to a slightly smaller value (consequently to restrain F_{xfbdmd_1} from increasing in the braking direction) and $K3$ is set to a slightly larger value (consequently to cause F_{xfbdmd_3} to increase in the braking direction), then the lateral force of the first wheel $W1$ (this functions to generate a moment in the opposite direction from M_{fbdmd_a} about the center-of-gravity point of the actual vehicle 1) slightly increases, whereas the lateral force of the third wheel $W3$ (this functions to generate a moment in the same direction as M_{fbdmd_a} about the center-of-gravity point of the actual vehicle 1) decreases. For this reason, there is a danger that it becomes difficult to adequately generate a moment in the positive direction (a moment about the yaw axis) required by M_{fbdmd_a} about the center-of-gravity point G of the actual vehicle 1. Hence, it has been decided to

determine the first wheel distribution gain $K1$ to be a slightly larger value and to determine the third wheel distribution gain $K3$ to be a slightly smaller value in the situation wherein $\beta_{f_act} > 0$ and $\beta_{r_act} > 0$.

[0282] If $M_{fbdmd_a} < 0$, then the FB target n-th wheel brake driving/braking force $F_{x_{fbdmd_n}}$ is determined such that the driving/braking forces of the second wheel $W2$ and the fourth wheel $W4$, which are the right wheels of the actual vehicle 1, are increased in the braking direction, as described above.

[0283] In this case, a situation wherein $\beta_{f_act} < 0$ and $\beta_{r_act} < 0$ is assumed. In such a situation, if $K2$ is set to a slightly smaller value (to consequently restrain $F_{x_{fbdmd_2}}$ from increasing in the braking direction) and $K4$ is set to a slightly larger value (to consequently cause $F_{x_{fbdmd_4}}$ to increase in the braking direction), then the lateral force of the second wheel $W2$ (this functions to generate a moment in the opposite direction from M_{fbdmd_a} about the center-of-gravity point of the actual vehicle 1) increases, whereas the lateral force of the fourth wheel $W4$ (this functions to generate a moment in the same direction as M_{fbdmd_a} about the center-of-gravity point of the actual vehicle 1) decreases. For this reason, there is a danger that it becomes difficult to adequately generate a moment in the negative direction (a moment about the yaw axis) required by M_{fbdmd_a} about the center-of-gravity point G of the actual vehicle 1. Hence, it has

been decided to determine the second wheel distribution gain K_2 to be a slightly larger value and to determine the fourth wheel distribution gain K_4 to be a slightly smaller value in the situation wherein $\beta_{f_act} < 0$ and $\beta_{r_act} < 0$.

[0284] Another situation wherein $\beta_{f_act} > 0$ and $\beta_{r_act} > 0$ when $M_{fbdmd_a} < 0$ will be assumed. In such a situation, if K_2 is set to a slightly larger value (consequently to cause $F_{x fbdmd_2}$ to increase in the braking direction) and K_4 is set to a slightly smaller value (consequently to restrain $F_{x fbdmd_4}$ from increasing in the braking direction), then the lateral force of the second wheel W_2 (this functions to generate a moment in the same direction as M_{fbdmd_a} about the center-of-gravity point of the actual vehicle 1) decreases, whereas the lateral force of the fourth wheel W_4 (this functions to generate a moment in the opposite direction from M_{fbdmd_a} about the center-of-gravity point of the actual vehicle 1) increases. For this reason, there is a danger that it becomes difficult to adequately generate a moment in the negative direction (a moment about the yaw axis) required by M_{fbdmd_a} about the center-of-gravity point G of the actual vehicle 1. Hence, it has been decided to determine the second wheel distribution gain K_2 to be a slightly smaller value and to determine the fourth wheel distribution gain K_4 to be a slightly larger value in the situation wherein $\beta_{f_act} > 0$ and $\beta_{r_act} > 0$.

[0285] Thus, determining the n-th wheel distribution gain

$K_n(n=1, 2, 3, 4)$ as described above makes it possible to prevent a lateral force that becomes an obstacle in generating a moment of M_{fbdmd_a} in the yaw direction about the center-of-gravity point G of the actual vehicle 1 from becoming excessive while at the same time preventing a lateral force that is effective in generating a moment of M_{fbdmd_a} in the yaw direction about the center-of-gravity point G of the actual vehicle 1 from becoming too small.

[0286] Moreover, by determining the n-th wheel distribution gain $K_n(n=1, 2, 3, 4)$ as described above, the sum of a value of K_1 and a value of K_3 and the sum of a value of K_2 and a value of K_4 , respectively, become substantially one in a situation wherein β_{f_act} and β_{r_act} agree or substantially agree with each other, as in the case where the actual vehicle 1 is in a normal circular turn mode or a normal straight travel mode. This means that if the braking device of the driving/braking device 3A is operated faithfully in accordance with the FB target n-th wheel brake driving/braking force $F_{x_{fbdmd_n}}$, then the gain of a transfer function from M_{fbdmd_a} to a moment (a moment in the yaw direction) actually generated about the center-of-gravity point G of the actual vehicle 1 becomes substantially one (a moment in the yaw direction actually generated becomes substantially equal to M_{fbdmd_a}).

[0287] Supplementally, there is a case where the difference between β_{f_act} and β_{r_act} increases in a transient motion situation or the like of the actual

vehicle 1. And, in this case, the sum of a value of K1 and a value of K3 and the sum of a value of K2 and a value of K4, respectively, considerably deviate from one. To solve this problem, preferably, after the values of K1 and K3 are determined as described above, the values of K1 and K3 are corrected while maintaining the ratio of the values at a constant level such that the sum of the corrected values of K1 and K3 becomes substantially one. Similarly, it is preferred that, after the values of K2 and K4 are determined as described above, the values of K2 and K4 are corrected while maintaining the ratio of the values at a constant level such that the sum of the corrected values of K2 and K4 becomes substantially one. To be more specific, after the n-th distribution gain K_n ($n=1, 2, 3, 4$) is determined according to the graphs of Figs. 16(a) and (b), $K1'$, $K2'$, $K3'$ and $K4'$ are determined by $K1' = K1 / (K1 + K3)$, $K3' = K3 / (K1 + K3)$, $K2' = K2 / (K2 + K4)$, and $K4' = K4 / (K2 + K4)$, and then, the determined $K1'$, $K2'$, $K3'$ and $K4'$ may be respectively re-determined as the values of K1, K2, K3 and K4.

[0288] Further, in addition to determining the FB target n-th wheel brake driving/braking force $F_{x\text{fbdmd}_n}$ as described above, the actuator operation FB target value distribution processor 222 according to the present embodiment inputs the feedback yaw moment required value M_{fbdmd} to a processor 222e so as to determine, by the processor 222e, an active steering FB target lateral force

Fyfbdmd_f, which is a feedback target value of the lateral force of the front wheels W1 and W2 by an operation of the steering device 3B. Here, the graph of the processor 222e in the figure is a graph illustrating a relationship between Mfbdmd and Fyfbdmd_f, the values in the direction of the axis of abscissas related to the graph indicating the values of Mfbdmd, while the values in the direction of the axis of ordinates indicating the values of Fyfbdmd_f. As illustrated in the graph, the processor 222e basically determines Fyfbdmd_f such that Fyfbdmd_f monotonously increases as Mfbdmd increases. In this case, Fyfbdmd_f is determined by using, for example, a map, from a value of Mfbdmd supplied to the processor 222e.

[0289] Alternatively, Fyfbdmd_f may be determined by multiplying Mfbdmd by a predetermined gain. Further, Fyfbdmd_f may be determined on the basis of Mfbdmd within a range between a predetermined upper limit value (>0) and a predetermined lower limit value (<0).

[0290] Supplementally, the processing by the processor 222e may be omitted regardless of whether the steering device 3B is an active steering device or a mechanical steering device. When determining the active steering FB target lateral force Fyfbdmd_f by the processing performed by the processor 222e and manipulating the operation of the steering device 3B on the basis of the determined Fyfbdmd_f, it is further preferable to determine Fxfbdmd_n ($n=1, 2, 3, 4$) and Fyfbdmd_f such that the sum of

a moment in the yaw direction to be generated about the center-of-gravity point G of the actual vehicle 1 by the FB target n-th wheel brake driving/braking force $F_{x\text{fbdmd}_n}$ ($n=1, 2, 3, 4$) and a moment in the yaw direction generated about the center-of-gravity point G of the actual vehicle 1 by the active steering FB target lateral force $F_{y\text{fbdmd}_f}$ is substantially equal to the aforesaid feedback yaw moment basic required value M_{fbdmd} . For example, the active steering FB target lateral force $F_{y\text{fbdmd}_f}$ may be determined on the basis of a difference between M_{fbdmd} and M_{fbdmd_a} . In this case, it is desirable to determine $F_{y\text{fbdmd}_f}$ such that a moment in the yaw direction that is substantially equal to M_{fbdmd} is generated about the center-of-gravity point G of the actual vehicle 1 by $F_{y\text{fbdmd}_f}$ when $M_{\text{fbdmd}_a}=0$.

[0291] The above has described the details of the processing by the actuator operation FB target value determiner 20b in the present embodiment. This processing determines the FB target n-th wheel brake driving/braking force $F_{x\text{fbdmd}_n}$ ($n=1, 2, 3, 4$) or $F_{x\text{fbdmd}_n}$ ($n=1, 2, 3, 4$) and the active steering FB target lateral force $F_{y\text{fbdmd}_f}$ as the actuator operation FB target value such that M_{fbdmd} is approximated to zero (consequently to approximate the state amount errors γ_{err} and β_{err} to zero), as described above.

[0292] The limiter 222d_n ($n=1, 2, 3, 4$) may output, as $F_{x\text{fbdmd}_n}$, a value obtained by limiting $F_{x\text{fb}_n}$ input

thereto to not more than a predetermined positive upper limit value, which is slightly larger than zero. For example, if F_{xfb_n} is a value that is the upper limit value or less, then F_{xfb_n} is directly output as F_{xkbdmd_n} without processing it, or if F_{xfb_n} takes a positive value that is larger than the upper limit value, then the upper limit value is output as F_{xkbdmd_n} . In this case, F_{xkbdmd_n} of a positive value provides a feedback control input that functions to decrease the magnitude of the driving/braking force of the n-th wheel W_n in the braking direction by the braking device.

[0293] Further, for each wheel W_n ($n=1, 2, 3, 4$), the processing from the processor 222a_n to the limiter 222d_n (the processing for determining F_{xkbdmd_n} on the basis of M_{fbdmd_a} and δf_{act} or δr_{act} and βf_{act} or βr_{act}), or the processing from the processor 222b_n to the limiter 222d_n (the processing for determining F_{xkbdmd_n} on the basis of $F_{xfullfbdmd_n}$ and δf_{act} or δr_{act} and βf_{act} or βr_{act}), or the processing from the processor 222c_n to the limiter 222d_n (the processing for determining F_{xkbdmd_n} on the basis of an output of the processor 222b_n and βf_{act} or βr_{act}), or the processing that combines two or more portions of the processing from the processor 222a_n to the limiter 222d_n (e.g., the processing from the processor 222b_n to the processor 222c_n) may be changed to determine an output by using a map or a function expression from input values necessary

for such processing.

[0294] For instance, to carry out the processing from the processor 222c_n to the limiter 222d_n by using a map, a map for the first wheel may be set as illustrated in, for example, Figs. 17(a) to (e), and a map for the third wheel may be set as illustrated in, for example, Figs. 18(a) to (e). In this case, the graphs in Figs. 17(a) to (e), respectively, illustrate the relationships between outputs of the processor 222b₁ (=Fxfullfbdmd₁·K1_{str}) and Fxfbdmd₁ in association with a plurality of representative types of values of β_{f_act} , the individual values being shown in terms of the values in the direction of the axis of abscissas of the graphs and the values in the direction of the axis of ordinates. Further, the graphs in Figs. 18(a) to (e), respectively, illustrate the relationships between outputs of the processor 222b₃ (=Fxfullfbdmd₃·K3_{str}) and Fxfbdmd₃ in association with a plurality of representative types of values of β_{r_act} , the individual values being shown in terms of the values in the direction of the axis of abscissas of the graphs and the values in the direction of the axis of ordinates. In Fig. 17, regarding the values of β_{f_act} , " β_{f--} " means a negative value having a relatively large absolute value, " β_{f-} " means a negative value having a relatively small absolute value, " β_{f+} " means a positive value having a relatively small absolute value, and " β_{f++} " means a positive value having a relatively large absolute value.

Similarly, in Fig. 18, regarding the values of β_{r_act} , " β_{r--} " means a negative value having a relatively large absolute value, " β_{r-} " means a negative value having a relatively small absolute value, " β_{r+} " means a positive value having a relatively small absolute value, and " β_{r++} " means a positive value having a relatively large absolute value.

[0295] Although not shown, a map for the second wheel may be set such that the relationship between outputs of the processor 222b_2 ($=F_{xfullfbdmd_2} \cdot K2_str$) and F_{xfbdmd_2} will be the same at each value of β_{f_act} as that in the map for the first wheel associated with the values obtained by reversing the signs of the values (e.g., the relationship between an output of the processor 222b_2 when $\beta_{f_act} = \beta_{f-}$ ($=F_{xfullfbdmd_2} \cdot K2_str$) and F_{xfbdmd_2} will be the same as the relationship between an output of the processor 222b_1 when $\beta_{f_act} = \beta_{f+}$ and F_{xfbdmd_1} (the relationship illustrated by the graph of Fig. 17(c))). Similarly, although not shown, a map for the fourth wheel may be set such that the relationship between outputs of the processor 222b_4 ($=F_{xfullfbdmd_4} \cdot K4_str$) and F_{xfbdmd_4} will be the same at each value of β_{r_act} as that in the map for the third wheel associated with the values obtained by reversing the signs of the values (e.g., the relationship between an output of the processor 222b_4 when $\beta_{r_act} = \beta_{r-}$ ($=F_{xfullfbdmd_4} \cdot K4_str$) and F_{xfbdmd_4} will be the same as the relationship between an output of the

processor 222b_3 when $\beta_{r_act} = \beta_{r+}$ and $F_{x\text{fbdmd}_3}$ (the relationship illustrated by the graph of Fig. 18(c)).

[0296] In this example, if an output of the processor 222b_n (n=1, 2, 3, 4) is a value of zero or less, then $F_{x\text{fbdmd}_n}$ is determined in the same manner as that illustrated in Fig. 14 described above. Meanwhile, if an output of the processor 222b_n (n=1, 2, 3, 4) is a positive value, then $F_{x\text{fbdmd}_n}$ takes a positive value within a range of relatively small values as with the case where the upper limit value in the limiter 222d_n is set to a positive value as described above.

[0297] Supplementally, both the processors 222b_3 and 222b_4 associated with the third wheel W3 and the fourth wheel W4 share the same input values and output values; therefore, carrying out the processing from the processor 222c_3 to the limiter 222d_3 and the processing from the processor 222c_4 to the limiter 222d_4 on the third wheel W3 and the fourth wheel W4 by using the maps as described above is equivalent to carrying out the processing from the processor 222b_3 to the limiter 222d_3 and the processing from the processor 222b_4 to the limiter 222d_4 by using the maps.

[0298] Further, the n-th wheel distribution gain K_n (n=1, 2, 3, 4) may be determined on the basis of the actual vehicle center-of-gravity point side slip angle β_{act} in place of β_{f_act} or β_{r_act} . In this case, the relationship between β_{act} and the n-th wheel distribution gain K_n may

be set to a relationship that has a tendency similar to that of the relationship between the aforesaid β_{f_act} or β_{r_act} and the n-th wheel distribution gain K_n . For example, the n-th wheel distribution gain K_n may be determined according to graphs obtained by replacing the values β_{f_act} or β_{r_act} , respectively, in the direction of the axis of abscissas in the graphs of Figs. 16(a) and (b) by β_{act} .

[0299] Alternatively, the n-th wheel distribution gain K_n ($n=1, 2, 3, 4$) may be determined according to a map or a function expression on the basis of the actual vehicle center-of-gravity point side slip angle β_{act} , the actual yaw rate γ_{act} , and the actual traveling velocity V_{act} , or on the basis of β_{act} , γ_{act} , V_{act} , and the actual front wheel steering angle δ_{f_act} . For instance, the relationship between β_{f_act} and the first wheel distribution gain K_1 and the second wheel distribution gain K_2 described above (the relationship indicated by the graph of Fig. 16(a) described above) is converted beforehand into a relationship between β_{act} , γ_{act} , V_{act} , δ_{f_act} , and K_1 , K_2 on the basis of an expression obtained by replacing β_{f_d} , β_d , γ_d , V_d , and δ_{f_d} of the expression 02a related to the model vehicle by β_{f_act} , β_{act} , γ_{act} , V_{act} , and δ_{f_act} , then K_1 and K_2 are determined according to β_{act} , γ_{act} , V_{act} , and δ_{f_act} on the basis of the relationship obtained by the conversion. Similarly, the relationship among β_{r_act} and the third wheel distribution

gain $K3$ and the fourth wheel distribution gain $K4$ described above (the relationship indicated by the graph of Fig. 16(b) described above) is converted beforehand into a relationship between β_{act} , γ_{act} , V_{act} and $K3$, $K4$ on the basis of an expression obtained by replacing β_{r_d} , β_d , γ_d , and V_d of the expression 02b related to the model vehicle by β_{r_act} , β_{act} , γ_{act} , and V_{act} , then $K3$ and $K4$ are determined according to β_{act} , γ_{act} , and V_{act} on the basis of the relationship obtained by the conversion.

[0300] Further, in the case where the n -th wheel distribution gain K_n is determined on the basis of β_{f_act} or β_{r_act} or β_{act} , as described above, the values of β_{f_d} , β_{r_d} , and β_d of the model vehicle of the reference dynamic characteristic model 16 may be used in place of β_{f_act} , β_{r_act} , and β_{act} . According to the present embodiment, the motions of both the actual vehicle 1 and the model vehicle are operated so as to bring the state amount errors γ_{err} and β_{err} close to zero, so that the state amounts of their motions will not become significantly apart from each other. Hence, β_{f_d} , β_{r_d} , and β_d of the model vehicle may be used in place of β_{f_act} , β_{r_act} , and β_{act} .

[0301] Alternatively, the n -th wheel distribution gain K_n may be determined on the basis of the weighted mean value of the β_{f_act} and β_{r_act} of the actual vehicle 1 and the β_{f_d} and β_{r_d} of the model vehicle, or the n -th wheel distribution gain K_n may be determined on the basis of the

weighted mean value of the β_{act} of the actual vehicle 1 and the β_d of the model vehicle. In this case, the weights may be provided with a frequency characteristic (e.g., a frequency characteristic functioning as a phase compensating element).

[0302] Alternatively, for example, the first temporary value of the n-th wheel distribution gain K_n ($n=1, 2, 3, 4$) may be determined according to β_{f_act} or β_{r_act} or β_{act} , the second temporary value of the n-th wheel distribution gain K_n may be determined according to β_{f_d} or β_{r_d} or β_d , and then a resultant value of the weighed mean values or the weighted mean values or the like of the temporary values may be determined as the n-th wheel distribution gain K_n . For example, the first temporary value of K_1 related to the first wheel W_1 is determined on the basis of β_{f_act} as indicated by the graph provided in Fig. 16(a) described above and the second temporary value of K_1 is determined on the basis of β_{f_d} in the same manner as that for the first temporary value. In this case, the tendency of changes in the second temporary value relative to β_{f_d} may be the same as the tendency of changes in the first temporary value relative to β_{f_act} . Then, a weighed mean value of these first temporary value and second temporary value is determined as the first wheel distribution gain K_1 . The same applies to other n-th wheel distribution gains K_2 , K_3 , and K_4 .

[0303] Further desirably, the value of the n-th wheel

distribution gain K_n ($n=1, 2, 3, 4$) is determined such that the value is not only changed according to β_{f_act} , β_{r_act} , or β_{act} or the like, but also changed according to the estimated friction coefficient μ_{estm} . For example, when determining the n -th wheel distribution gain K_n on the basis of β_{f_act} or β_{r_act} , as described above in relation to the present embodiment, K_1 is desirably determined such that the first wheel distribution gain K_1 when β_{f_act} is a negative value having a large absolute value is further decreased as μ_{estm} is decreased. Further, K_3 is desirably determined such that the third wheel distribution gain K_3 when β_{r_act} is a positive value having a large absolute value is further decreased as μ_{estm} is decreased.

Similarly, K_2 is desirably determined such that the second wheel distribution gain K_2 when β_{f_act} is a positive value having a large absolute value is further decreased as μ_{estm} is decreased. Further, K_4 is desirably determined such that the fourth wheel distribution gain K_4 when β_{r_act} is a negative value having a large absolute value is further decreased as μ_{estm} is decreased. This is because, as μ_{estm} decreases, the lateral force of the n -th wheel W_n considerably reduces when the driving/braking force of the n -th wheel W_n ($n=1, 2, 3, 4$) in the braking direction is increased.

[0304] Further, a value of the n -th wheel distribution gain K_n ($n=1, 2, 3, 4$) (a value set on the basis of β_{f_act} or β_{r_act} (or on the basis of one of β_{act} , β_{f_d} , β_{r_d} , and

βd) may be adjusted also on the basis of an actual ground contact load of the n-th wheel (a detected value or an estimated value of a translational force, which is in the vertical direction or a direction perpendicular to a road surface, of a road surface reaction force acting on the n-th wheel). In this case, the value of the n-th wheel distribution gain K_n is desirably determined such that it decreases as the actual ground contact load of the n-th wheel W_n decreases.

[0305] Alternatively, when the actual ground contact load of each n-th wheel W_n is expressed by F_{zact_n} ($n=1, 2, 3, 4$) and the total sum thereof is expressed by ΣF_{zact} ($= F_{zact_1} + F_{zact_2} + F_{zact_3} + F_{zact_4}$), the values of the n-th wheel distribution gains K_1 and K_2 related to the front wheels W_1 and W_2 may be adjusted on the basis of the sum of the actual ground contact loads of the front wheels W_1 and W_2 ($= F_{zact_1} + F_{zact_2}$) or may be adjusted on the basis of a ratio of the sum with respect to ΣF_{zact} ($= (F_{zact_1} + F_{zact_2}) / \Sigma F_{zact}$). Similarly, the n-th wheel distribution gains K_3 and K_4 related to the rear wheels W_3 and W_4 may be adjusted on the basis of the sum of the actual ground contact loads of the rear wheels W_3 and W_4 ($= F_{zact_3} + F_{zact_4}$) or may be adjusted on the basis of a ratio of the sum with respect to ΣF_{zact} ($= (F_{zact_3} + F_{zact_4}) / \Sigma F_{zact}$). Alternatively, the value of each n-th wheel distribution gain K_n ($n=1, 2, 3, 4$) may be adjusted on the basis of the ratio of the actual ground

contact load of each n-th wheel W_n with respect to ΣF_{zact} ($=F_{zact_n}/\Sigma F_{zact}$).

[0306] Further, in the present embodiment, as the feedback control input to the braking device of the driving/braking device 3A (as the actuator operation FB target value), the FB target n-th wheel brake driving/braking force $F_{x\text{fbdmd}_n}$ ($n=1, 2, 3, 4$) has been determined; alternatively, however, instead of $F_{x\text{fbdmd}_n}$, a target slip ratio of each wheel W_n ($n=1, 2, 3, 4$) by the braking device may be determined or both the target slip ratio and $F_{x\text{fbdmd}_n}$ may be determined.

[0307] Further, the actuator operation FB target value may be directly determined by using a map or the like from the state amount errors γ_{err} and β_{err} , without determining M_{fbdmd} or M_{fbdmd_a} , which is an intermediate variable, to determine an actuator operation FB target value, such as $F_{x\text{fbdmd}_n}$. For example, the actuator operation FB target value may be determined by using a multidimensional map which uses variables, such as γ_{err} , γ_d (or γ_{act}), β_d (or β_{act}), V_{act} , and μ_{estm} , as inputs.

[0308] The feedback yaw moment basic required value M_{fbdmd} may be determined such that M_{fbdmd} not only causes the state amount errors γ_{err} and β_{err} to approximate zero but also causes the deviation amounts γ_{over} and β_{over} determined by the $\gamma\beta$ limiter 202 of the virtual external force determiner 20a to approximate zero (thereby to restrain the γ_{da} and β_{da} from deviating from their

- 150 -

permissible ranges $[\gamma_{damin}, \gamma_{damax}]$ and $[\beta_{damin}, \beta_{damax}]$, respectively). For example, M_{fbdmd} may be determined according to expression 28 given below by using appropriate coefficients K_{fbdmd1} to K_{fbdmd4} .

[0309]

$$M_{fbdmd} = K_{fbdmd1} \cdot \gamma_{err} + K_{fbdmd2} \cdot \beta_{err} - K_{fbdmd3} \cdot \gamma_{over} - K_{fbdmd4} \cdot \beta_{over} \quad \dots \text{Expression 28}$$

Supplementally, according to the present embodiment, the virtual external force temporary values M_{virtmp} and F_{virtmp} are manipulated to approximate γ_{over} and β_{over} to zero by the $\gamma\beta$ limiter 202, as described above, thereby determining the virtual external forces M_{vir} and F_{vir} . This alone restrains γ_d and β_d of the model vehicle from deviating from their permissible ranges $[\gamma_{damin}, \gamma_{damax}]$ and $[\beta_{damin}, \beta_{damax}]$, respectively, when they change. Accordingly, the actuator operation FB target value changes such that γ_{act} and β_{act} of the actual vehicle 1 are brought close to γ_d and β_d , respectively. Therefore, even when the actuator operation FB target value is determined such that only γ_{err} and β_{err} are brought close to zero, the γ_{act} and β_{act} can be also consequently restrained from deviating from the permissible ranges $[\gamma_{damin}, \gamma_{damax}]$ and $[\beta_{damin}, \beta_{damax}]$. However, determining M_{fbdmd} or M_{fbdmd_a} (so as to determine the actuator operation FB target value) such that γ_{over} and β_{over} are also brought close to zero in

addition to γ_{err} and β_{err} as described above makes it possible to further effectively restrain the γ_{act} and β_{act} from deviating from the permissible ranges $[\gamma_{damin}, \gamma_{damax}]$ and $[\beta_{damin}, \beta_{damax}]$, respectively.

[0310]

[About the FF law]

The processing by the FF law 22 will now be described in detail with reference to Fig. 19. Fig. 19 is a functional block diagram illustrating the processing by the FF law 22.

[0311] As described above, according to the present embodiment, a feedforward target value determined by the FF law 22 (a basic target value of the actuator devices 3 on the basis of drive manipulation inputs) includes the feedforward target values of the driving/braking forces of the wheels W1 to W4 of the actual vehicle 1 by the braking device of the driving/braking device 3A (hereinafter referred to as the FF target n-th wheel brake driving/braking forces (n=1, 2, 3, 4)), the feedforward target values of the driving/braking forces of the driving wheels W1 and W2 of the actual vehicle 1 by the driving system of the driving/braking device 3A (hereinafter referred to as the FF target n-th wheel driving system driving/braking forces (n=1, 2)), the feedforward target value of a reduction gear ratio (change gear ratio) of the speed change gear of the driving/braking device 3A (hereinafter referred to as the FF target transmission

reduction gear ratio), and the feedforward target values of the steering angles of the steering control wheels W1 and W2 of the actual vehicle 1 by the steering device 3B (hereinafter referred to as the FF target front wheel steering angle δf_{ff}).

[0312] As illustrated in Fig. 19, the FF target front wheel steering angle δf_{ff} is determined by a processor 230 on the basis of the steering angle θ_h (or on the basis of θ_h and V_{act}) of drive manipulation inputs. In Fig. 19, it is assumed that the steering device 3B is the actuator-driven steering device. In this case, the processor 230 determines the FF target front wheel steering angle δf_{ff} by the same processing as the processing by the processor 14a of the reference manipulated variable determiner 14. More specifically, the steering angle θ_h is divided by a predetermined overall steering ratio "is" or an overall steering ratio "is" set on the basis of V_{act} to determine δf_{ff} . The value of δf_{ff} thus determined is the same as the value of the unlimited front wheel steering angle δf_{unltd} determined by the processor 14a of the reference manipulated variable determiner 14.

[0313] If the steering device 3B is the actuator-assisted steering device or a mechanical steering device, then it is unnecessary to determine δf_{ff} . Alternatively, δf_{ff} may be always set to zero. However, if the steering device 3B is the actuator-assisted steering device and has a function for correcting, on the basis of V_{act} , the

steering angles of the front wheels W1 and W2 mechanically determined on the basis of the steering angle θ_h , then the correction may be determined on the basis of V_{act} and the obtained correction may be determined as δf_{ff} .

[0314] Supplementally, if the steering device 3B is an actuator-assisted steering device, then the basic steering angles of the front wheels W1 and W2 (the basic values of δf_{act}) are mechanically determined on the basis of the steering angle θ_h , so that δf_{ff} has a meaning as the feedforward target values of the correction amounts of the steering angles of the front wheels W1 and W2 by an actuator.

[0315] Further, the FF target n-th wheel brake driving/braking forces ($n=1, 2, 3, 4$) are respectively determined by processors 231a_n ($n=1, 2, 3, 4$) on the basis of a brake pedal manipulated variable of drive manipulation inputs. The graphs provided in the processors 231a_n in the figure respectively are graphs illustrating the relationship between brake pedal manipulated variables and the FF target n-th wheel brake driving/braking forces ($n=1, 2, 3, 4$), the values in the direction of the axis of abscissas in the graphs indicating the values of the brake pedal manipulated variables, while the values in the direction of the axis of ordinates indicating the FF target n-th wheel brake driving/braking forces. As illustrated in the graphs of the figure, the FF target n-th wheel brake driving/braking

forces (<0) are basically determined such that the magnitudes (absolute values) thereof monotonously increase as the brake pedal manipulated variable increases. In the illustrated examples, the FF target n-th wheel brake driving/braking forces are set such that they are saturated when a brake pedal manipulated variable exceeds a predetermined amount (the increasing rate of the absolute value of the FF target n-th wheel brake driving/braking force relative to an increase in the brake pedal manipulated variable approaches zero or reaches zero), thereby preventing the magnitude of the FF target n-th wheel brake driving/braking force from becoming excessive.

[0316] The FF target n-th wheel driving system driving/braking forces ($n=1, 2$) and the FF target transmission reduction gear ratio are determined by a driving system actuator operation FF target value determiner 232 on the basis of an accelerator (gas) pedal manipulated variable, V_{act} , and a shift lever position among drive manipulation inputs. The processing by the driving system actuator operation FF target value determiner 232 may be the same method for determining a driving force transmitted from an engine to driving wheels and the reduction gear ratio of a speed change gear on the basis of an accelerator (gas) pedal manipulated variable, V_{act} , and the shift lever position of the speed change gear in a publicly known regular car, so that detailed

explanation thereof in the present description will be omitted.

[0317] The above has described the specific processing by the FF law 22 in the present embodiment.

[0318]

[About the actuator operation target value synthesizer]

The processing by the actuator operation target value synthesizer 24 will now be described in detail. Fig. 20 is a functional block diagram illustrating the processing by the actuator operation target value synthesizer 24.

[0319] Referring to the figure, regarding the first wheel W1, the actuator operation target value synthesizer 24 determines, by an adder 240, the sum of the FF target first wheel brake driving/braking force of the actuator operation FF target value and the FF target first wheel driving system driving/braking force. Then, the sum is input as an FF total target first wheel driving/braking force FFtotal₁ into an optimum target first driving/braking force determiner 241a₁. Further, the sum of this FFtotal₁ and the FB target first wheel brake driving/braking force Fxfgdmd₁ of the actuator operation FB target value is determined by an adder 242. Then, the sum is input as an unlimited target first wheel driving/braking force Fxdmd₁ into the optimum target first driving/braking force determiner 241a₁.

[0320] Regarding the second wheel W2, the actuator operation target value synthesizer 24 determines, by an adder 243, the sum of the FF target second wheel brake driving/braking force of the actuator operation FF target value and the FF target second wheel driving system driving/braking force. Then, the sum is input as an FF total target second wheel driving/braking force FFtotal_2 into an optimum target second driving/braking force determiner 241a_2. Further, the sum of this FFtotal_2 and the FB target second wheel brake driving/braking force Fxfbdmd_2 of the actuator operation FB target value is determined by an adder 244 and then, the sum is input as an unlimited target second wheel driving/braking force Fxdmd_2 into the optimum target second driving/braking force determiner 241a_2.

[0321] Regarding the third wheel W3, the actuator operation target value synthesizer 24 directly inputs an FF target third wheel brake driving/braking force of the actuator operation FF target value as an FF total target third wheel driving/braking force FFtotal_3 into an optimum target third driving/braking force determiner 241a_3. Further, the sum of this FFtotal_3 and the FB target third wheel brake driving/braking force Fxfbdmd_3 of the actuator operation FB target value is determined by an adder 245 and then, the sum is input as an unlimited target third wheel driving/braking force Fxdmd_3 into the optimum target third driving/braking force determiner

241a_3.

[0322] Regarding the fourth wheel W4, the actuator operation target value synthesizer 24 directly inputs an FF target fourth wheel brake driving/braking force of the actuator operation FF target value as an FF total target fourth wheel driving/braking force FFtotal_4 into an optimum target fourth driving/braking force determiner 241a_4. Further, the sum of this FFtotal_4 and the FB target fourth wheel brake driving/braking force Fxkbdmd_4 of the actuator operation FB target value is determined by an adder 246 and then, the sum is input as an unlimited target fourth wheel driving/braking force Fxdmd_4 into the optimum target fourth driving/braking force determiner 241a_4.

[0323] Here, to generalize the FF total target n-th wheel driving/braking force FFtotal_n (n=1, 2, 3, 4), it means the total sum of a feedforward target value of the driving/braking force of the n-th wheel Wn by an operation of the driving system of the driving/braking device 3A (FF target n-th wheel driving system driving/braking force) and a feedforward target value of the driving/braking force of the n-th wheel Wn by an operation of the braking device (FF target n-th wheel brake driving/braking force). In this case, according to the embodiments in the present description, the driving wheels of the actual vehicle 1 are the front wheels W1 and W2, and the rear wheels W3 and W4 are the driven wheels; hence, for the rear wheels W3

and W4, the FF target n-th wheel brake driving/braking force (n=3, 4) is directly determined as the FF total target n-th wheel driving/braking force FF_{total_n} .

[0324] Further, the unlimited target n-th wheel driving/braking force F_{xdmd_n} (n=1, 2, 3, 4) is the sum of the FF total target n-th wheel driving/braking force FF_{total_n} and the FB n-th wheel brake driving/braking force, so that it means the total driving/braking force of the n-th wheel required by a feedforward control operation of the driving/braking device 3A (a feedforward control operation based on at least a drive manipulation input) and a feedback control operation (a feedback control operation based on at least state amount errors γ_{err} and β_{err}).

[0325] Then, the actuator operation target value synthesizer 24 determines the target n-th wheel driving/braking force F_{xcmd_n} , which is the final target value of the driving/braking force of each n-th wheel W_n , by the optimum target n-th driving/braking force determiner 241a_n (n=1, 2, 3, 4), and also determines a target n-th wheel slip ratio, which is the final target value of the slip ratio of the n-th wheel.

[0326] In this case, the optimum target n-th driving/braking force determiner 241a_n (n=1, 2, 3, 4) receives a latest value (current time value) of the actual side slip angle of the n-th wheel W_n (more specifically, the actual front wheel side slip angle β_{f_act} when n=1, 2

or the actual rear wheel side slip angle β_{r_act} when $n=3, 4$) and a latest value (current time value) of the estimated friction coefficient μ_{estm} in addition to FF_{total_n} and F_{xdmd_n} . Although not shown, the optimum target n -th driving/braking force determiner 241a $_n$ ($n=1, 2$) associated with the front wheels W1 and W2 also receives a latest value (current time value) of the actual front wheel steering angle δf_{act} . Then, the optimum target n -th driving/braking force determiner 241a $_n$ ($n=1, 2, 3, 4$) determines the target n -th wheel driving/braking force F_{xcmd_n} and the target n -th wheel slip ratio on the basis of the inputs supplied thereto, respectively, as will be described later.

[0327] Further, the actuator operation target value synthesizer 24 inputs the active steering FB target lateral force F_{yfbdmd_f} of the actuator operation FB target value and the FF target front wheel steering angle δf_{ff} of the actuator operation FF target value into an optimum target active steering angle determiner 247 so as to determine target front wheel steering angles $\delta\text{-fcmd}$, which are the final steering angle target values of the front wheels W1 and W2, by the optimum target active steering angle determiner 247. Incidentally, the $\delta\text{-fcmd}$ means the final target values of the steering angles themselves (the steering angles based on the longitudinal direction of the actual vehicle 1) of the front wheels W1 and W2 by an operation of an actuator if the steering

device 3B is the actuator-driven steering device. Meanwhile, if the steering device 3B is the actuator-assisted steering device, then it means the final target values of the correction amounts of the steering angles of the front wheels W1 and W2 by an operation of an actuator. [0328] The actuator operation target value synthesizer 24 directly outputs the FF target n-th wheel driving system driving/braking force ($n=1, 2$) of the actuator operation FF target value as the target n-th wheel driving system driving/braking force, which is the final target value of the driving/braking force of the n-th wheel Wn by an operation of the driving system of the driving/braking device 3A. Moreover, the actuator operation target value synthesizer 24 directly outputs the FF target transmission reduction gear ratio of the actuator operation FF target value as a target transmission reduction gear ratio, which is the final target value of the reduction gear ratio (speed change ratio) of the speed change gear of the driving/braking device 3A.

[0329] The processing by the optimum target n-th driving/braking force determiner 241a_n ($n=1, 2, 3, 4$) will be described below in detail. Fig. 21 is a flowchart illustrating the processing by the optimum target n-th driving/braking force determiner 241a_n.

[0330] Referring to the figure, first, in S100, it is preconditioned that the side slip angle of the n-th wheel Wn ($n=1, 2, 3, 4$) is an actual side slip angle (more

specifically, the actual front wheel side slip angle β_{f_act} for $n=1, 2$ and the actual rear wheel side slip angle β_{r_act} for $n=3, 4$), and a road surface friction coefficient (the coefficient of friction between the n -th wheel W_n and a road surface) is the estimated friction coefficient μ_{estm} . Then, based on the precondition, an n -th wheel driving/braking force candidate F_{xcand_n} , which is the value of the driving/braking force of the n -th wheel W_n closest to the unlimited target n -th wheel driving/braking force F_{xdmd_n} (including a case of agreement therebetween), and an n -th wheel slip ratio candidate S_{cand_n} , which is the value of the slip ratio of the n -th wheel W_n associated therewith, are determined.

[0331] Here, in general, there is a predetermined correlation based on the characteristics of wheel tires or the characteristics of a suspension device among the side slip angle and a road surface reaction force (a driving/braking force, a lateral force, and a ground contact load), a slip ratio and a road surface friction coefficient of each wheel. For example, there is a correlation indicated by expressions (2.57), (2.58), (2.72), and (2.73) in the aforesaid non-patent document 1 among a side slip angle, a road surface reaction force (a driving/braking force, a lateral force, and a ground contact load), a slip ratio and a road surface friction coefficient of each wheel. Moreover, if, for example, the ground contact load and the road surface friction

coefficient are set to be constant, then there is a correlation as illustrated in Fig. 2.36 of the aforesaid non-patent document 1 among the side slip angle, the driving/braking force, the lateral force, and the slip ratio of each wheel. Hence, the road surface reaction force and the slip ratio of each wheel when the side slip angle and the road surface friction coefficient individually take certain values cannot respectively take independent values; instead, the values thereof change according to the aforesaid correlations (hereinafter referred to as wheel characteristics relations). The slip ratio takes a negative value when the driving/braking force is a driving/braking force in the driving direction (>0), while it takes a positive value when the driving/braking force is a driving/braking force in the braking direction (<0).

[0332] Thus, the processing in S100 in the present embodiment determines a driving/braking force that is closest to or agrees with the unlimited target n-th wheel driving/braking force F_{xdmd_n} (a driving/braking force that provides a minimum absolute value of a difference from F_{xdmd_n}) and a slip ratio associated with the driving/braking force from the actual side slip angle β_{f_act} or β_{r_act} (latest value) of the n-th wheel W_n and the estimated road surface friction coefficient μ_{estm} (latest value) on the basis of a map which illustrates a relationship among a side slip angle, a road surface

friction coefficient, a driving/braking force, and a slip ratio of the n-th wheel W_n and which has been prepared in advance. Then, the driving/braking force and the slip ratio determined as described above are determined as an n-th wheel driving/braking force candidate F_{xcand_n} and an n-th wheel slip ratio candidate S_{cand_n} .

[0333] For the map used for the processing, the aforesaid wheel characteristics relationship, for example, may be specified or estimated beforehand by various experiments or the like or on the basis of the tire characteristics of the wheels W_1 to W_4 or the characteristics of the suspension device 3C, and the map may be prepared on the basis of the specified or estimated wheel characteristics relationship. The ground contact loads of n-th wheels W_n may be added as variable parameters to the map. In this case, the actual ground contact load F_{zact_n} of the n-th wheel W_n may be input to the optimum target n-th driving/braking force determiner 241a_n to determine F_{xcand_n} and S_{cand_n} from the actual side slip angle β_{f_act} or β_{r_act} , the estimated friction coefficient μ_{estm} , and the actual ground contact load F_{zact_n} of the n-th wheel W_n . However, fluctuations in the actual ground contact load F_{zact_n} are relatively small in general, so that the actual ground contact load F_{zact_n} may be regarded as a fixed value.

[0334] Supplementally, if F_{xdmd_n} exists in a range of values of driving/braking forces that can be generated

(that can be applied from a road surface) in the n-th wheel W_n (driving/braking forces that can be generated on the basis of the aforesaid wheel characteristics relationship) corresponding to a set of the actual side slip angle β_{f_act} or β_{r_act} and the estimated road surface friction coefficient μ_{estm} of the n-th wheel W_n or a set of these and the actual ground contact load F_{zact_n} , then the F_{xdmd_n} may be directly determined as F_{xcand_n} . Further, if F_{xdmd_n} deviates from the range, then an upper limit value (>0) or a lower limit value (<0) of the range, whichever is closer to F_{xdmd_n} may be determined as F_{xcand_n} .

[0335] Further, in association with the set of the actual side slip angle β_{f_act} or β_{r_act} and the estimated road surface friction coefficient μ_{estm} of the n-th wheel W_n or in association with the set of these and the actual ground contact load F_{zact_n} , a relationship between the slip ratio and the driving/braking force that can be generated in the n-th wheel W_n (a relationship between the slip ratio and the driving/braking force that can be generated according to the wheel characteristics relationship) will generally be a relationship in which the driving/braking forces have peak values (extremal values) with respect to changes in the slip ratio (a graph having slip ratio values on the axis of abscissas and the driving/braking force magnitude values on the axis of ordinates will be a graph that bulges upward). For this reason, in some cases,

there are two types of slip ratio values that correspond to the values of driving/braking forces whose absolute values are smaller than the peak values. If there are two types of slip ratio values corresponding to F_{xcand_n} as described above, then, of the two types of slip ratio values, the slip ratio value that is closer to zero may be determined as an n-th wheel slip ratio candidate $Scand_n$. In other words, in the relationship between the slip ratio and the driving/braking force of the n-th wheel W_n (the relationship based on the wheel characteristics relationship), the n-th wheel slip ratio candidate $Scand_n$ may be determined within a range between the slip ratio value, at which the driving/braking force reaches a peak value, and zero.

[0336] Supplementally, within the range between the slip ratio value, at which the driving/braking force reaches a peak value, and zero, the absolute value of a driving/braking force monotonously increases as the absolute value of the slip ratio increases from zero.

[0337] Subsequently, the procedure proceeds to S102 wherein an n-th wheel driving/braking force at the generation of a maximum moment F_{xmmax_n} and an n-th wheel slip ratio at the generation of a maximum moment S_{mmax_n} , which is a slip ratio corresponding to the above F_{xmmax_n} , are determined under the same precondition as that in S100. Here, the n-th wheel driving/braking force at the generation of a maximum moment F_{xmmax_n} means the value of

a driving/braking force component of a road surface reaction force that causes a moment in the yaw direction generated about the center-of-gravity point G of the actual vehicle 1 by a road surface reaction force to become maximum toward the same polarity (direction) as the polarity of the aforesaid feedback yaw moment basic required value M_{fbdmd} , the driving/braking force component being a component in a road surface reaction force that can be generated in the n-th wheel W_n when the side slip angle of the n-th wheel W_n is the actual side slip angle β_{f_act} or β_{r_act} and the road surface friction coefficient is the estimated friction coefficient μ_{estm} (more specifically, the resultant force of the driving/braking force and the lateral force that can be applied to the n-th wheel W_n from a road surface according to the wheel characteristics relationship). In this case, F_{xmax_n} and S_{max_n} are determined within a range wherein the absolute value of the driving/braking force monotonously increases as the absolute value of the slip ratio increases from zero in the relationship between the driving/braking force and the slip ratio of the n-th wheel W_n (the relationship based on the wheel characteristics relationship). Thus, S_{max_n} is determined to take a value between the slip ratio value, at which the driving/braking force reaches a peak value, and zero.

[0338] In S102, regarding the front wheels W_1 and W_2 (when $n=1$ or 2), the n-th wheel driving/braking force at

the generation of a maximum moment $F_{x\max_n}$ and the n -th wheel slip ratio at the generation of a maximum moment S_{\max_n} corresponding thereto are determined from, for example, the actual front wheel side slip angle β_{f_act} , the estimated friction coefficient μ_{estm} , and the actual front wheel steering angle δ_{f_act} according to a map prepared beforehand (a map illustrating the relationship among front wheel side slip angles, road surface friction coefficients, front wheel steering angles, driving/braking forces at the generation of maximum moments, and slip ratios at the generation of maximum moments (the relationship based on the wheel characteristics relationship)). Alternatively, from among the sets of driving/braking forces and lateral forces of the n -th wheel W_n ($n=1$ or 2) that can be generated with respect to sets of β_{f_act} and μ_{estm} , the set of a driving/braking force and a lateral force that causes a moment in the yaw direction generated by the resultant force thereof about the center-of-gravity point G of the actual vehicle 1 to reach its maximum level is exploratively determined on the basis of the map illustrating the relationship among the front wheel side slip angles, road surface friction coefficients, slip ratios, driving/braking forces, and lateral forces, and the actual front wheel steering angle δ_{f_act} . Then, the driving/braking force and the slip ratio associated with the set may be determined as $F_{x\max_n}$ and S_{\max_n} , respectively.

[0339] Further, regarding the rear wheels W3 and W4, (when $n=3$ or 4), the n -th wheel driving/braking force at the generation of a maximum moment $F_{x\max_n}$ and the n -th wheel slip ratio at the generation of a maximum moment S_{\max_n} corresponding thereto are determined from, for example, the actual rear wheel slip angle β_{r_act} and the estimated friction coefficient μ_{estm} according to a map prepared beforehand (a map illustrating the relationship among rear wheel side slip angles, road surface friction coefficients, driving/braking forces at the generation of maximum moments, and slip ratios at the generation of maximum moments (the relationship based on the wheel characteristics relationship)). Alternatively, from among the sets of driving/braking forces and lateral forces of the n -th wheel W_n ($n=3$ or 4) that can be generated with respect to sets of β_{r_act} and μ_{estm} , the set of a driving/braking force and a lateral force that causes a moment in the yaw direction generated by the resultant force thereof about the center-of-gravity point G of the actual vehicle 1 to reach a maximum level is exploratively determined according to the map illustrating the relationship among the rear wheel side slip angles, the road surface friction coefficients, the slip ratios, the driving/braking forces, and the lateral forces. Then, the driving/braking force and the slip ratio associated with the set may be determined as $F_{x\max_n}$ and S_{\max_n} , respectively.

[0340] Incidentally, the processing in S102 may include the actual ground contact load F_{zact_n} of the n-th wheel W_n as a variable parameter as with the case described in relation to the processing in S100 described above.

[0341] Subsequently, the processing in S104 to S112 is carried out, as will be described later, so as to determine the target n-th wheel driving/braking force F_{xcmd_n} . In this case, the target n-th wheel driving/braking force F_{xcmd_n} is determined to satisfy the following conditions (1) to (3). Regarding conditions (1) to (3), the priority rank is higher in the order of (1), (2), and (3). If no target n-th wheel driving/braking force F_{xcmd_n} that satisfies all the conditions (1) to (3) can be determined, then the target n-th wheel driving/braking force F_{xcmd_n} is determined such that a condition with higher priority is preferentially satisfied.

[0342]

Condition (1): If an FF total target n-th wheel driving/braking force FF_{total_n} and a target n-th wheel driving/braking force F_{xcmd_n} are driving/braking forces in the braking direction, then the magnitude (the absolute value) of the target n-th wheel driving/braking force F_{xcmd_n} is not smaller than the magnitude (the absolute value) of the FF total target n-th wheel driving/braking force FF_{total_n} . In other words, $0 > F_{xcmd_n} > FF_{total_n}$ does not happen.

Condition (2): If the target n-th wheel

driving/braking force F_{xcmd_n} has the same polarity as that of the n -th wheel driving/braking force at the generation of a maximum moment F_{xmmax_n} , then the magnitude (the absolute value) of F_{xcmd_n} does not exceed the magnitude (the absolute value) of the F_{xmmax_n} . In other words, $F_{xcmd_n} > F_{xmmax_n} > 0$ or $F_{xcmd_n} < F_{xmmax_n} < 0$ does not happen.

Condition (3): The target n -th wheel driving/braking force F_{xcmd_n} agrees with the n -th wheel driving/braking force candidate F_{xcand_n} as much as possible (more precisely, the absolute value of a difference between F_{xcmd_n} and F_{xcand_n} is minimized).

Here, condition (1) is a condition for preventing the target n -th wheel driving/braking force F_{xcmd_n} from becoming smaller than the driving/braking force in the braking direction of the n -th wheel W_n of the actual vehicle 1 (this corresponds to FF_{total_n}) required by an operation of the brake pedal performed by the driver of the actual vehicle 1. Supplementally, according to the embodiments in the present description, the rear wheels W_3 and W_4 are driven wheels, so that the FF total target n -th wheel driving/braking force $FF_{total_n}(n=3, 4)$ and the target n -th wheel driving/braking force $F_{xcmd_n}(n=3, 4)$ related to the rear wheels W_3 and W_4 always take values of zero or less. Therefore, regarding the rear wheels W_3 and W_4 , condition (1) is equivalent to a condition that "the

- 171 -

magnitude (the absolute value) of the target n-th wheel driving/braking force F_{xcmd_n} does not become smaller than the magnitude (the absolute value) of the FF total target n-th wheel driving/braking force FF_{total_n} ."

[0343] Further, condition (2) is a condition for preventing a lateral force generated in the n-th wheel W_n on the basis of the target n-th wheel driving/braking force F_{xcmd_n} from becoming excessively small.

[0344] Further, condition (3) is a condition for satisfying as much as possible the control requirements (targets) of operations of the actuator devices 3 determined by the actuator operation FB target value determiner 20b and the FF law 22. Incidentally, F_{xcand_n} is, as described above, the value of a driving/braking force closest to the unlimited target n-th wheel driving/braking force F_{xdmd_n} (including a case of agreement therebetween) within a range of the values of driving/braking forces that can be generated in the n-th wheel W_n according to the wheel characteristics relationship (a wheel characteristics relationship observed when it is preconditioned that the side slip angle of the n-th wheel W_n is an actual side slip angle β_{f_act} or β_{r_act} and a road surface friction coefficient is the estimated friction coefficient μ_{estm}). Therefore, the condition (3) is, in other words, equivalent to a condition that the target n-th wheel driving/braking force F_{xcmd_n} takes a value within the range of values of

- 172 -

driving/braking forces that can be generated in the n-th wheel W_n according to the wheel characteristics relationship (the wheel characteristics relationship observed when it is preconditioned that the side slip angle of the n-th wheel W_n is the actual side slip angle β_{f_act} or β_{r_act} and a road surface friction coefficient is the estimated friction coefficient μ_{estm}) and agrees with or approximates (the absolute value of a difference from F_{xdmd_n} is minimized) the unlimited target n-th wheel driving/braking force F_{xdmd_n} (a driving/braking force based on a control requirement) as much as possible.

[0345] To be more specific, the processing of S104 to S112 described above is carried out as follows. First, the procedure proceeds to S104 wherein it is determined whether the magnitude relationship between F_{xcand_n} determined in S100 and F_{xmmax_n} determined in S102 is $0 > F_{xmmax_n} > F_{xcand_n}$ or $0 < F_{xmmax_n} < F_{xcand_n}$. If the result of the determination is NO, then the procedure proceeds to S106 wherein the value of F_{xcand_n} is substituted into the target n-th wheel driving/braking force F_{xcmd_n} . More specifically, if F_{xcand_n} and F_{xmmax_n} have polarities that are different from each other or if the F_{xcand_n} and F_{xmmax_n} have the same polarity and the magnitude (the absolute value) of F_{xcand_n} is the magnitude (the absolute value) of F_{xmmax_n} or less, then the value of F_{xcand_n} is directly substituted into F_{xcmd_n} . Incidentally, the value of F_{xcand_n} is substituted into F_{xcmd_n} (provided

- 173 -

Fxcmd_n=0) also when Fxcand_n=0 (at this time, Fxdmd_n is also zero).

[0346] Meanwhile, if the determination result in S104 is YES, then the procedure proceeds to S108 wherein the value of Fxmmax_n (the value determined in S102) is substituted into the target n-th wheel driving/braking force Fxcmd_n.

[0347] By the processing up to this point, Fxcmd_n is determined such that the conditions (2) and (3) are satisfied (provided that condition (2) is given a higher priority).

[0348] After the processing in S106 or S108, the procedure proceeds to S110 wherein it is determined whether the magnitude relationship between the FF total target n-th wheel driving/braking force FFtotal_n and the current target n-th wheel driving/braking force Fxcmd_n (the value determined in S106 or S108) is expressed by $0 > Fxcmd_n > FFtotal_n$. If the result of the determination is YES, then the procedure proceeds to S112 wherein FFtotal_n is re-substituted into the target n-th wheel driving/braking force Fxcmd_n. More specifically, if the FF total target n-th wheel driving/braking force FFtotal_n and the n-th wheel driving/braking force candidate Fxcmd_n determined in S106 or S108 are driving/braking forces in the braking direction and the magnitude (the absolute value) of Fxcmd_n is smaller than the magnitude (the absolute value) of FFtotal_n, then the value of FFtotal_n is substituted into Fxcmd_n. If the determination result

in S110 is NO, then the value of Fxcmd_n at that instant is maintained as it is.

[0349] By the aforesaid processing in S104 to S112, as previously described, basically, the target n-th wheel driving/braking force Fxcmd_n is determined such that the conditions (1) to (3) are satisfied. Further, if no target n-th wheel driving/braking force Fxcmd_n that satisfies all the conditions (1) to (3) can be determined, then the target n-th wheel driving/braking force Fxcmd_n is determined such that a condition having a higher priority is preferentially satisfied.

[0350] If the determination result in S110 is NO, or after the processing in S112, the processing in S114 is carried out. In this S114, a slip ratio associated with Fxcmd_n determined by the processing in S106 to S112 as described above is determined as the target n-th wheel slip ratio Scmd_n. In this case, by the processing in S104 to S112, Fxcmd_n takes the value of one of Fxcand_n, Fxmmax_n, and FFtotal_n. And, if Fxcmd_n=Fxcand_n, then the n-th wheel slip ratio candidate Scand_n determined in S100 is determined as Scmd_n. If Fxcmd_n=Fxmmax_n, then the n-th wheel slip ratio at the generation of a maximum moment Smmax_n determined in S102 is determined as Scmd_n. If Fxcmd_n=FFtotal_n, then the slip ratio associated with FFtotal_n is determined according to, for example, a map used for the processing in S100, and the determined slip ratio may be determined as Scmd_n. In this case, if there

are two types of values of the slip ratio associated with FF_{total_n} , then a slip ratio value that is closer to zero (a value within the range between a slip ratio value, at which the driving/braking force of the n-th wheel W_n reaches a peak value, and zero) may be determined as $Scmd_n$. If FF_{total_n} deviates from the range of the values of driving/braking forces that can be generated in the n-th wheel W_n in the map, then a slip ratio associated with the value of the driving/braking force that is closest to FF_{total_n} may be determined as $Scmd_n$.

[0351] The above has described in detail the processing by the optimum target n-th driving/braking force determiner 241a_n (n=1, 2, 3, 4).

[0352] In the present embodiment, the target n-th wheel driving/braking force $Fxcmd_n$ has been determined first and then the target n-th wheel slip ratio $Scmd_n$ associated therewith has been determined; reversely, however, the target n-th wheel slip ratio $Scmd_n$ may be determined, and then the target n-th wheel driving/braking force $Fxcmd_n$ associated therewith may be determined. In this case, the target n-th wheel slip ratio $Scmd_n$ may be determined by the same processing as that in S104 to S112 described above on the basis of conditions related to the target n-th wheel slip ratio $Scmd_n$ associated with the aforesaid conditions (1) to (3), and after that, $Fxcmd_n$ associated with the $Scmd_n$ may be determined. In this case, in the relationship between the slip ratios and the

driving/braking forces based on the wheel characteristics relationship of the n-th wheel W_n , $Scmd_n$ is determined within a range between the slip ratio value, at which the driving/braking force reaches a peak value, and zero.

[0353] The processing by the optimum target active steering angle determiner 247 will now be described. Fig. 22 is a functional block diagram illustrating the processing by the optimum target active steering angle determiner 247.

[0354] Referring to the figure, the optimum target active steering angle determiner 247 first determines, by a processor 247a on the basis of $Fyfbcmd_f$, the FB active steering angle δf_fb , which indicates change amounts of the steering angles of the front wheels $W1$ and $W2$ required for the actual vehicle 1 to generate the active steering FB target lateral force $Fyfbcmd_f$ determined by the actuator operation FB target value determiner 20b in the front wheels $W1$ and $W2$ (more specifically, the resultant force of a lateral force of the front wheel $W1$ and a lateral force of the front wheel $W2$ is changed by $Fyfbcmd_f$). In this case, the processor 247a determines the cornering power Kf_1 of the first wheel $W1$ according to a predetermined function expression or a map on the basis of, for example, the actual ground contact load $Fzact_1$ of the first wheel $W1$, and also determines the cornering power Kf_2 of the second wheel $W2$ according to a predetermined function expression or a map on the basis of

the actual ground contact load F_{zact_2} of the second wheel W2. The function expression or map is set in advance on the basis of the tire characteristics of the front wheels W1 and W2 of the actual vehicle 1. Then, the cornering powers Kf_1 and Kf_2 are used to determine the FB active steering angle δf_fb according to the following expression 30.

[0355]

$$\delta f_fb = (1 / (Kf_1 + Kf_2)) \cdot Fyfbdmd_f \quad \dots \text{Expression 30}$$

The FB active steering angle δf_fb determined as shown above corresponds to the correction amount of a front wheel side slip angle required to change the resultant force of the lateral forces of the front wheels W1 and W2 by $Fyfbdmd_f$.

[0356] Normally, changes in the actual ground contact loads F_{zact_1} and F_{zact_2} are small, so that the coefficient $(1 / (Kf_1 + Kf_2))$ by which $Fyfbdmd_f$ is multiplied in expression 30 may be set to a constant value. Further, the cornering power Kf_1 and Kf_2 may be determined on the basis of the actual ground contact loads F_{zact_1} , F_{zact_2} and the estimated friction coefficient μ_{estm} .

[0357] Subsequently, the optimum target active steering angle determiner 247 adds the δf_fb determined as described above to the FF target front wheel steering angle δf_ff by an adder 247b so as to determine the target

front wheel steering angle δf_{cmd} .

[0358] If the active steering FB target lateral force F_{yfbcmd_f} based on the state amount errors γ_{err} and β_{err} is not determined or if $F_{yfbcmd_f}=0$ is always maintained, then δf_{ff} may be directly determined as the target front wheel steering angle δf_{cmd} .

[0359] The above has presented the detailed explanation of the processing by the actuator operation target value synthesizer 24.

[0360]

[About the actuator drive control unit]

The actuator drive control unit 26 operates the actuator devices 3 of the actual vehicle 1 such that the target value determined by the actuator operation target value synthesizer 24 is satisfied. For example, the actuator manipulated variable of the driving system is determined such that the driving/braking force (the driving/braking force in the driving direction) of the first wheel W1 by an operation of the driving system of the driving/braking device 3A becomes the target first wheel driving system driving/braking force, and the driving system is operated on the basis thereof. Further, the actuator manipulated variable of the braking device is determined such that the driving/braking force of the actual road surface reaction force of the first wheel W1 (the sum of the driving/braking force of the first wheel W1 by an operation of the driving system and the

driving/braking force of the first wheel W1 by an operation of the braking device (the driving/braking force in the braking direction)) becomes the target first wheel driving/braking force F_{xcmd_1} , and the braking device is actuated on the basis thereof. Further, in this case, the operation of the driving system or the braking device is adjusted so as to bring a difference between the actual slip ratio of the first wheel W1 and the target first wheel slip ratio S_{cmd_1} close to zero. The same applies to the remaining wheels W2 to W4.

[0361] Further, if the steering device 3B is an actuator-driven steering device, then the actuator manipulated variable of the steering device 3B is determined such that the actual front wheel steering angle δf_{act} agrees with the target front wheel steering angle δf_{cmd} , and the operation of the steering device 3B is controlled on the basis thereof. If the steering device 3B is an actuator-assisted steering device, then the operation of the steering device 3B is controlled such that the actual front wheel steering angle δf_{act} agrees with the sum of the target front wheel steering angle δf_{cmd} and a mechanical steering angle component based on the steering angle θ_h .

[0362] The reduction gear ratio of the speed change gear of the driving system of the driving/braking device 3A is controlled on the basis of the target transmission reduction gear ratio.

[0363] Regarding the control amounts of the driving/braking forces, the lateral forces and the like of the wheels W1 to W4, the operations of the driving/braking device 3A, the steering device 3B, and the suspension device 3C tend to interfere with each other. In such a case, the operations of the driving/braking device 3A, the steering device 3B, and the suspension device 3C are desirably controlled integrally by the processing of decoupling in order to control the control amounts to target values.

[0364]

[Second Embodiment]

The following will describe a second embodiment of the present invention. The present embodiment differs from the aforesaid first embodiment only in the characteristics adjusting matrix K for adjusting the transient response characteristic of a model vehicle. Hence, the explanation will be focused mainly on the different aspect, and the explanation of the same construction and the same processing as those in the first embodiment will be omitted.

[0365] The aforesaid first embodiment has shown an example wherein k_2 out of the model characteristics adjusting parameters k_1 and k_2 , which are the diagonal components of the characteristic adjusting matrix K of the expression 01, has been variably set according to the traveling velocity V_{act} ($=V_d$) and k_1 has been fixed to "1"

in order to enhance the attenuation properties of the state amounts γ_d and β_d of the model vehicle based on stepped changes in the steering angle θ_h .

[0366] In contrast to this, according to the present embodiment, the value of k_2 out of the model characteristics adjusting parameters k_1 and k_2 is fixed to "1." Further, the value of k_1 is variably set according to the traveling velocity V_{act} in the processing by the reference dynamic characteristic model 16 in order to enhance the attenuation properties of the state amounts β_d and γ_d of the model vehicle based on stepped changes in the steering angle θ_h .

[0367] Specifically, the value of the model characteristics adjusting parameter k_1 is variably set according to the traveling velocity V_{act} in the same manner as that for setting the value of k_2 in, for example, the aforesaid first embodiment. More specifically, in a situation wherein $V_{act} \leq V_{d_critical}$ holds, k_1 is set to 1. Further, in a situation wherein $V_{act} > V_{d_critical}$ holds, the value of k_1 is set according to V_{act} such that the response characteristics of the state amounts β_d and γ_d of the model vehicle based on stepped changes in the steering angle θ_h become the critical braking characteristics. In this case, the value of k_1 when $V_{act} > V_{d_critical}$ is the value of k that satisfies expression 105 given below.

[0368]

$$(k_1 \cdot a_{11} + a_{22})^2 - 4 \cdot k_1 \cdot (a_{11} \cdot a_{22} + a_{12} \cdot a_{21}) = 0 \quad \dots \text{Expression 105}$$

The value of k_1 set as described above is set to a value that is larger than "1" in a situation wherein $V_{act} > V_{d_critical}$ holds. At this time, the value of k_1 monotonously increases as V_{act} rises.

[0369] Thus, variably setting the value of the model characteristics adjusting parameter k_1 on the basis of the traveling velocity V_{act} makes it possible to turn the transient response characteristics of the state amounts β_d and γ_d of the model vehicle based on stepped changes in the steering angle θ_h into non-oscillatory characteristics while maintaining the steady-state characteristics of the model vehicle at characteristics that approximate the steady-state characteristics of the actual vehicle 1, as with the first embodiment.

[0370] The construction and processing other than those described above are the same as those in the first embodiment.

[0371] Supplementally, the value of k_1 in the case where $V_{act} > V_{d_critical}$ holds may be set to a value which is slightly larger than the value of k_1 which causes the response characteristics of the state amounts β_d and γ_d of the model vehicle represented by expression 01 to turn into the critical braking characteristic. In other words, the value of k_1 may be set such that the response characteristics of the state amounts β_d and γ_d of the model vehicle turn into the over-braking characteristics.

Further, in the case where the traveling velocity V_{act} is extremely slow (a traveling velocity of not more than a predetermined value which is smaller than the critical braking velocity $V_{d_critical}$), the value of k_1 may be set to be smaller than "1" within the range wherein the responsiveness of the model vehicle does not turn into an oscillatory characteristic.

[0372]

[Third Embodiment]

A third embodiment of the present invention will now be described. The present embodiment differs from the aforesaid first embodiment or the second embodiment only in the characteristics adjusting matrix K for adjusting the transient response characteristic of a model vehicle. Hence, the explanation will be focused mainly on the different aspect, and the explanation of the same construction and the same processing as those in the first embodiment or the second embodiment will be omitted.

[0373] In the first embodiment and the second embodiment, only one of the model characteristics adjusting parameters k_1 and k_2 of the characteristics adjusting matrix K of the aforesaid expression 01 has been variably set in order to enhance the attenuation properties of the state amounts β_d and γ_d of the model vehicle based on stepped changes in the steering angle θ_h . In this case, if the traveling velocity $V_{act}(=V_d)$ is higher than the critical braking velocity $V_{d_critical}$, then the absolute value of a

solution (eigenvalue) of the characteristics equation $\det(\lambda \cdot I - K \cdot A) = 0$ of the model vehicle tends to become excessively large. Consequently, the responsiveness (velocity responsiveness) of the state amounts y_d and β_d of the model vehicle to stepped changes in the steering angle θ_h tends to become higher than that of the actual vehicle 1. For example, the absolute value of a solution (eigenvalue) of the characteristics equation of the model vehicle in the aforesaid first embodiment changes according to the traveling velocity V_{act} , as illustrated by the dashed-line graph of Fig. 23. As illustrated in the figure, in a high-velocity area wherein the traveling velocity V_{act} is higher than a predetermined velocity $V_x (> V_{d_critical})$, the absolute value of a solution (eigenvalue) of the characteristics equation of the model vehicle increases as the traveling velocity V_{act} rises.

[0374] Hence, especially in a case where the gains of the virtual external forces F_{vir} and M_{vir} (model operation control inputs) relative to the state amount errors β_{err} and y_{err} have been set to be small values, the state amount errors β_{err} and y_{err} sometimes become relatively large in a transient period when the actual vehicle 1 is traveling at a high velocity. And, in such a case, there is a danger in which the manipulated variable of an actuator based on the feedback control by the actuator devices 3 (the driving/braking device 3A and the steering device 3B) on the basis of the state amount errors β_{err}

and γ_{err} becomes excessive.

[0375] According to the third embodiment, therefore, both model characteristics adjusting parameters k_1 and k_2 of the characteristics adjusting matrix K of expression 01 are variably set. This arrangement prevents the solution of the characteristics equation $\det(\lambda \cdot I - K \cdot A) = 0$ of the model vehicle, i.e., the absolute value of the eigenvalue of the model vehicle, from becoming excessive while enhancing the attenuation properties of the state amounts β_d and γ_d of the model vehicle.

[0376] Specifically, according to the present embodiment, the values of both model characteristics adjusting parameters k_1 and k_2 are variably set according to the traveling velocity V_{act} . In this case, the values of k_1 and k_2 are set such that the response characteristics of the state amounts γ_d and β_d of the model vehicle represented by expression 01 will not be oscillatory (such that the response characteristics will be the critical braking or over-braking characteristics) and the absolute value of the solution of the characteristics equation of the model vehicle will remain at a predetermined value or less. The sets of values of k_1 and k_2 that may satisfy such a condition are, for example, mapped beforehand on the basis of the traveling velocity V_{act} . Then, the processing by the reference dynamic characteristic model 16 at each control processing cycle sets the values of k_1 and k_2 from the value of the traveling velocity V_{act} (the

current time value) according to the map.

[0377] Figs. 24(a) and (b) are graphs illustrating the setting examples of the values of k_1 and k_2 , respectively, based on the actual traveling velocity V_{act} in the present embodiment.

[0378] In this example, the values of k_1 and k_2 in a situation wherein $V_{act} \leq V_{d_critical}$ applies are both set to "1." Further, in a situation wherein $V_{act} > V_{d_critical}$ holds, the value of k_2 is set such that it monotonously increases as V_{act} increases as approximately with the aforesaid first embodiment, as illustrated in Fig. 24(b). Meanwhile, the value of k_1 is maintained at "1" until V_{act} rises to the aforesaid predetermined velocity V_x , as shown in Fig. 24(a). Then, when V_{act} becomes larger than V_x , i.e., $V_{act} > V_x$, the value of k_1 is set such that it monotonously decreases as V_{act} rises. In this case, in the example illustrated in Fig. 24, in a situation wherein $V_{act} > V_x$ holds, the value of k_1 is set such that the absolute value of the solution (eigenvalue) of the characteristics equation $\det(\lambda \cdot I - K \cdot A) = 0$ of the model vehicle is equal to the absolute value of the solution of the characteristics equation when $V_{act} = V_x$ and the response characteristic of the state amounts γ_d and β_d of the model vehicle becomes the critical braking characteristic.

[0379] By setting the values of k_1 and k_2 as described above, the absolute value of the solution (eigenvalue) of the characteristics equation of the model vehicle becomes

a value which is not more than the absolute value of the solution of the characteristics equation when $V_{act}=V_x$ at any traveling velocity V_{act} at which $V_{act}>V_x$ holds. In the present embodiment, as illustrated by the solid-line graph of Fig. 23, the absolute value of the solution (eigenvalue) of the characteristics equation of the model vehicle is maintained at a value that is equal to the absolute value of the solution of the characteristics equation when $V_{act}=V_x$ at any traveling velocity V_{act} at which $V_{act}>V_x$ holds.

[0380] Supplementally, in the case where the values of all diagonal components k_1 and k_2 of the characteristics adjusting matrix K are variably set, as in the present embodiment, the value of the solution of the characteristics equation of the model vehicle can be arbitrarily set.

[0381] According to the present embodiment, variably setting the values of both model characteristics adjusting parameters k_1 and k_2 on the basis of the traveling velocity V_{act} makes it possible to prevent the response characteristics of the state amounts β_d and γ_d of the model vehicle from becoming oscillatory characteristics and also prevent the absolute value of the solution of the characteristics equation of the model vehicle and the consequent responsiveness (velocity responsiveness) of the state amounts β_d and γ_d of the model vehicle relative to changes in the steering angle θ_h from becoming excessive.

Incidentally, the characteristics adjusting matrix K does not influence the steady-state characteristics of the model vehicle. Hence, the steady-state characteristics of the model vehicle can be maintained at characteristics that approximate the steady-state characteristics of the actual vehicle 1, independently of changes in the values of the model characteristics adjusting parameters k1 and k2, as with the first embodiment and the second embodiment.

[0382]

In the embodiments described above, the description has been given by taking, as an example, the case where the dynamic characteristic model of the second-order system is used; however, the present invention can be applied to the case where a dynamic characteristic model of the third order or more is used.

[0383] For instance, as the reference dynamic characteristic model, a model that takes into account the response delay of a change in a lateral force relative to a change in the side slip angle of a wheel may be used.

[0384] In this case, the dynamic characteristics of the reference dynamic characteristic model are represented by, for example, expression 110 given below.

[0385] [Mathematical Expression 9]

$$\frac{d}{dt} \begin{bmatrix} \beta_d \\ \gamma_d \\ F_{fy_d} \\ F_{ry_d} \end{bmatrix} = K_{4a} \cdot \left(A_{4a} \cdot \begin{bmatrix} \beta_d \\ \gamma_d \\ F_{fy_d} \\ F_{ry_d} \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ -k_{yf} \cdot V_d \\ 0 \end{bmatrix} \cdot \delta f_d + \begin{bmatrix} 0 \\ 0 \\ F_{vir1} \\ F_{vir2} \end{bmatrix} \right)$$

..... Expression 110

where

$$K_{4a} = \begin{bmatrix} k_1 & 0 & 0 & 0 \\ 0 & k_2 & 0 & 0 \\ 0 & 0 & k_3 & 0 \\ 0 & 0 & 0 & k_4 \end{bmatrix}$$

$$A_{4a} = \begin{bmatrix} 0 & -1 & 2/(m \cdot V_d) & 2/(m \cdot V_d) \\ 0 & 0 & 2 \cdot L_f / I & -2 \cdot L_f / I \\ k_{yf} \cdot V_d & k_{yf} \cdot L_f & -k_{yf} \cdot V_d / K_f & 0 \\ k_{yr} \cdot V_d & k_{yr} \cdot L_r & 0 & -k_{yr} \cdot V_d / K_r \end{bmatrix}$$

[0386] k_{yf} and k_{yr} in the note of expression 110 denote the lateral rigidity of a front wheel and the lateral rigidity of a rear wheel, respectively. The meanings of m , L_f , L_r , and I are the same as those of the aforesaid expression 01. Further, F_{fy_d} and F_{ry_d} denote the lateral force per wheel of the front wheels and the lateral force per wheel of the rear wheels, respectively. Further, F_{vir1} and F_{vir2} denote the virtual external forces (virtual translational forces) additionally applied to the model vehicle as the model manipulated variable control inputs to approximate the differences in state amount (the difference in yaw rate and the difference in vehicle center-of-gravity point side slip angle) between the actual vehicle 1 and the model vehicle of expression

110 to zero. F_{vir1} and F_{vir2} mean virtual lateral translational forces to be applied to the model vehicle at a front wheel position and a rear wheel position, respectively.

[0387] Further, K_{4a} in expression 110 denotes a diagonal matrix for adjusting the dynamic characteristics of the reference dynamic characteristic model, as with the characteristics adjusting matrix K in the aforesaid expression 01. Variably setting the value of one or more diagonal components among the diagonal components k_1 , k_2 , k_3 , and k_4 of the characteristics adjusting matrix K_{4a} in expression 110 to a value other than zero makes it possible to enhance the attenuation properties of the state amounts β_d and γ_d relative to stepped changes in the steering angle θ_h (stepped changes in the front wheel steering angle δf_d) to be higher than the attenuation property of the actual vehicle 1 while at the same time maintaining the steady-state characteristics of the model of expression 110 constant.

[0388] Further, as the reference dynamic characteristic model, a model which has interference between a motion about the roll axis of a vehicle and a motion about the yaw axis may be used. Such a model is represented in a form of the following expression 111 obtained by, for example, adding a virtual external force for operating a model (a model operation control input) and a characteristics adjusting parameter to expressions (6.29)',

(6.30)' and (6.31)' of the aforesaid non-patent document 1.
[0389]

$$\begin{aligned} \frac{d}{dt}(\beta_d, \gamma_d, \phi_d, \phi_d')^T = & K_{4b} \cdot (A_{4b} \cdot (\beta_d, \gamma_d, \phi_d, \phi_d')^T \\ & + B \cdot \delta f_d + B_{vir} \cdot (F_{yvir}, M_{zvir}, M_{xvir})^T) \\ & \dots\dots \text{Expression 111} \end{aligned}$$

where ϕ_d in expression 111 denotes the roll angle of a vehicle body 1B (the angle of inclination about the roll axis), ϕ_d' denotes a differential value of ϕ_d (the angular velocity of a roll angle), A_{4b} denotes a square matrix of 4 rows and 4 columns, B denotes a matrix of 4 rows and 1 column, and B_{vir} denotes a matrix of 4 rows and 3 columns. Further, F_{yvir} , M_{zvir} , and M_{xvir} are virtual external forces as the model operation control inputs for bringing state amount errors (e.g., a vehicle center-of-gravity point side slip angle error, a yaw rate error, and an error of a roll angle or an angular velocity thereof) close to zero. In this case, F_{yvir} denotes a lateral virtual translational force, M_{zvir} denotes a virtual moment about the yaw axis, and M_{xvir} denotes a virtual moment about the roll axis. These virtual external forces F_{yvir} , M_{zvir} , and M_{xvir} are determined on the basis of the state amount errors.

[0390] Further, K_{4b} of expression 111 denotes a diagonal matrix (a diagonal matrix of 4 rows and 4 columns) for adjusting the dynamic characteristics of the reference dynamic characteristic model, as with the characteristics

adjusting matrix K of expression 01 described above. By defining one or more diagonal components among the four diagonal components of the characteristics adjusting matrix K_{4b} of expression 111 as the parameter or parameters for adjusting the response characteristic of the model of expression 111, and by variably setting the value or values thereof to a non-zero value or values, it is possible to enhance the attenuation properties of the state amounts β_d and γ_d relative to stepped changes in the steering angle θ_h (stepped changes in the front wheel steering angle δf_d) to be higher than the attenuation property of the actual vehicle 1 while maintaining the steady-state characteristics of the model of expression 111 constant.

[0391] Further, the first to the third embodiments described above have shown the examples wherein the state amount related to a side slip of the vehicle and the state amount related to a rotation about the yaw axis have been used as the state amounts to be controlled; however, the state amounts related to other motions of the vehicle may be used. For example, the state amount related to a rotative motion about the roll axis (e.g., a roll angle and an angular velocity thereof) may be used. In this case, the attenuation property of the roll angle or the angular velocity thereof may be enhanced in the case where the traveling velocity of the vehicle is relatively high.

[0392] Further, the aforesaid first to third embodiments

have presented the description, taking the four-wheeled vehicle as an example; however, the present invention can be applied also to a vehicle, such as a two-wheeled motor vehicle.

Industrial Applicability

[0393] As explained above, the present invention is useful in that the invention permits the provision of a vehicle, such as an automobile, which is capable of turning the response characteristic of a vehicle relative to a change in a drive manipulated variable, such as a steering angle, into a characteristic with a high attenuation property, independently of a motional state of the vehicle, and which exhibits excellent behavior characteristics.

Brief Description of the Drawings

[0394]

[Fig. 1] is a block diagram illustrating a schematic construction of a vehicle in an embodiment of the present invention.

[Fig. 2] is a functional block diagram schematically illustrating a general control processing function of a controller provided in a vehicle in a first embodiment of the present invention.

[Fig. 3] is a diagram illustrating the structure of a vehicle on a reference dynamic characteristic model (vehicle model) in the first embodiment.

Fig. 4(a) is a graph illustrating the response

characteristic of a yaw rate in each of an actual vehicle and a vehicle model, and Fig. 4(b) is a graph illustrating the response characteristic of a vehicle center-of-gravity point side slip angle in each of the actual vehicle and the vehicle model.

[Fig. 5] is a graph illustrating a setting example of a model characteristics adjusting parameter k_2 in the first embodiment.

[Fig. 6] is a functional block diagram illustrating the details of a processing function of a reference manipulated variable determiner in the first embodiment.

[Fig. 7] is a graph for describing the processing by a limiter for preventing excessive centrifugal forces, which is provided in the reference manipulated variable determiner in the first embodiment.

[Fig. 8] is a graph for describing another example of the processing by the limiter for preventing excessive centrifugal forces in the first embodiment.

[Fig. 9] is a graph for describing still another example of the processing by the limiter for preventing excessive centrifugal forces in the first embodiment.

[Fig. 10] is a functional block diagram illustrating another example of processing for determining a second limited front wheel steering angle δf_ltd2 in the reference manipulated variable determiner in the first embodiment.

[Fig. 11] is a functional block diagram illustrating the processing function of an FB distribution law in the first embodiment.

[Fig. 12] is a functional block diagram illustrating another example of the processing by a virtual external force determiner in the first embodiment.

[Fig. 13] is a graph for describing another example of the processing by an $\gamma\beta$ limiter in the first embodiment.

[Fig. 14] is a functional block diagram illustrating the processing by an actuator operation FB target value determiner in the first embodiment.

[Fig. 15] is a diagram for describing a variable used in the processing by the actuator operation FB target value determiner in the first embodiment.

Figs. 16(a) and (b) are graphs illustrating distribution gain setting examples used in the processing by the actuator operation FB target value determiner in the first embodiment.

Figs. 17(a) to (e) are diagrams illustrating the maps used with another example of the processing by the actuator operation FB target value determiner in the first embodiment.

Figs. 18(a) to (e) are diagrams illustrating the maps used with still another example of the processing by the actuator operation FB target value determiner in the first embodiment.

[Fig. 19] is a functional block diagram illustrating the processing by an FF law in the first embodiment.

[Fig. 20] is a functional block diagram illustrating the processing by an actuator operation target value synthesizer in the first embodiment.

[Fig. 21] is a flowchart illustrating the processing by an optimum target n-th wheel driving/braking force determiner provided in the actuator operation target value synthesizer in the first embodiment.

[Fig. 22] is a functional block diagram illustrating the processing by an optimum target active steering angle determiner provided in the actuator operation target value synthesizer in the first embodiment.

[Fig. 23] is a graph illustrating the relationship between the eigenvalues of a model vehicle and the traveling velocities of a vehicle in a third embodiment.

Fig. 24(a) and (b) are a graph illustrating setting examples of model characteristics adjusting parameters k_1 and k_2 in the third embodiment.

CLAIMS

1. A vehicle control device equipped with a drive manipulated variable detecting means which detects a drive manipulated variable that indicates a state of drive manipulation of a vehicle by a driver of the vehicle having a plurality of wheels, an actuator device provided in the vehicle so as to permit the manipulation of a predetermined motion of the vehicle, an actual state amount grasping means which detects or estimates an actual state amount vector, which is a set of the values of a plurality of types of state amounts related to a predetermined motion of an actual vehicle, a model state amount determining means which determines a model state amount vector, which is a set of the values of a plurality of types of state amounts of a vehicle on a vehicle model established beforehand as a model representing the dynamic characteristic of the vehicle, and a state amount error calculating means which calculates a state amount error, which is the difference between the value of each type of state amount of the detected or estimated actual state amount vector and the value of a state amount of each type of the determined model state amount vector, to control the operation of at least the actuator device such that the state amount error approximates zero, the vehicle control device comprising:

a state amount error response control means which determines an actual vehicle actuator operation control input for operating the actuator device of the actual vehicle and a vehicle model operation control input for manipulating a motion of the vehicle on the vehicle model

on the basis of at least the calculated state amount error such that the state amount error approximates zero;

an actuator device control means which controls the operation of the actuator device on the basis of at least the determined actual vehicle actuator operation control input;

the model state amount determining means being a means which determines the model state amount vector on the basis of at least the detected drive manipulated variable and the determined vehicle model operation control input; and

a vehicle model characteristics setting means which variably sets the value of at least one parameter of the vehicle model on the basis of a motional state of the actual vehicle such that an attenuation property of the value of each type of state amount of the model state amount vector based on a stepped change in the drive manipulated variable in a state wherein the vehicle model operation control input is maintained at zero turns into a high attenuation characteristic which is a characteristic higher than an attenuation property of the value of each type of state amount of the actual state amount vector based on a stepped change in the drive manipulated variable in a state wherein the actual vehicle actuator operation control input is maintained at zero.

2. The vehicle control device according to Claim 1, wherein the high attenuation characteristic is a critical-braking or over-braking response characteristic.

3. The vehicle control device according to Claim 1, wherein the plurality of types of state amounts includes two or more types of state amounts related to a side slip and a rotation about a yaw axis of the vehicle, and the vehicle model characteristics setting means variably sets the value of a parameter of the vehicle model according to the traveling velocity of the actual vehicle.

4. The vehicle control device according to Claim 3, wherein the vehicle model characteristics setting means variably sets the value of a parameter of the vehicle model according to the traveling velocity such that the absolute value of the eigenvalue of the vehicle model becomes a predetermined value or less at least when the traveling velocity is higher than a predetermined velocity.

5. The vehicle control device according to Claim 1, wherein the vehicle model characteristics setting means variably sets the value of a parameter of the vehicle model such that the relationship between the steady-state value of the drive manipulated variable when the manipulated variable of drive manipulation is changed in steps in a state wherein the vehicle model operation control input is maintained at zero and the steady-state value of each type of state amount of the model state amount vector is maintained to be constant even if the value of a parameter of the vehicle model is variably set.

FIG.1

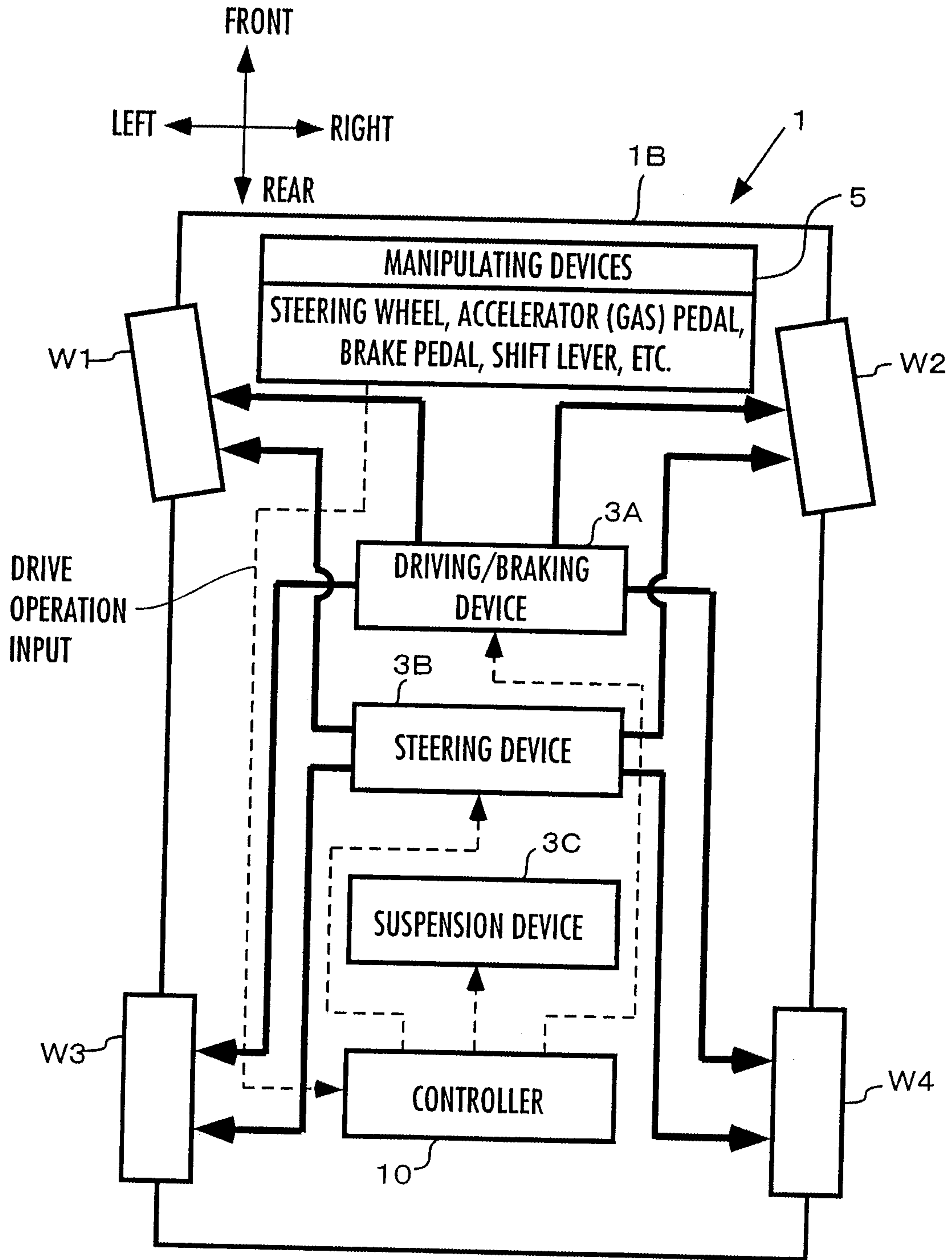


FIG.2

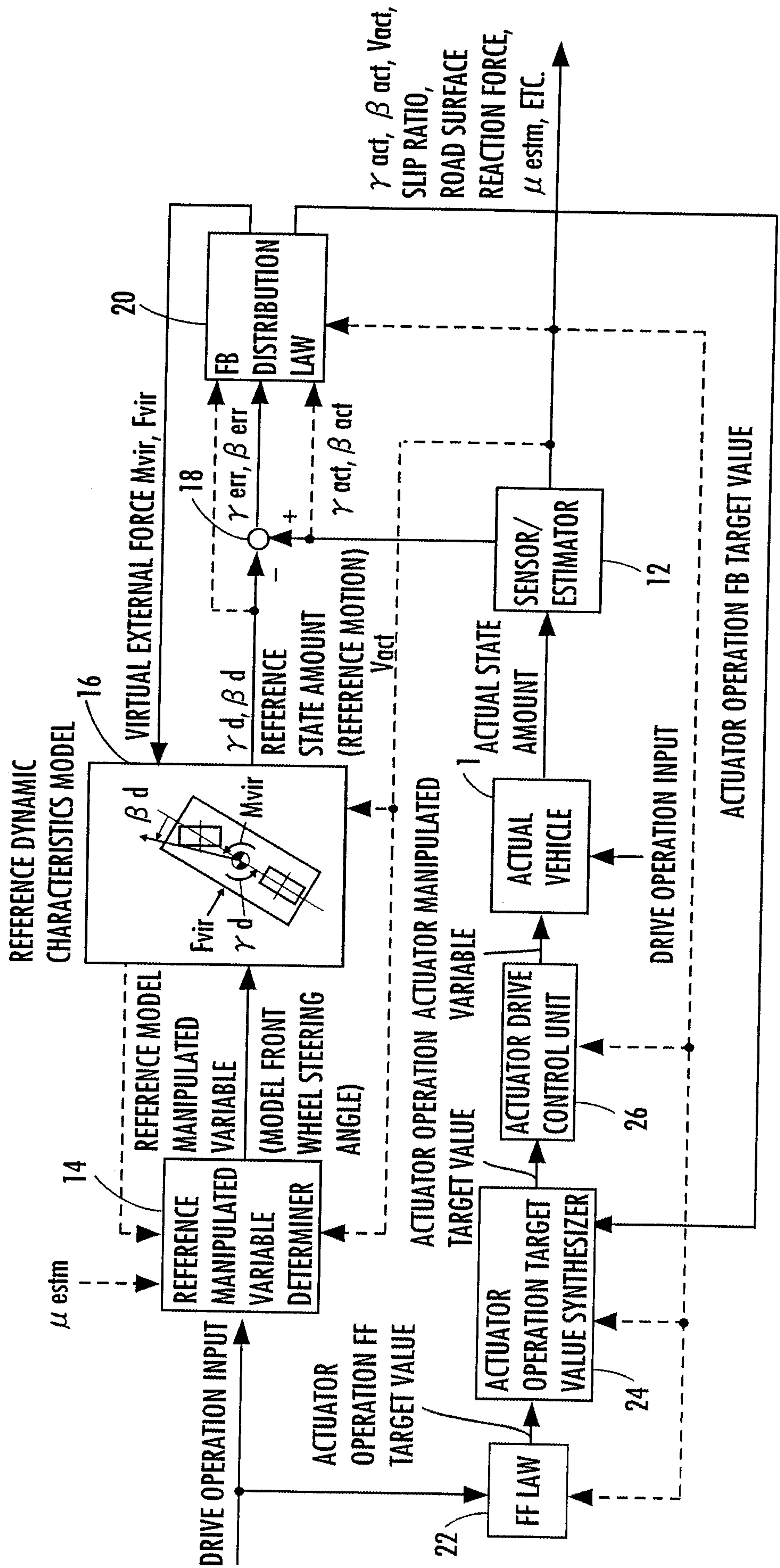


FIG.3

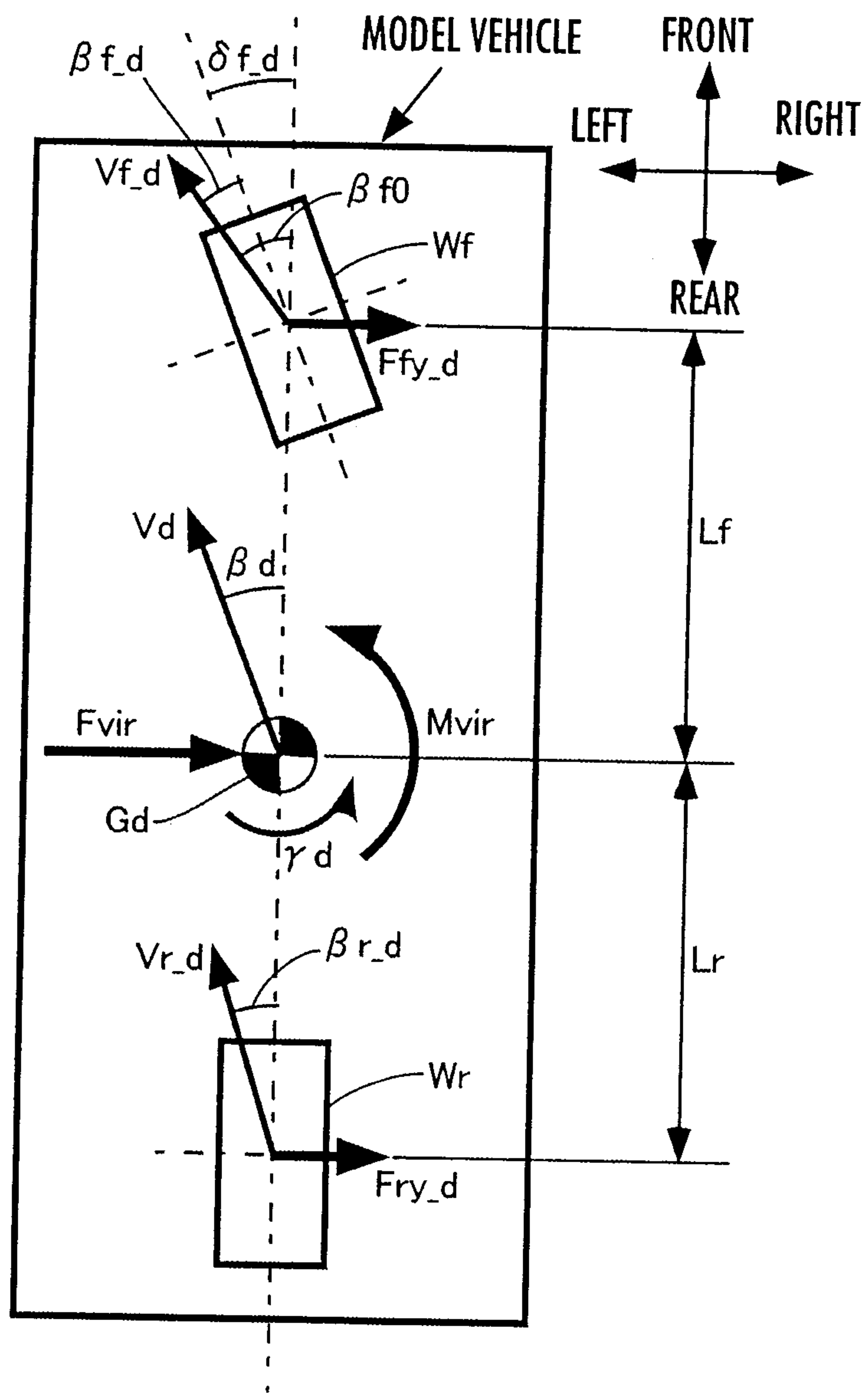


FIG.4(a)

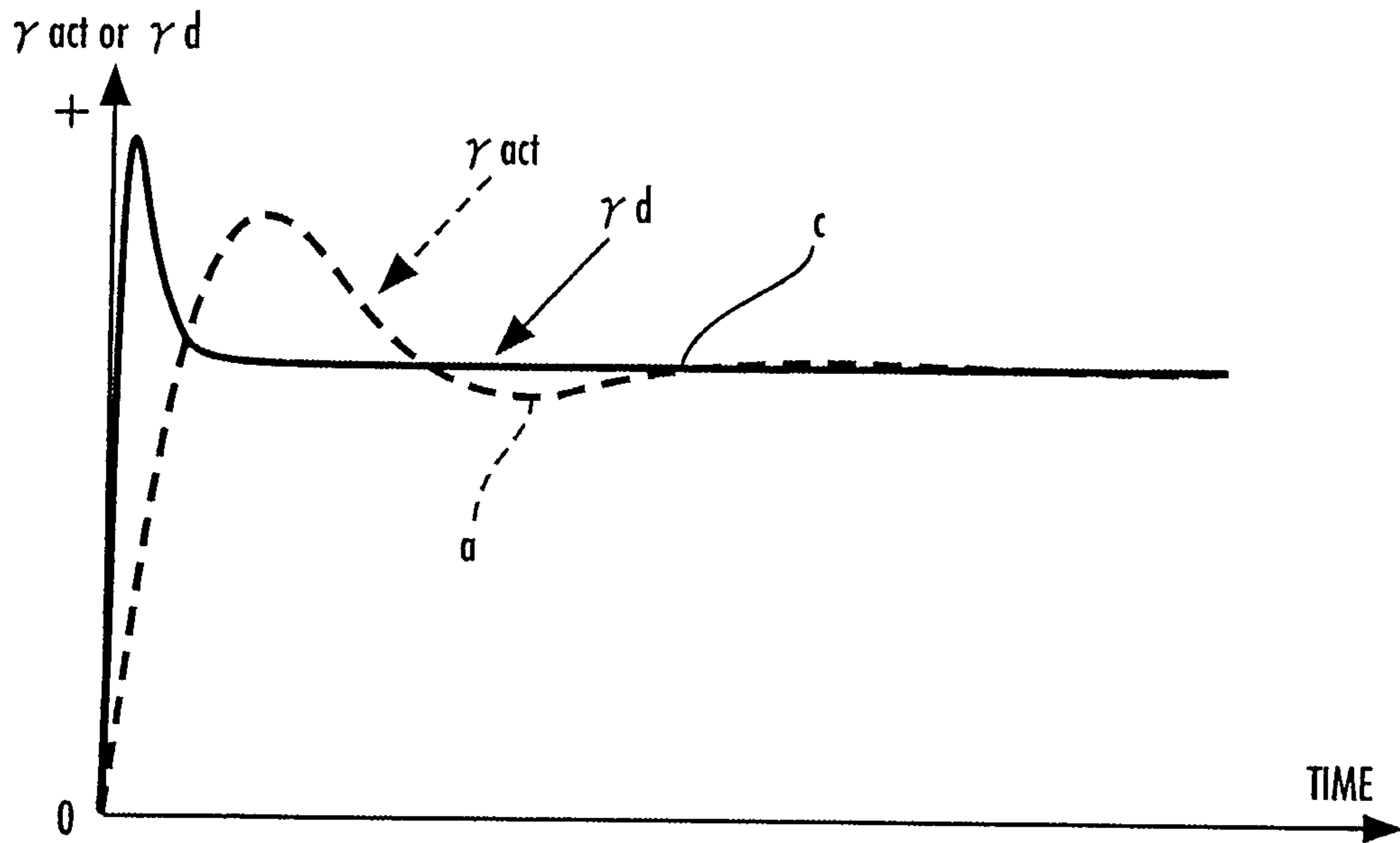


FIG.4(b)

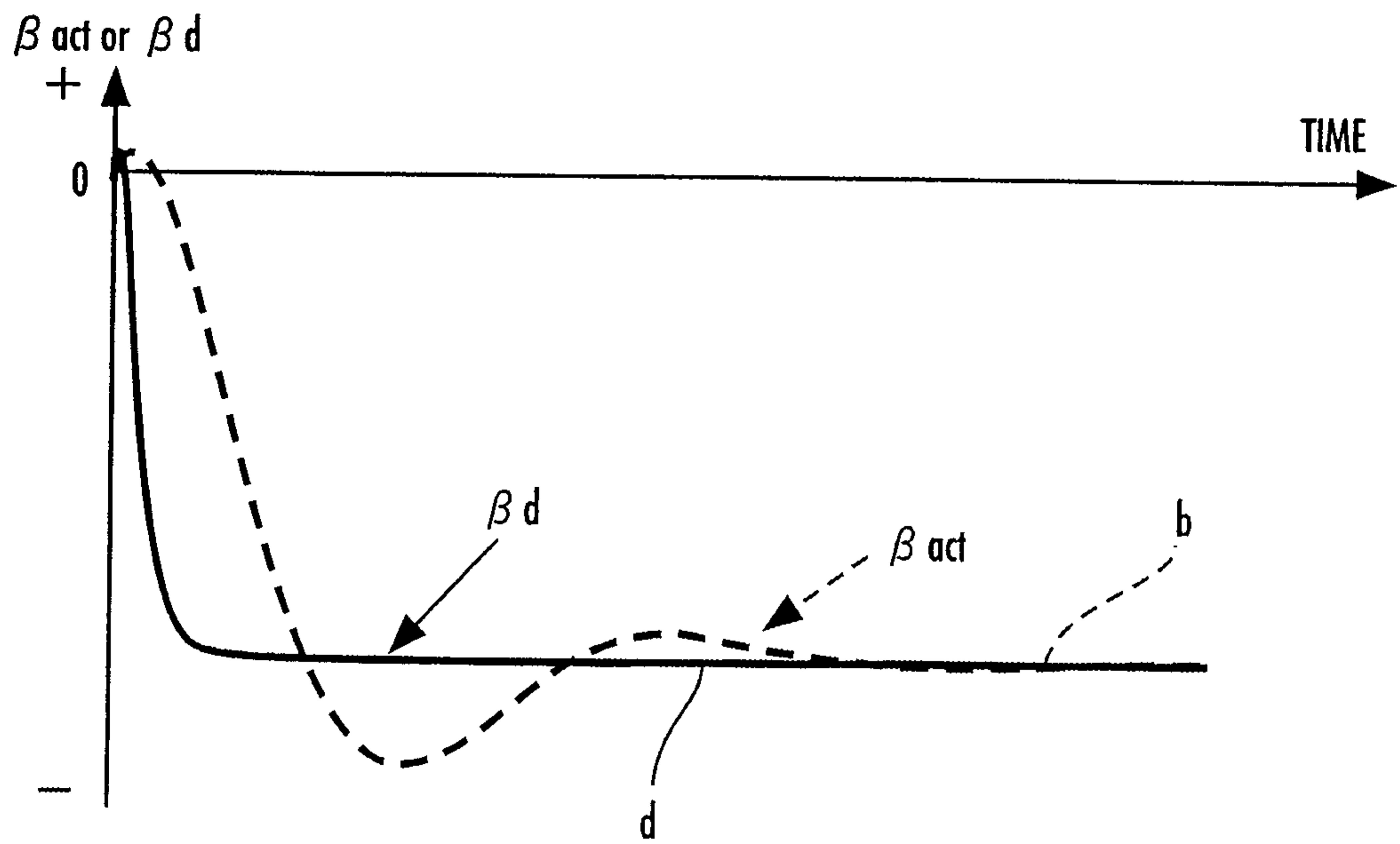


FIG.5

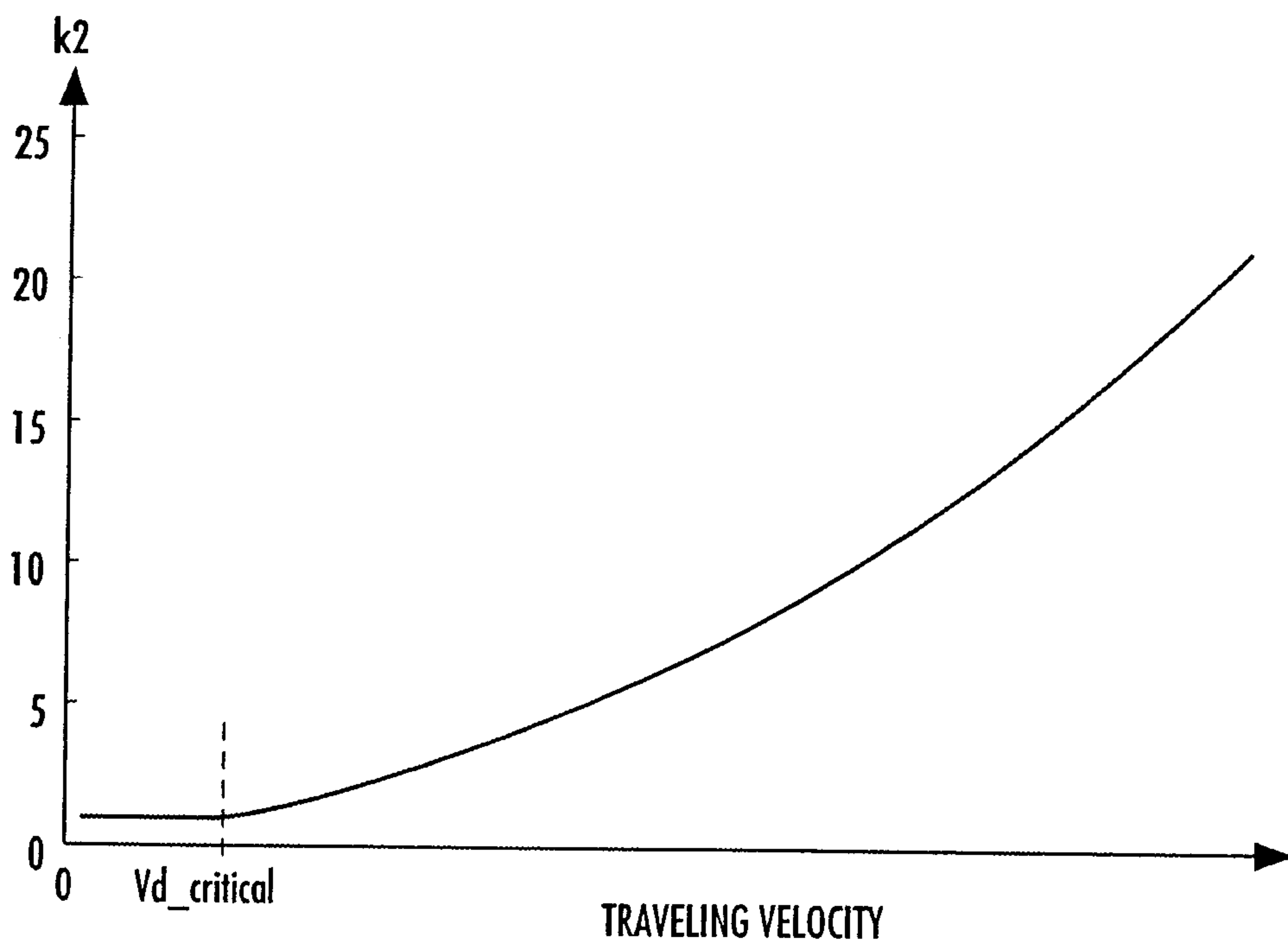


FIG.6

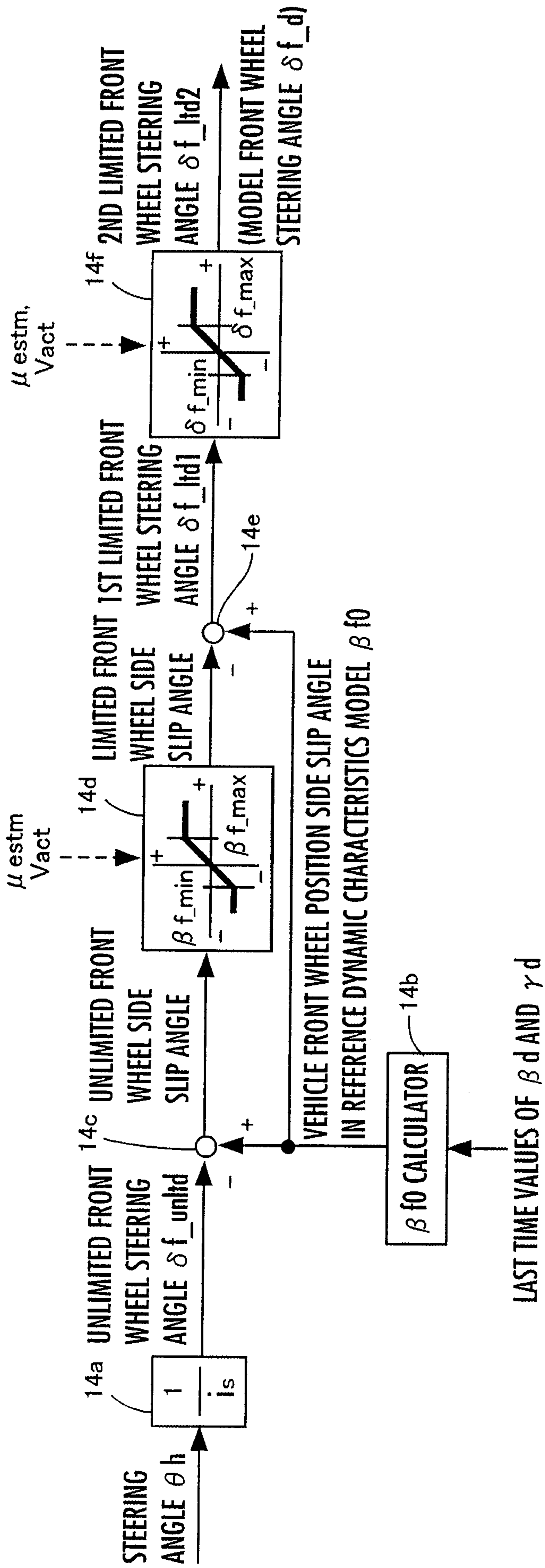


FIG.7(a)

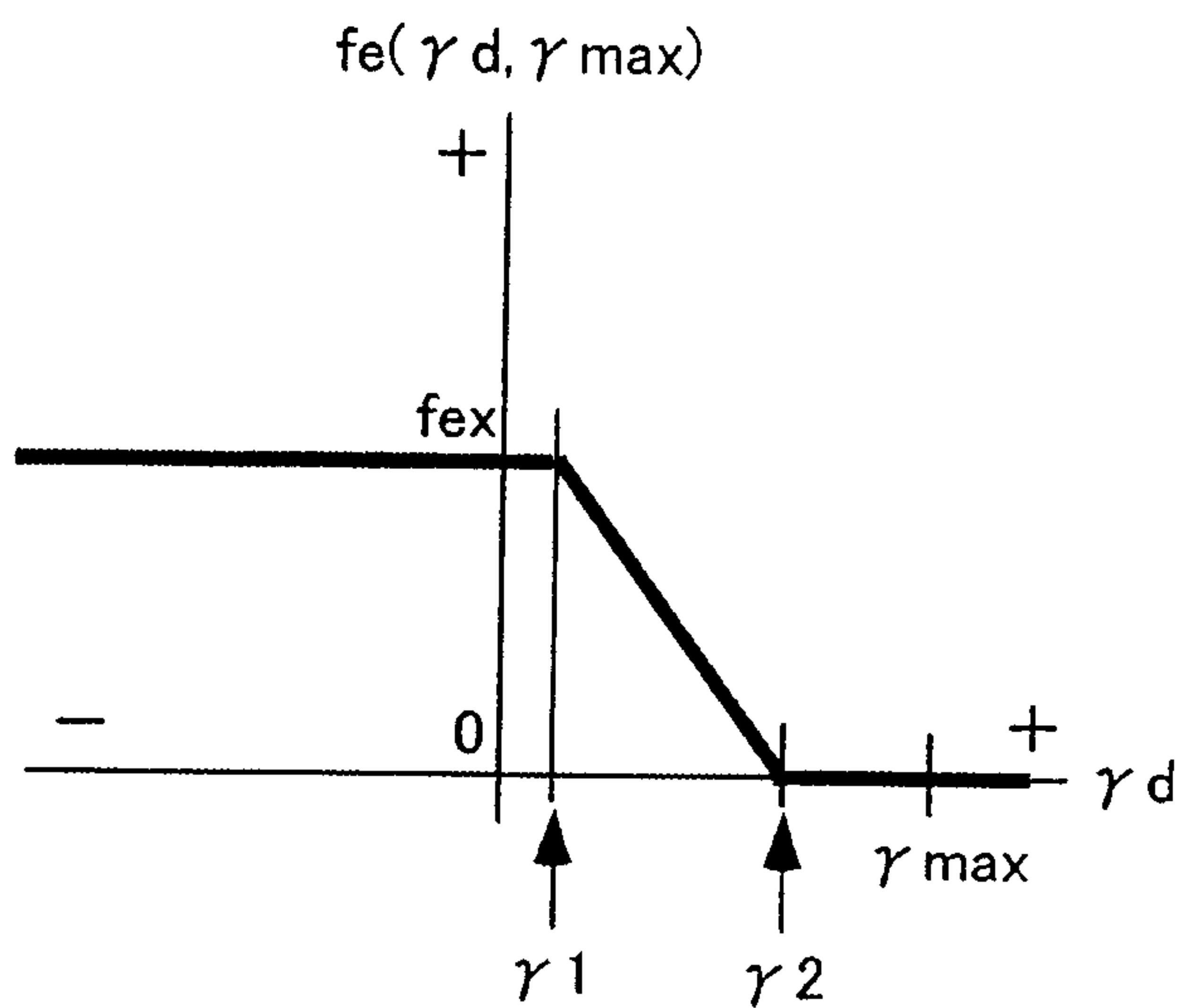


FIG.7(b)

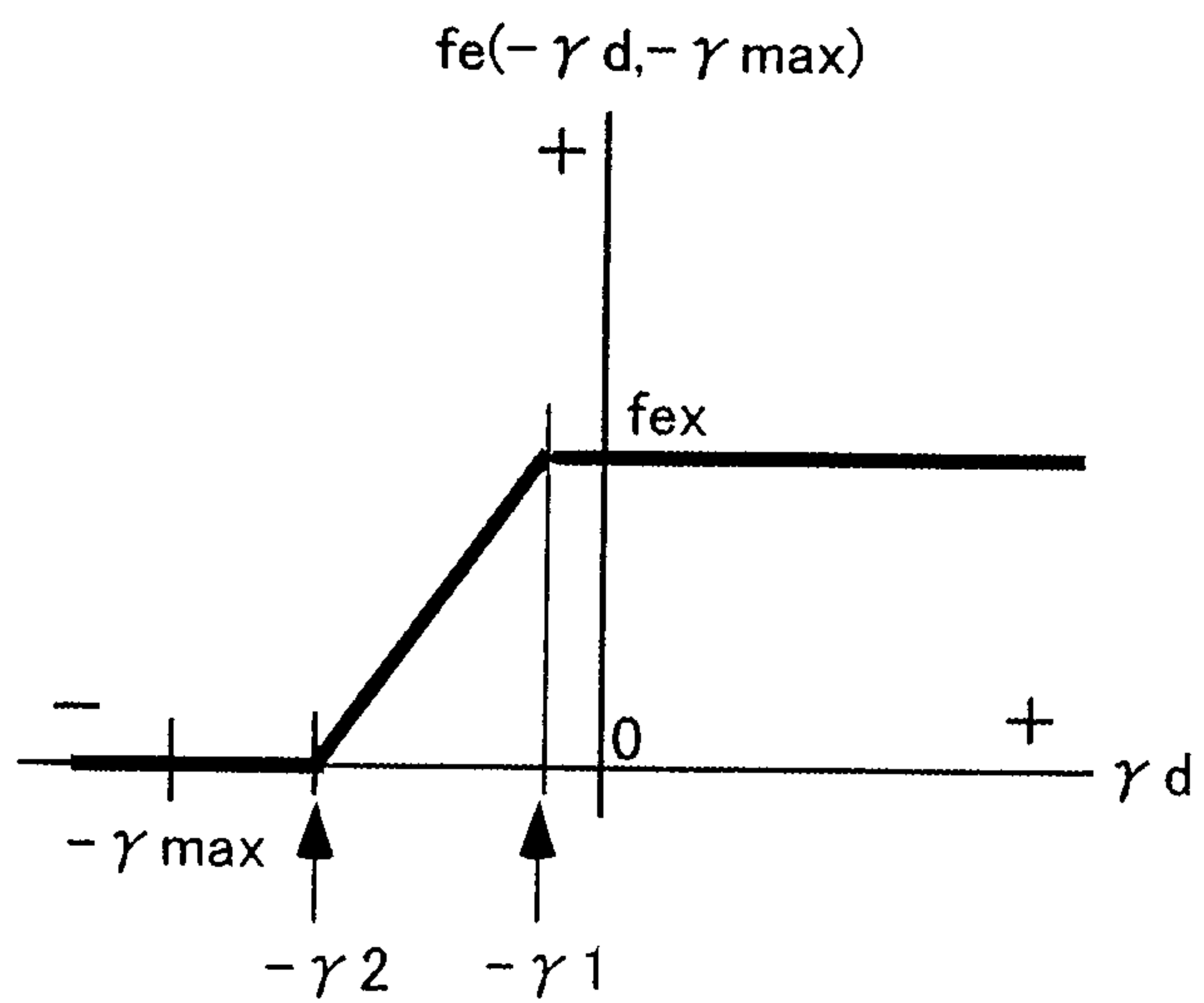


FIG.8

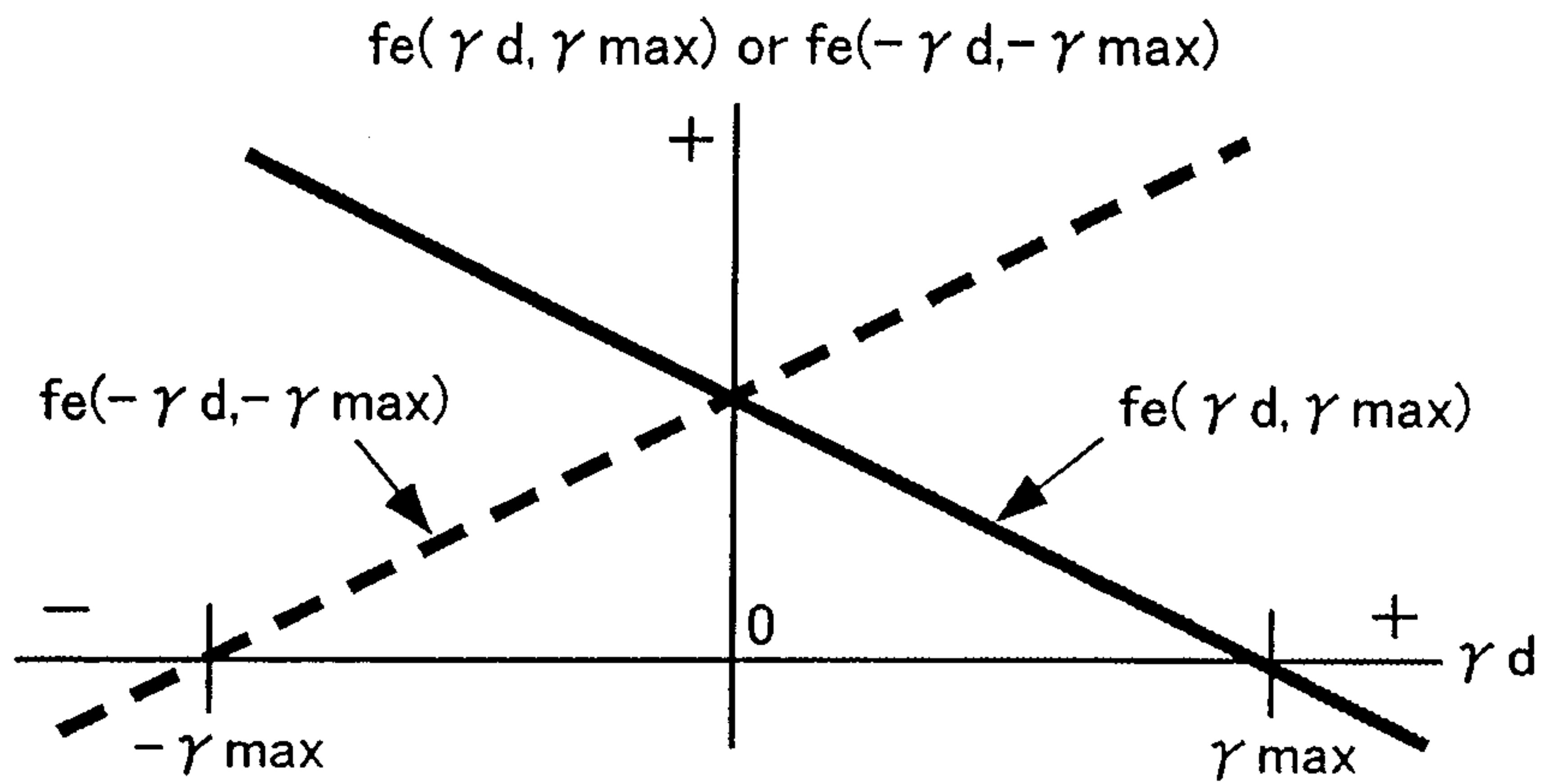


FIG.9

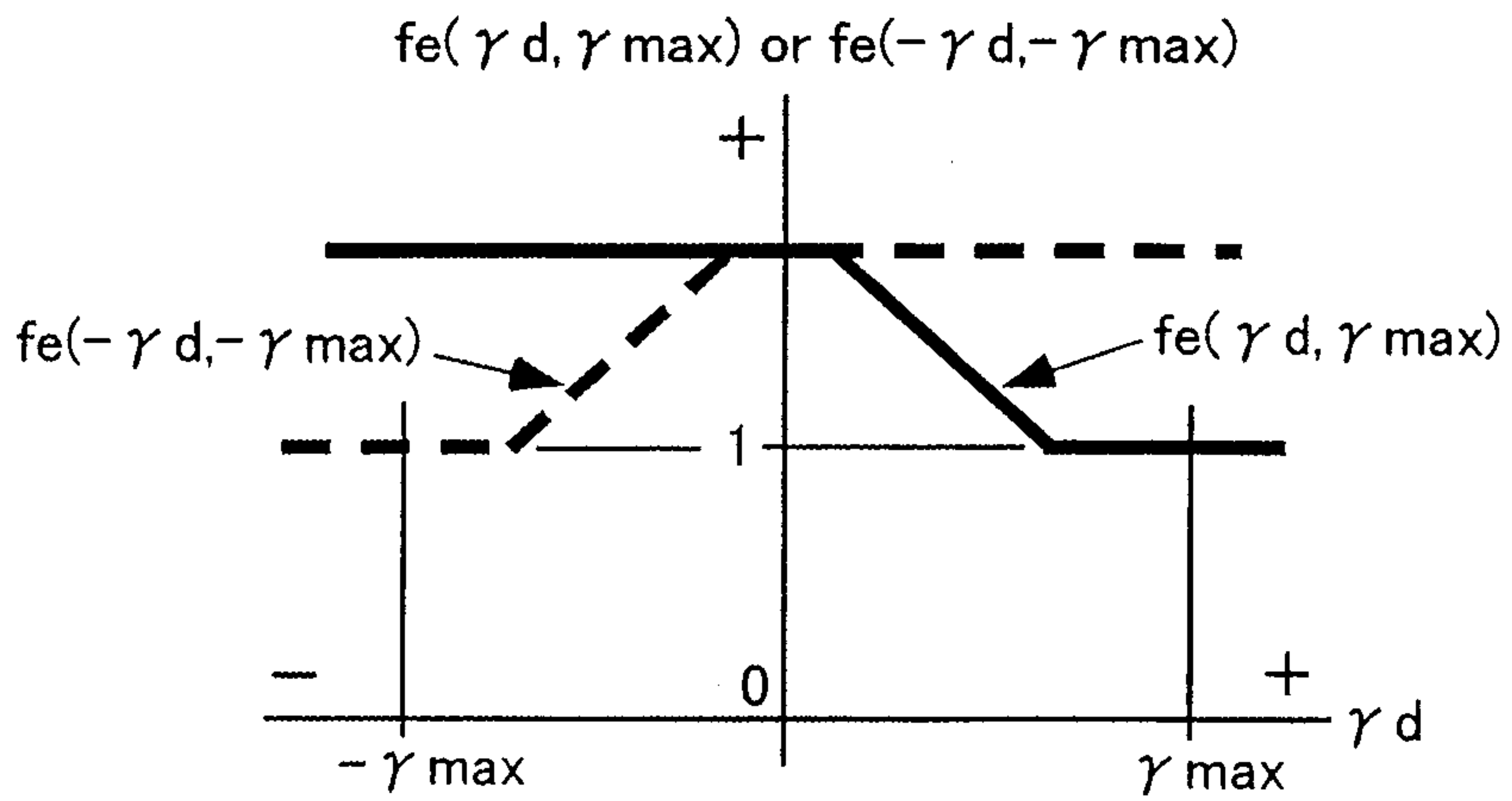


FIG.10

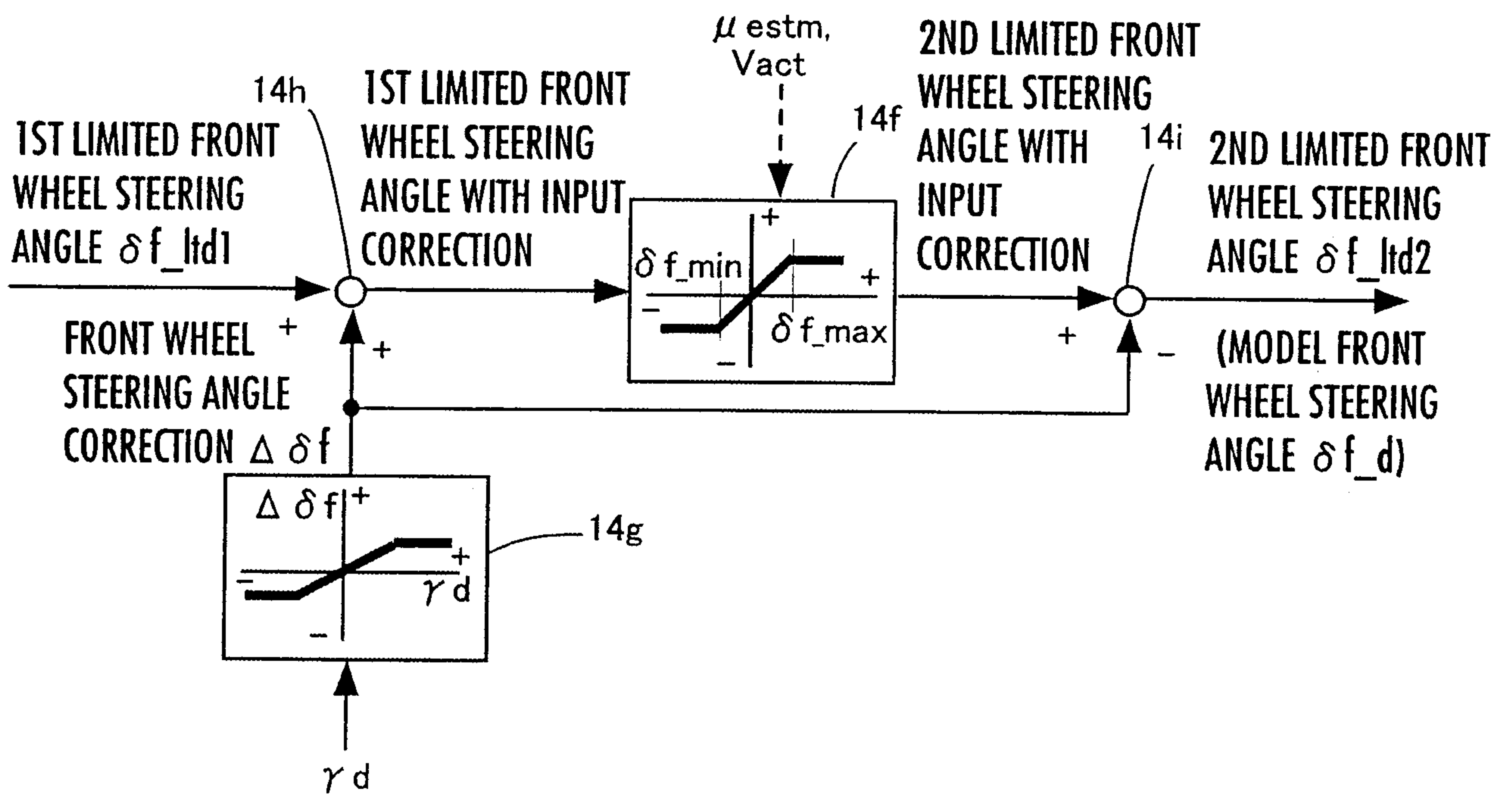


FIG.11

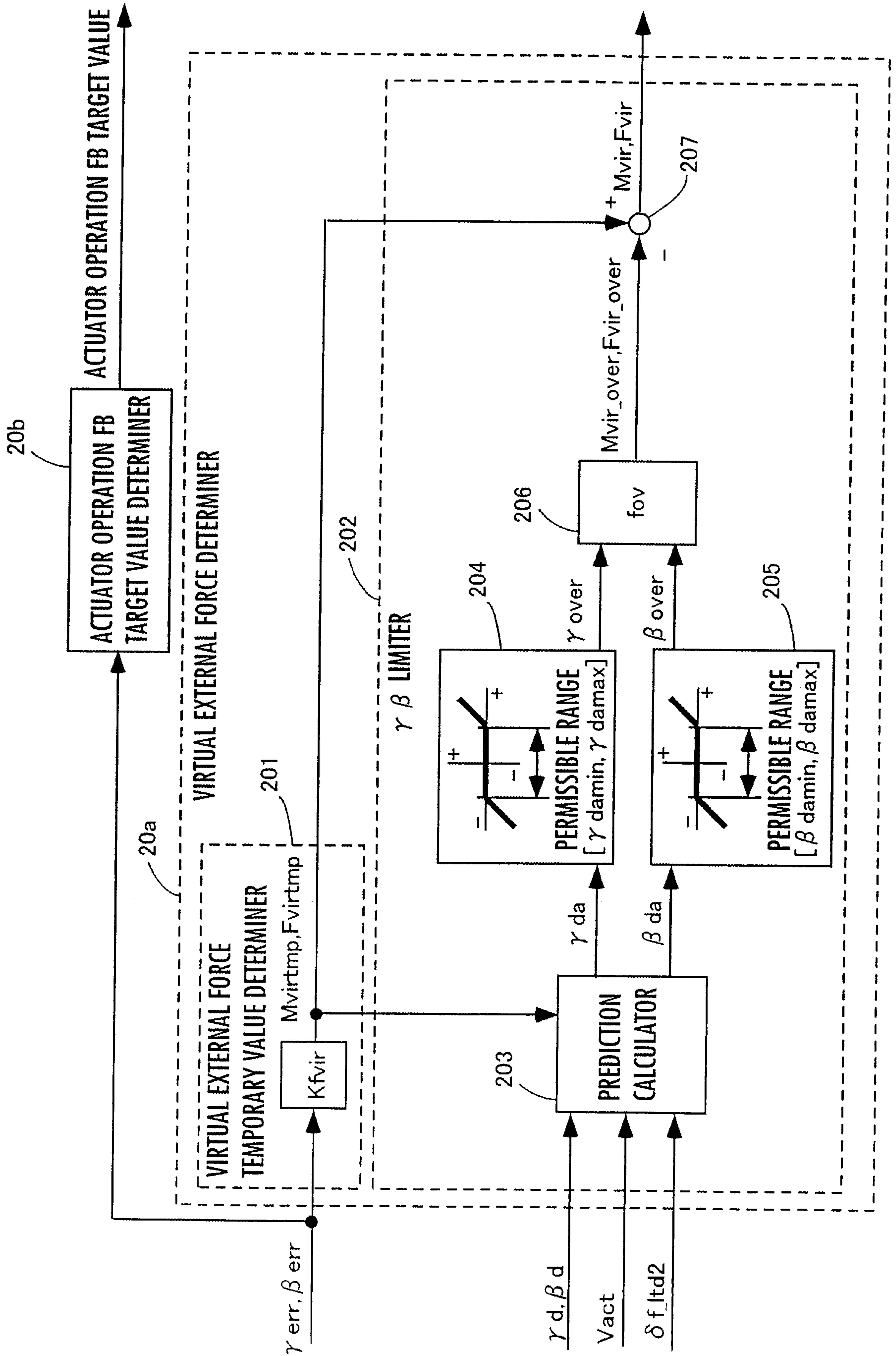


FIG.12

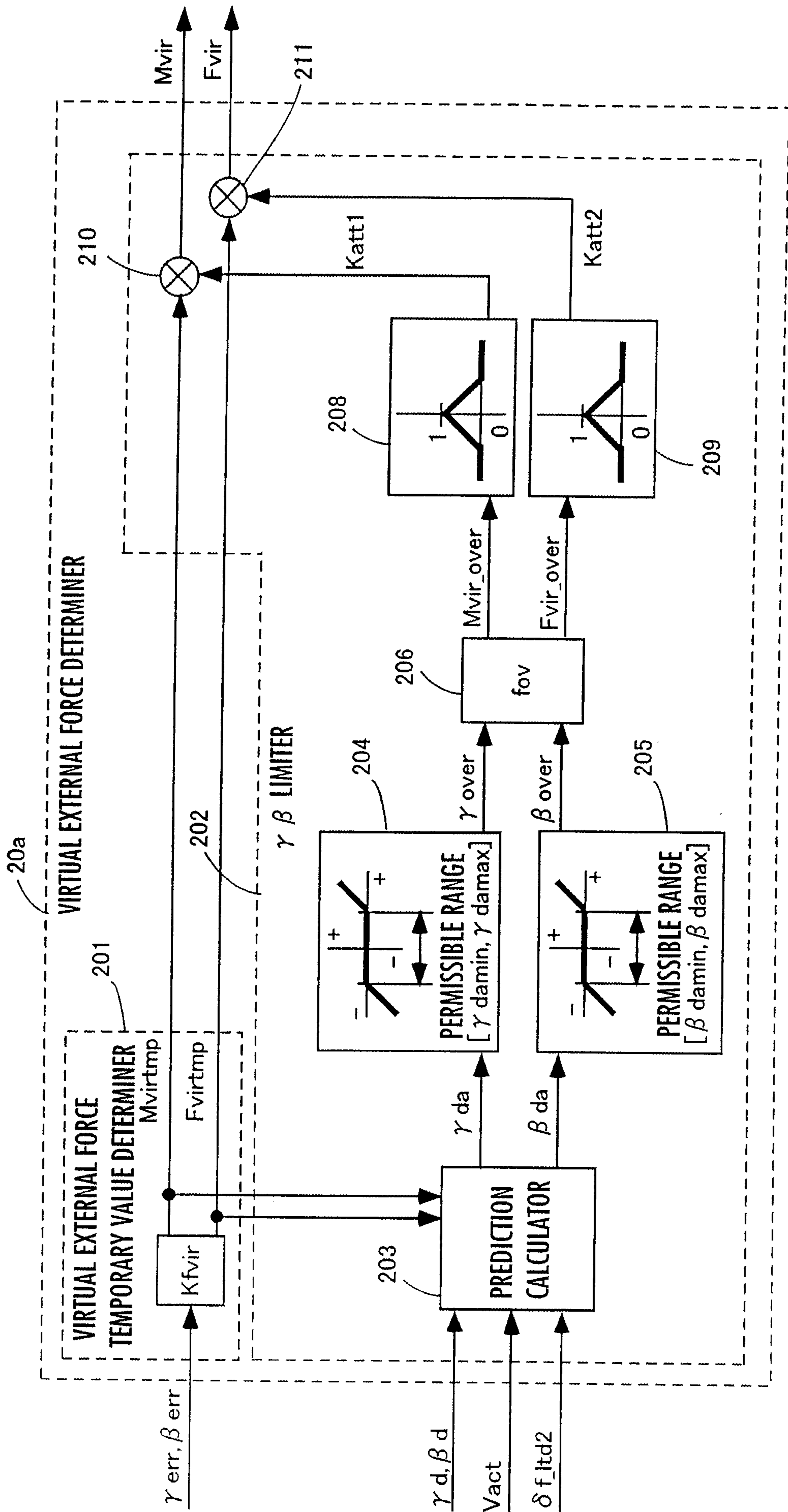


FIG.13

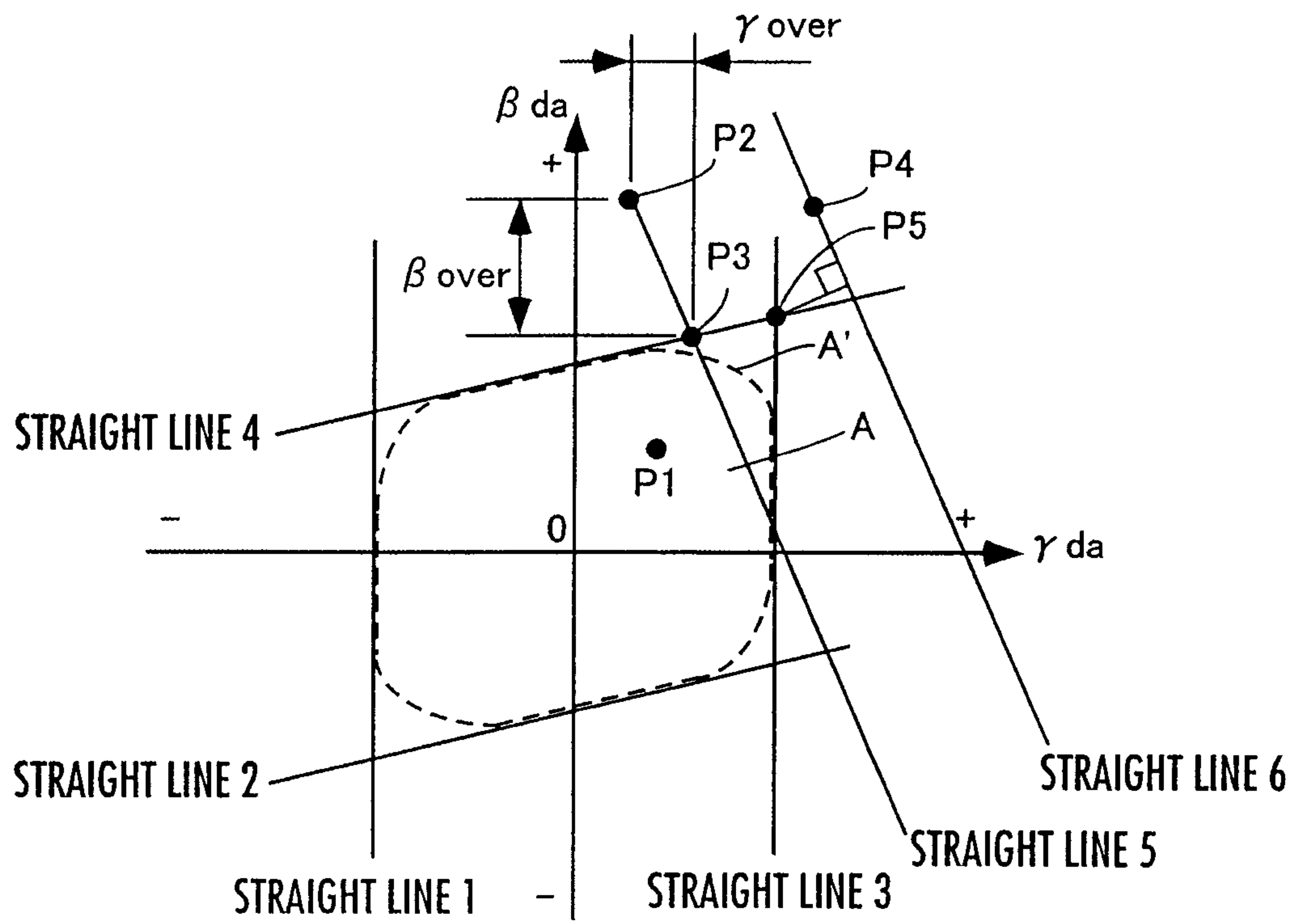


FIG. 14

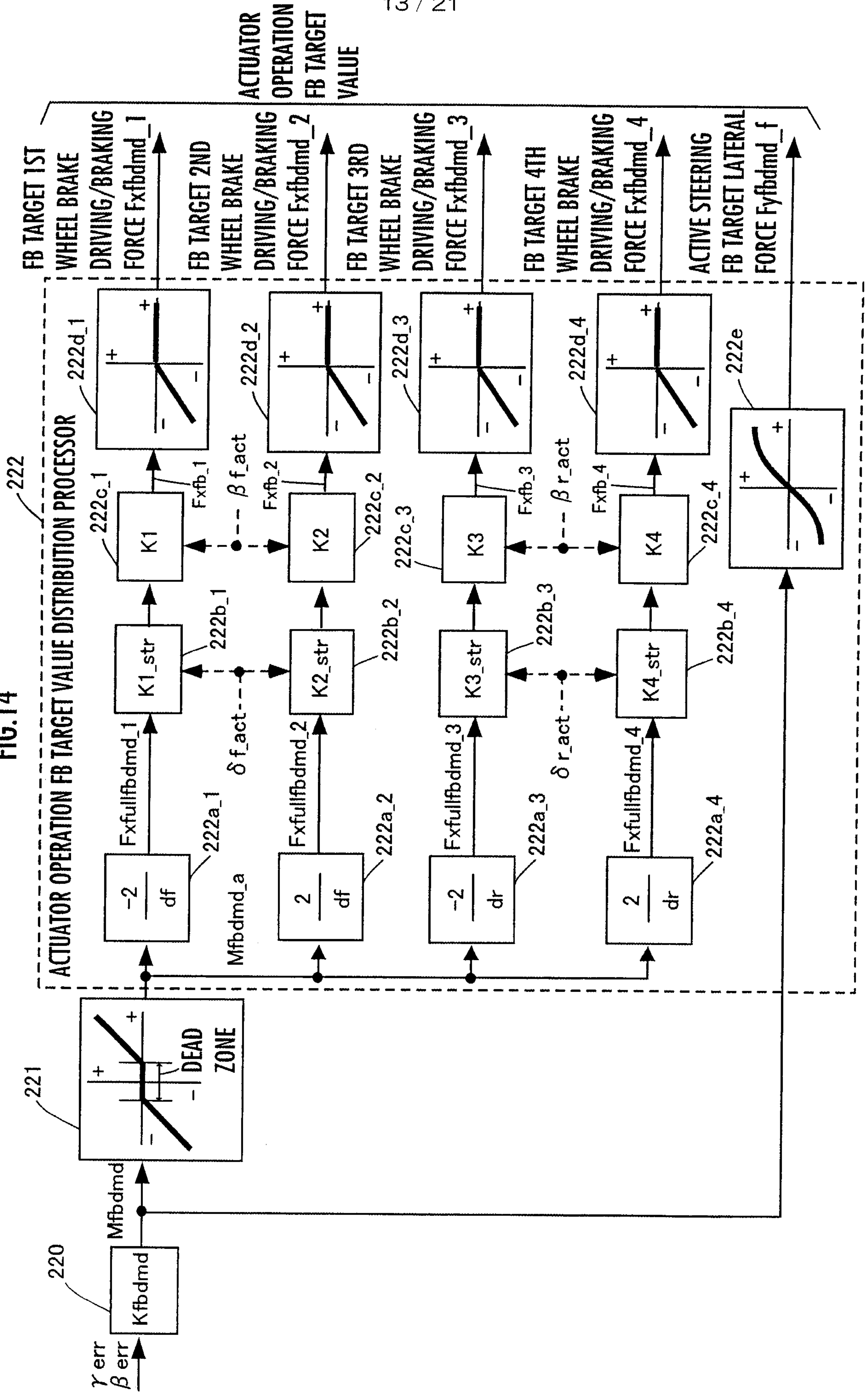


FIG.15

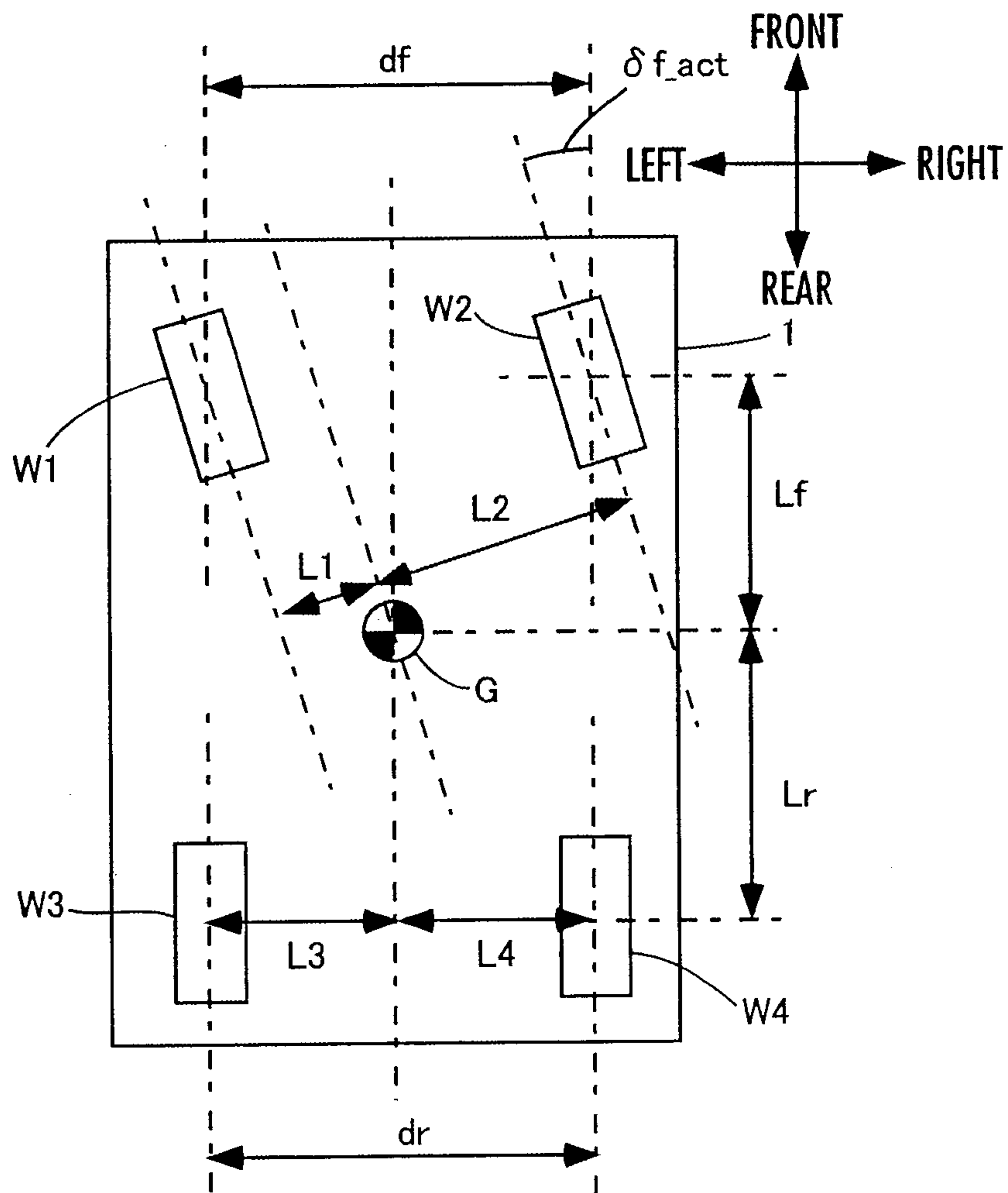


FIG.16(a)

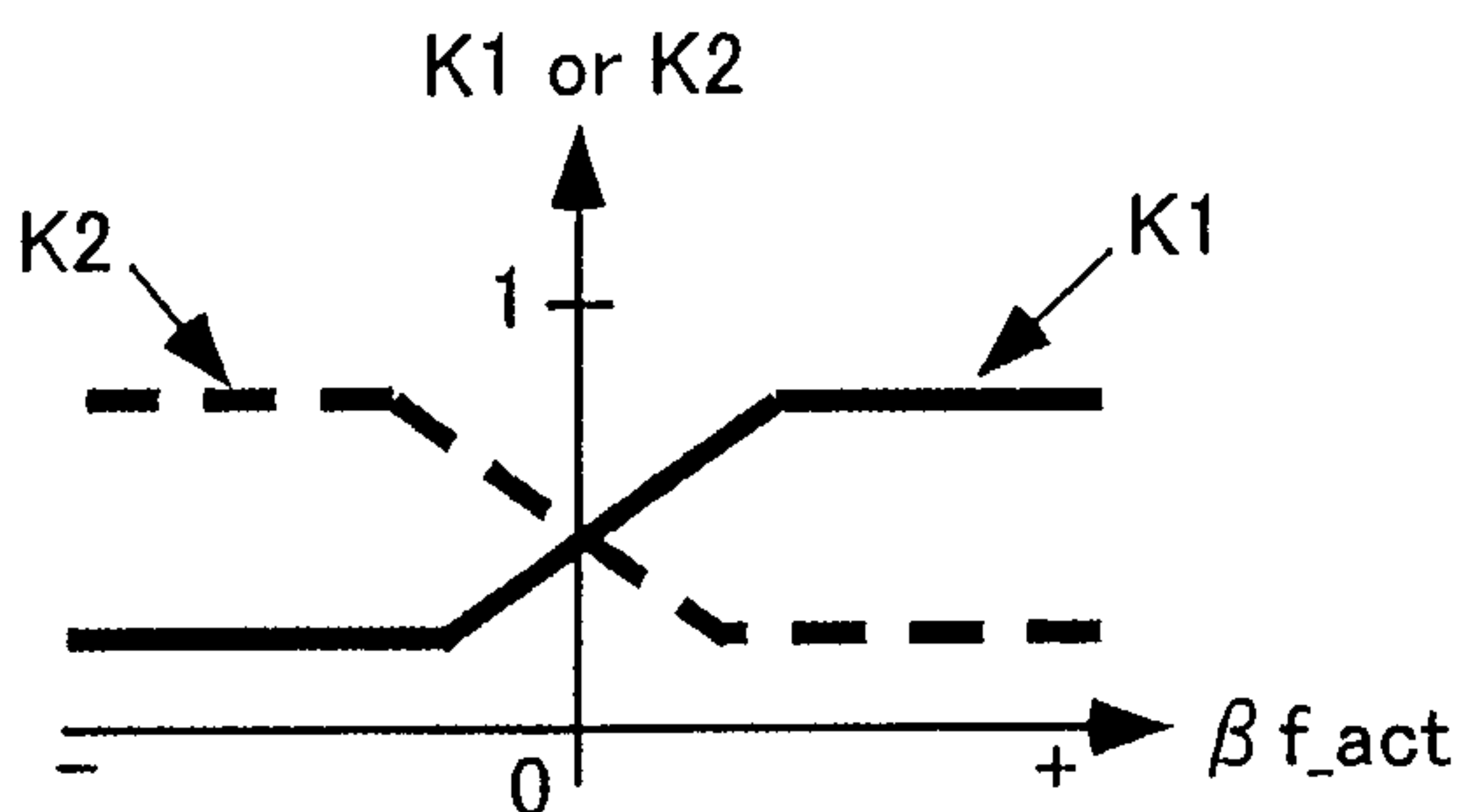


FIG.16(b)

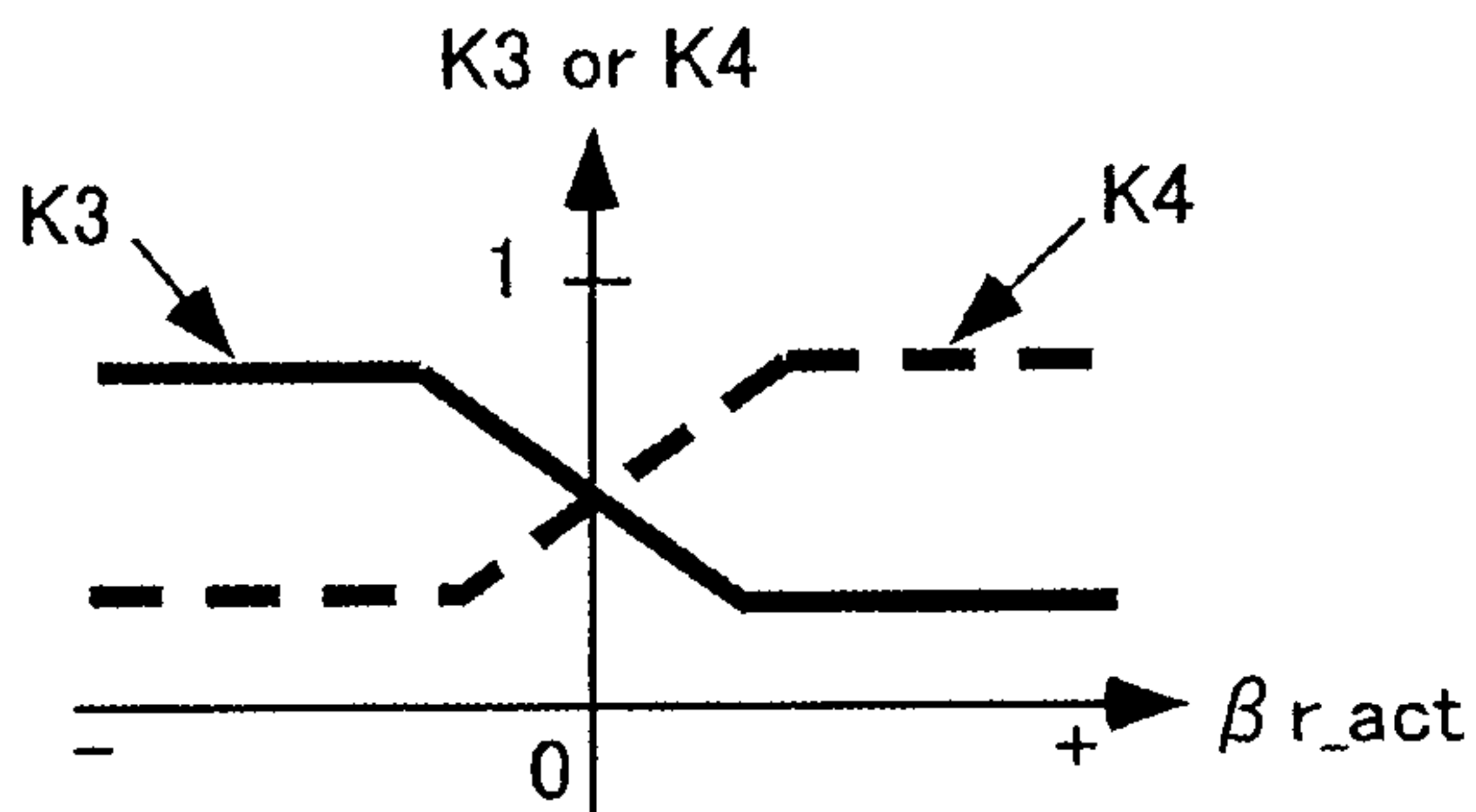


FIG.17(a)

$\beta f_{act} = \beta f_{--}$

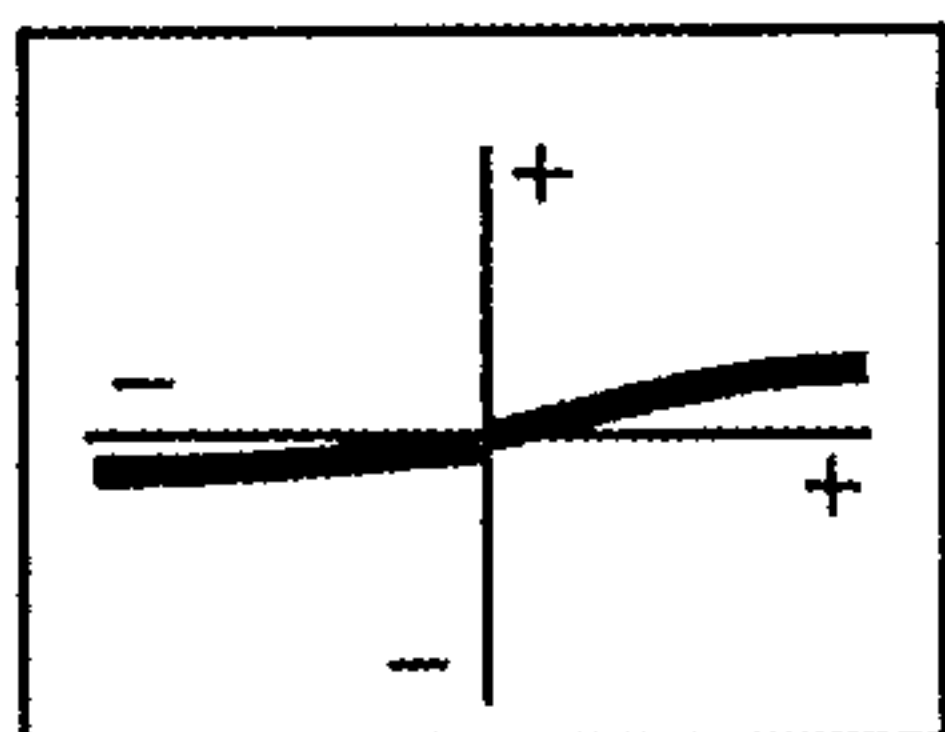


FIG.17(b)

$\beta f_{act} = \beta f_{-}$

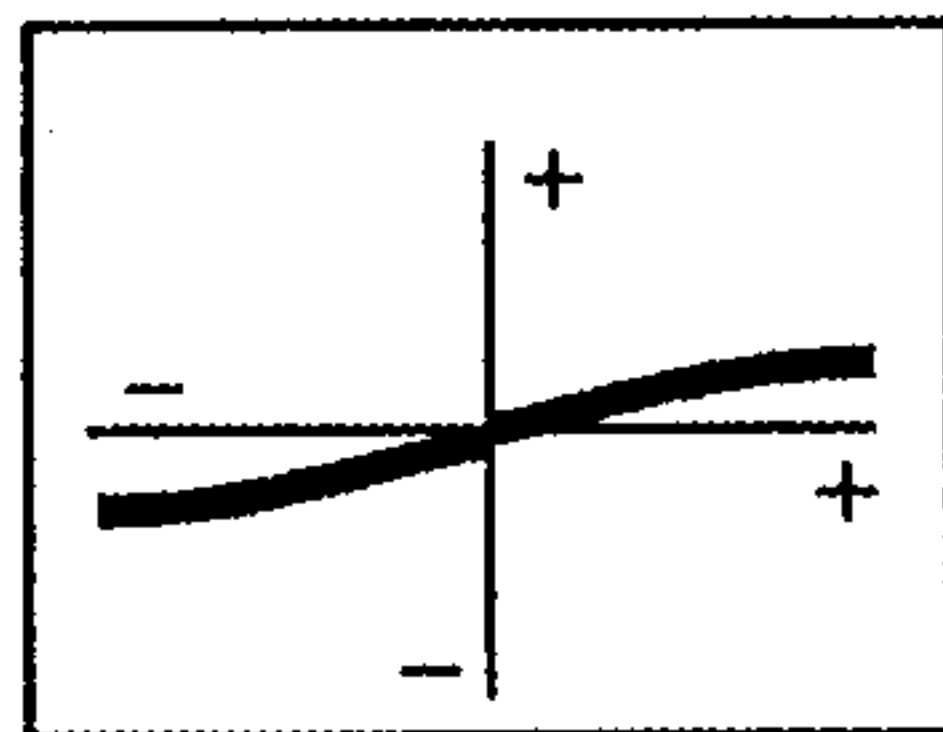


FIG.17(c)

$\beta f_{act} = 0$

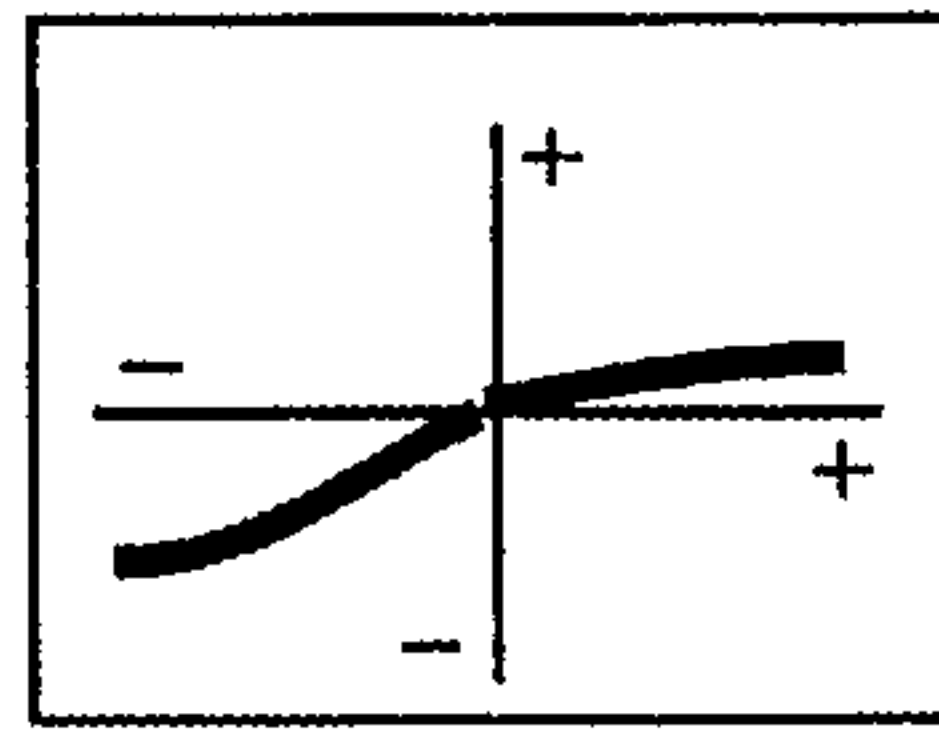


FIG.17(d)

$\beta f_{act} = \beta f_{+}$

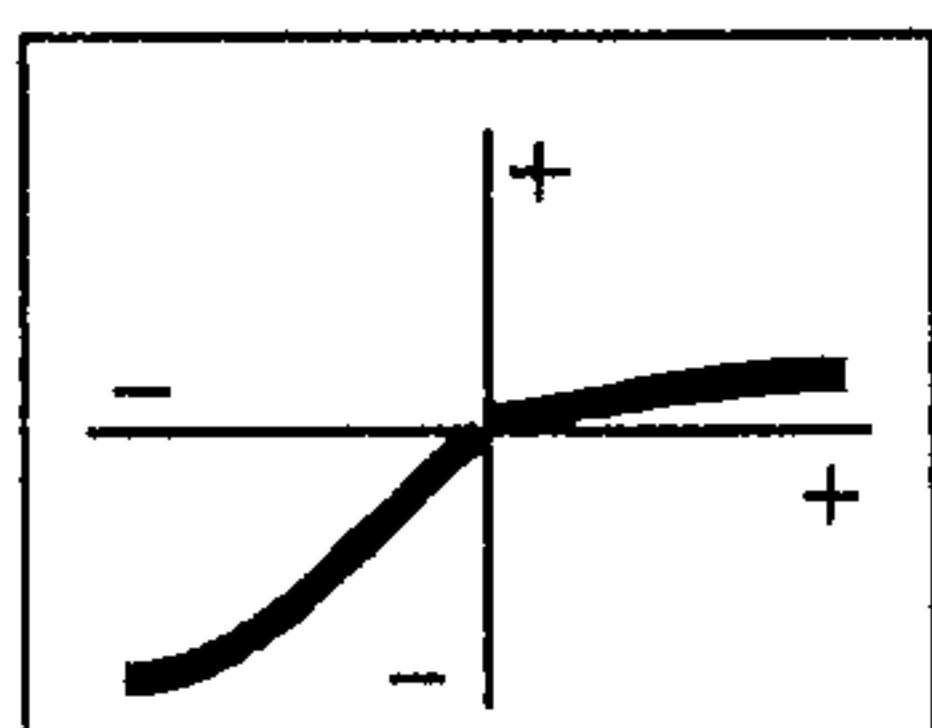


FIG.17(e)

$\beta f_{act} = \beta f_{++}$

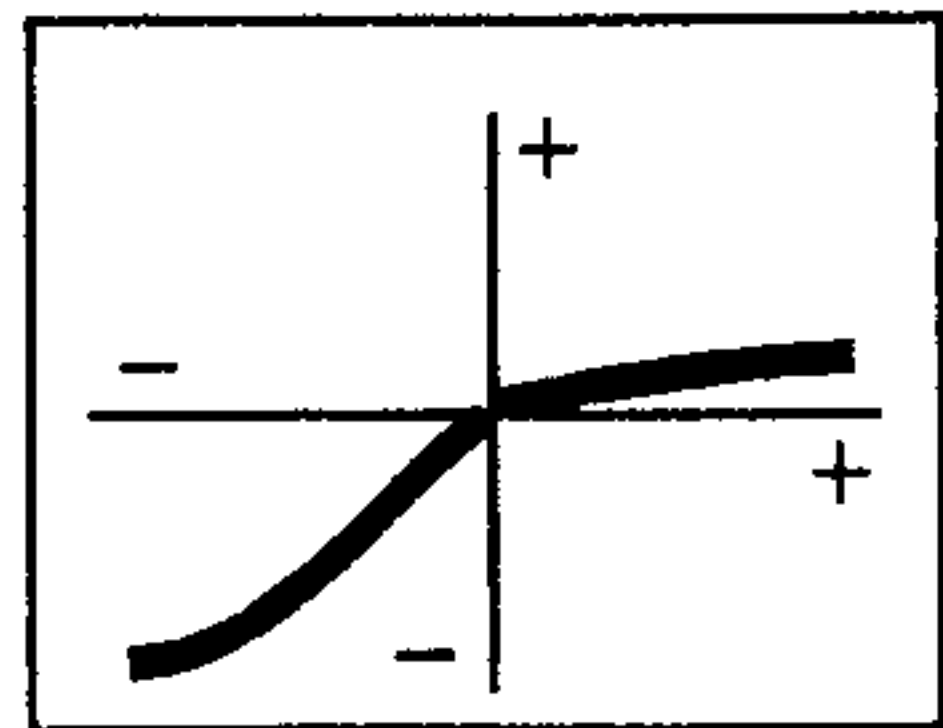


FIG.18(a)

$$\beta r_{act} = \beta r_{--}$$

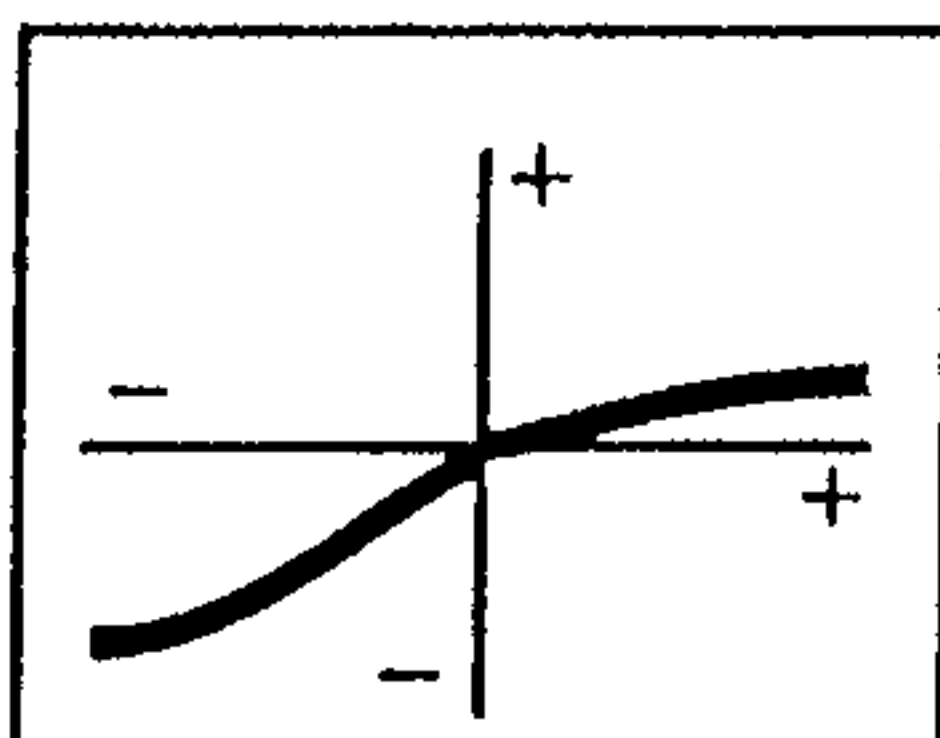


FIG.18(b)

$$\beta r_{act} = \beta r_{-}$$

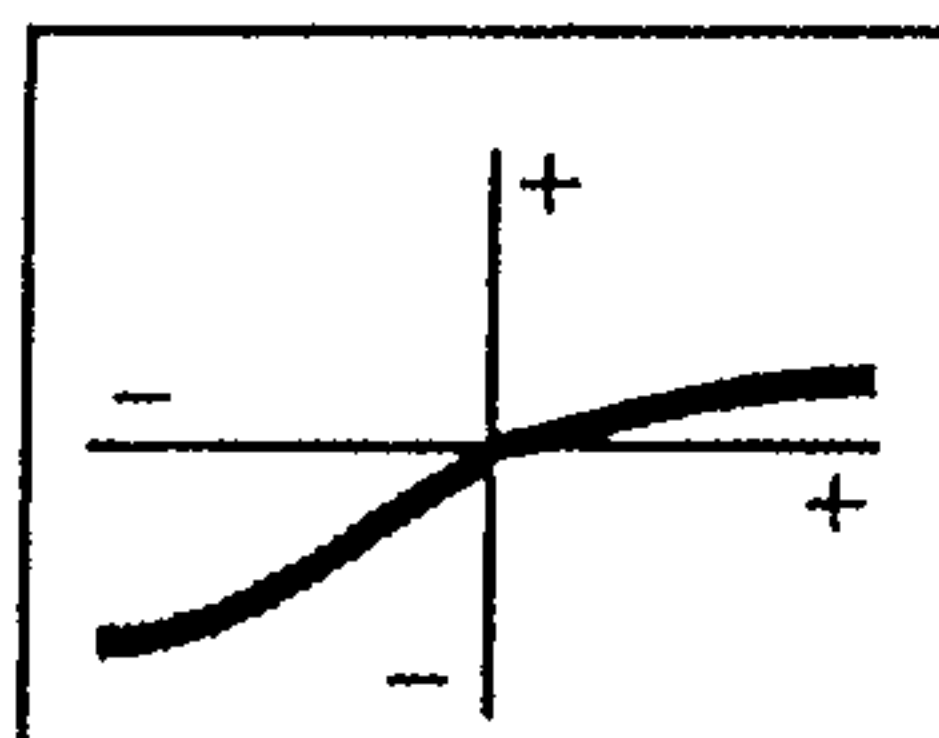


FIG.18(c)

$$\beta r_{act} = 0$$

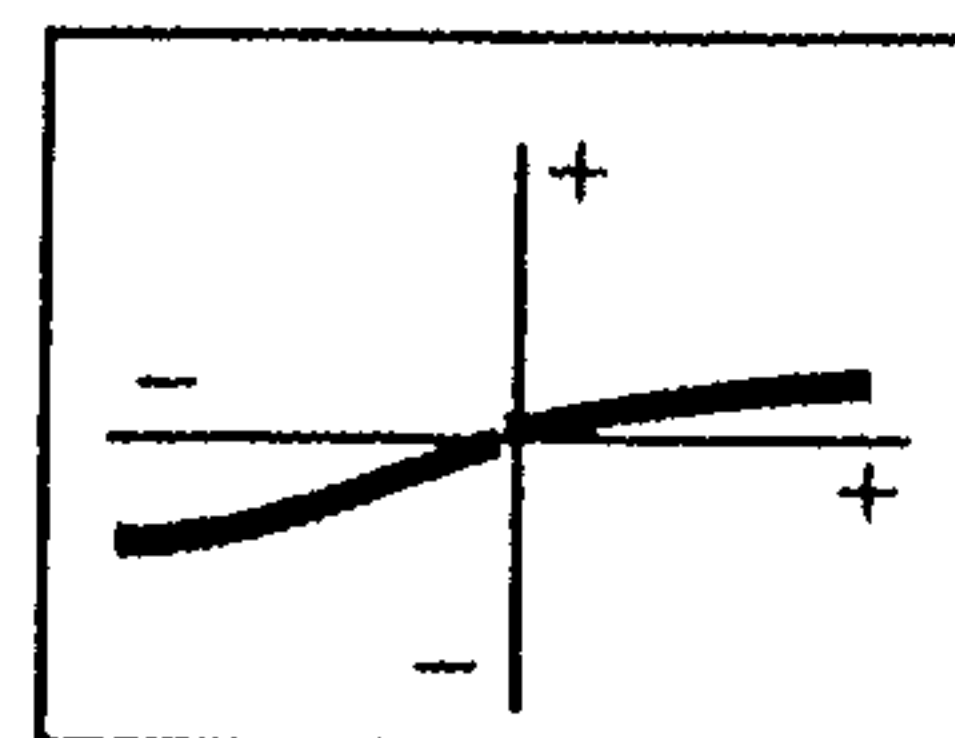


FIG.18(d)

$$\beta r_{act} = \beta r_{+}$$

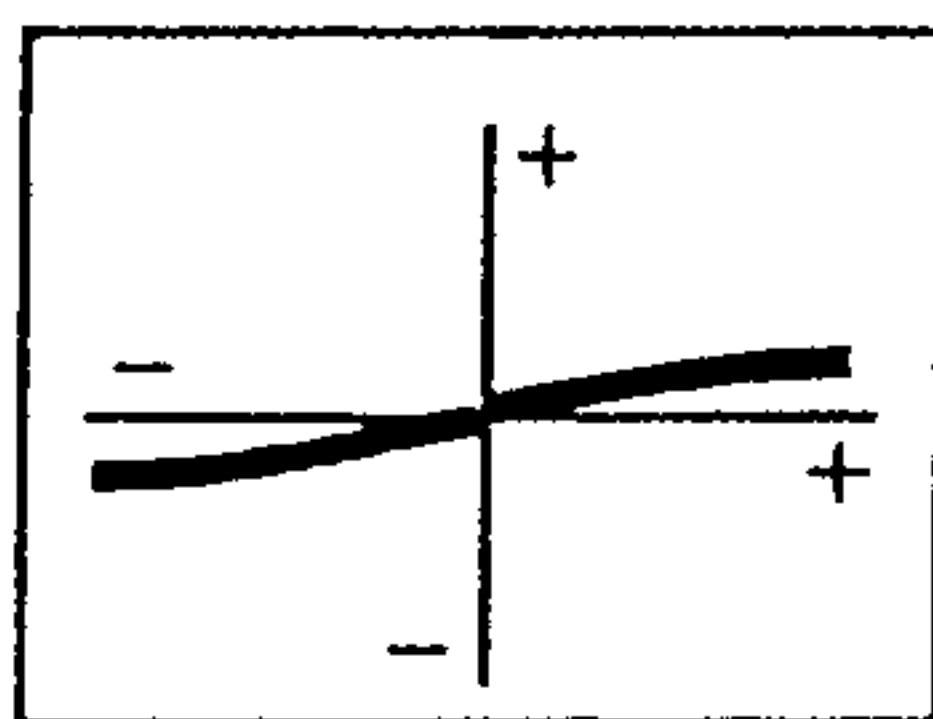


FIG.18(e)

$$\beta r_{act} = \beta r_{++}$$

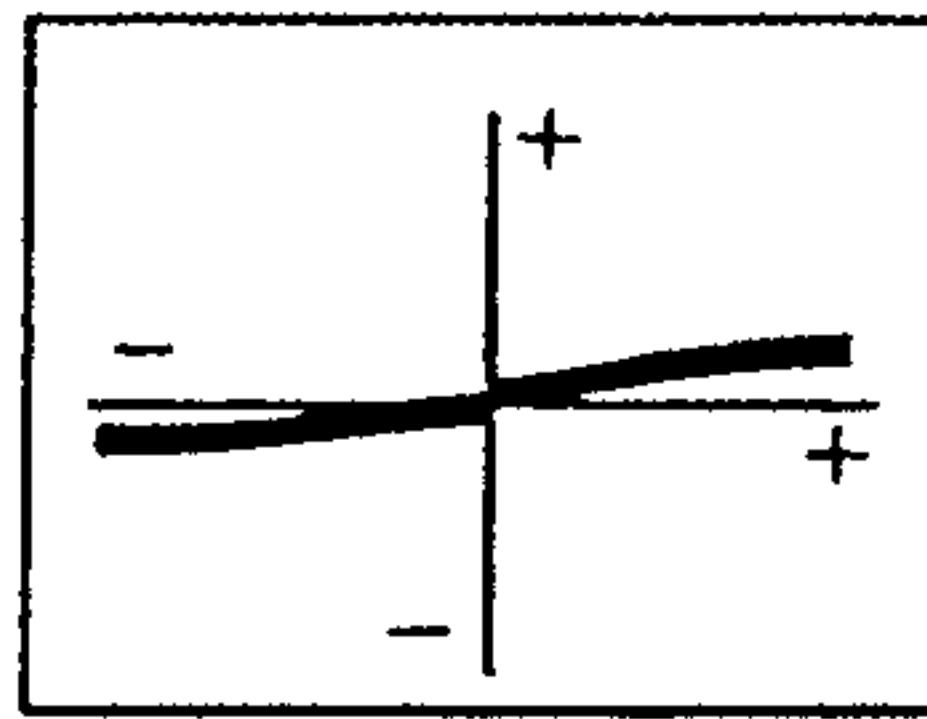
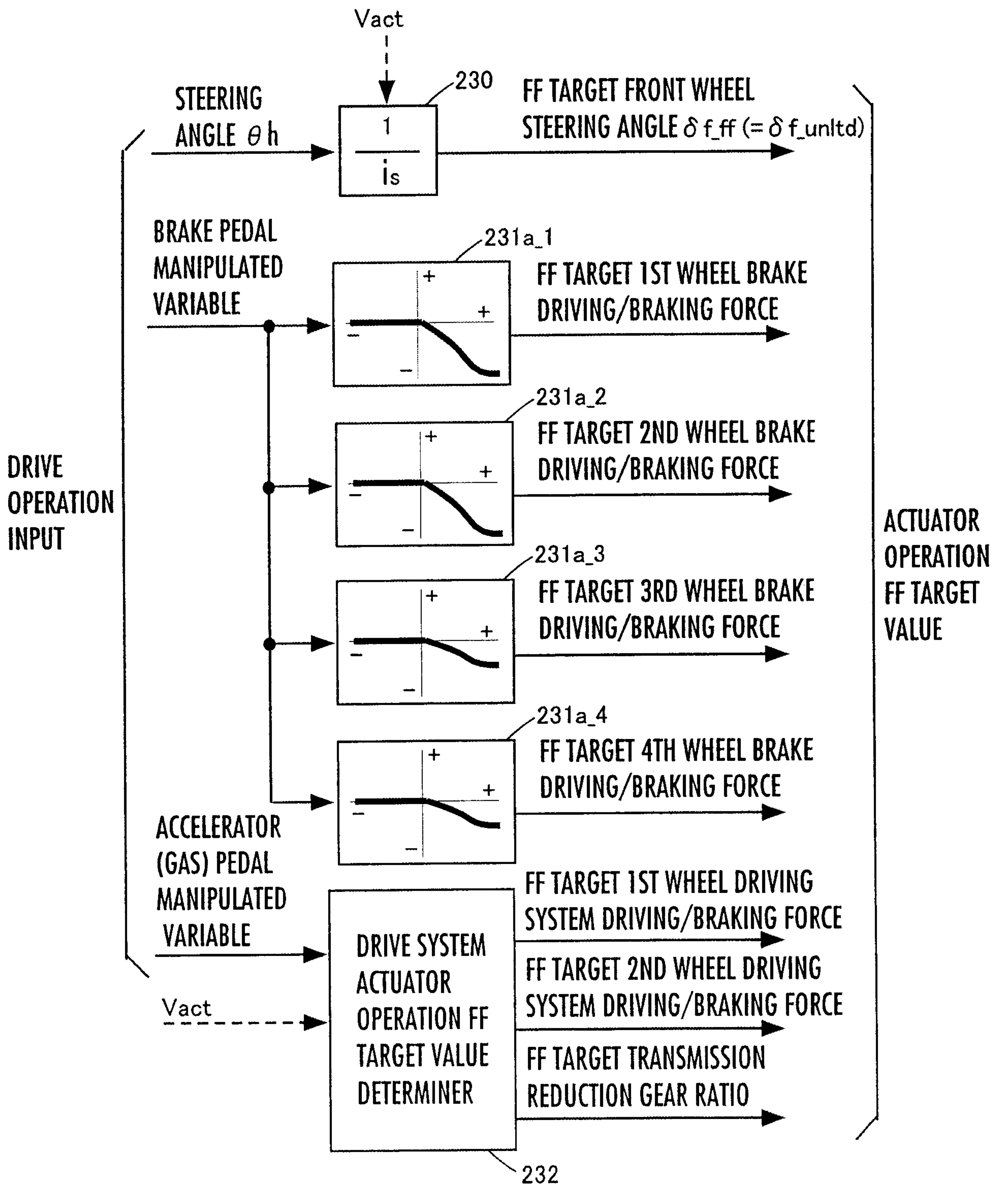


FIG.19



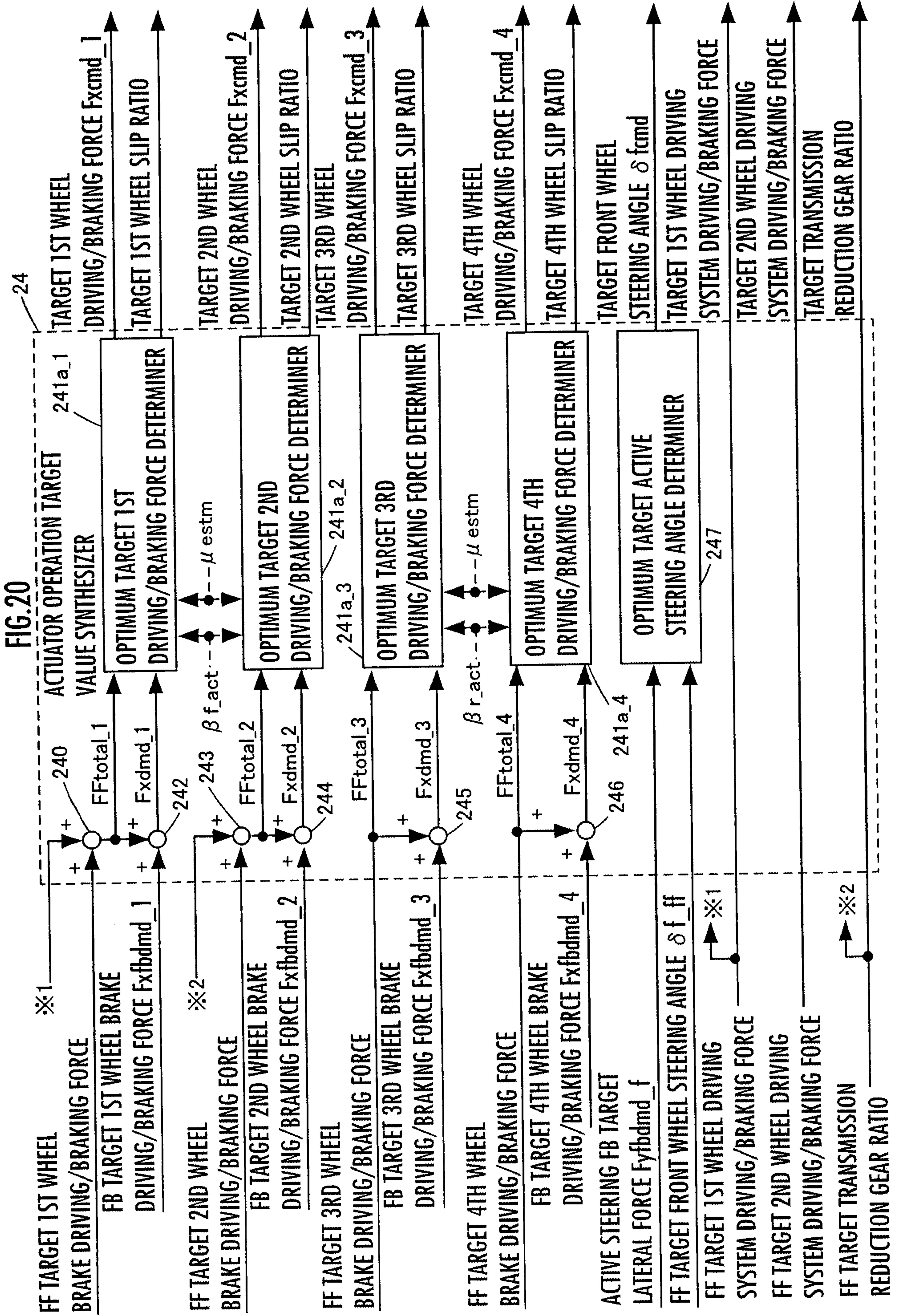


FIG.21

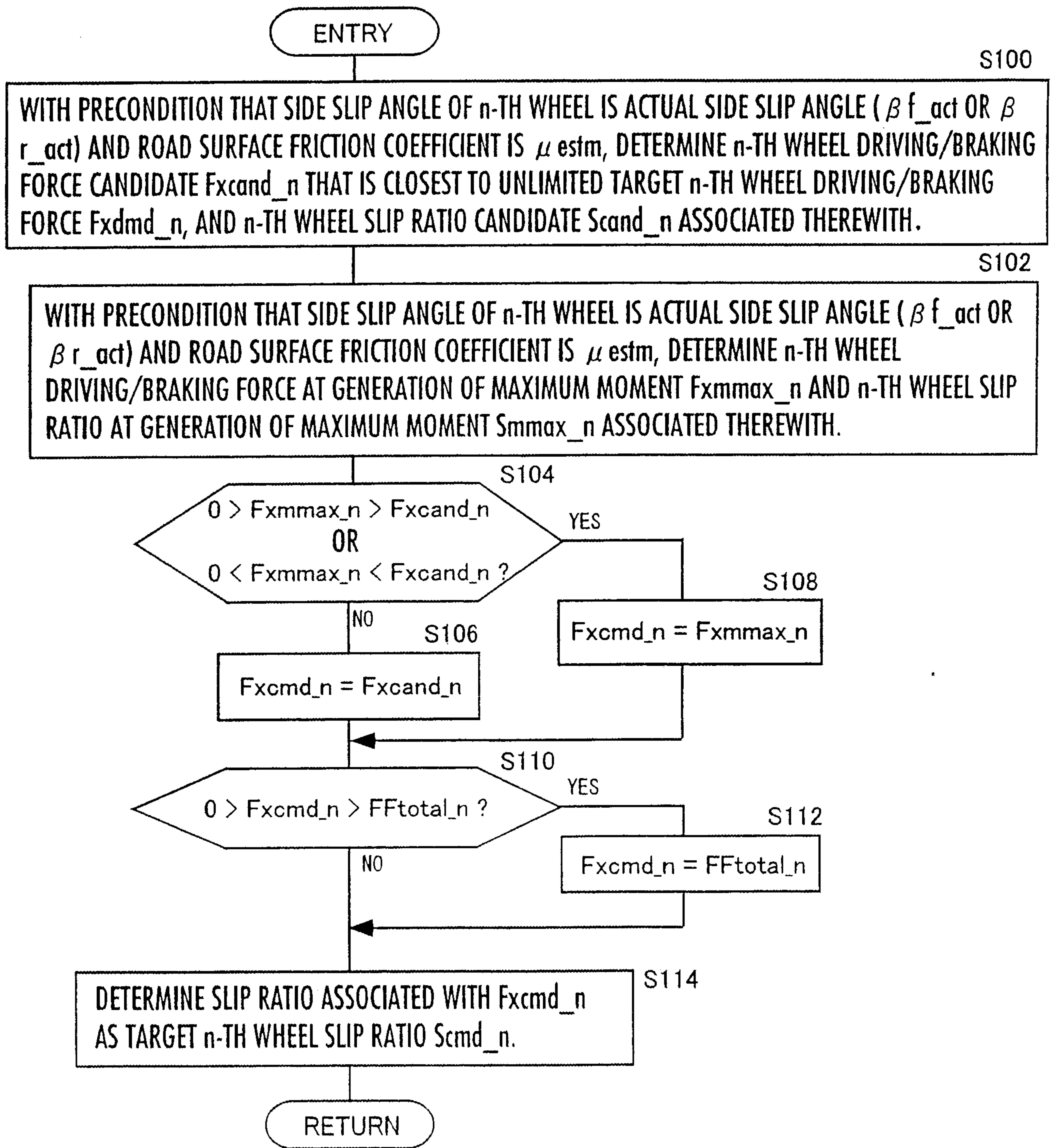


FIG.22

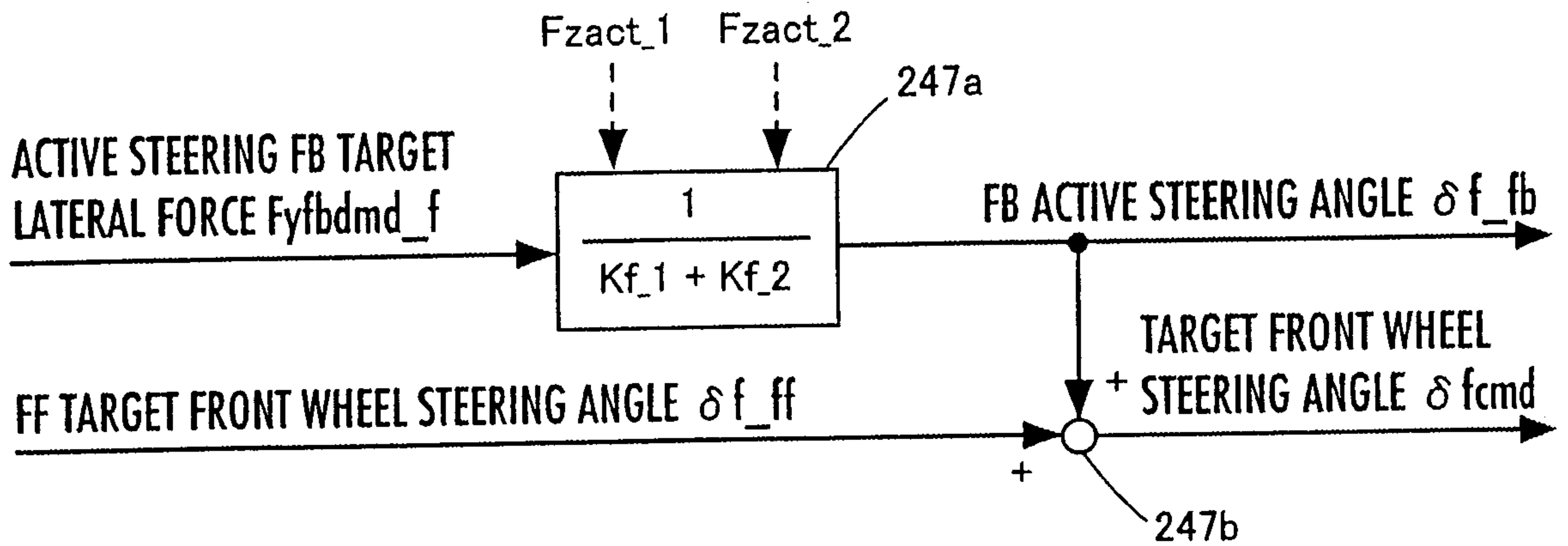


FIG.23

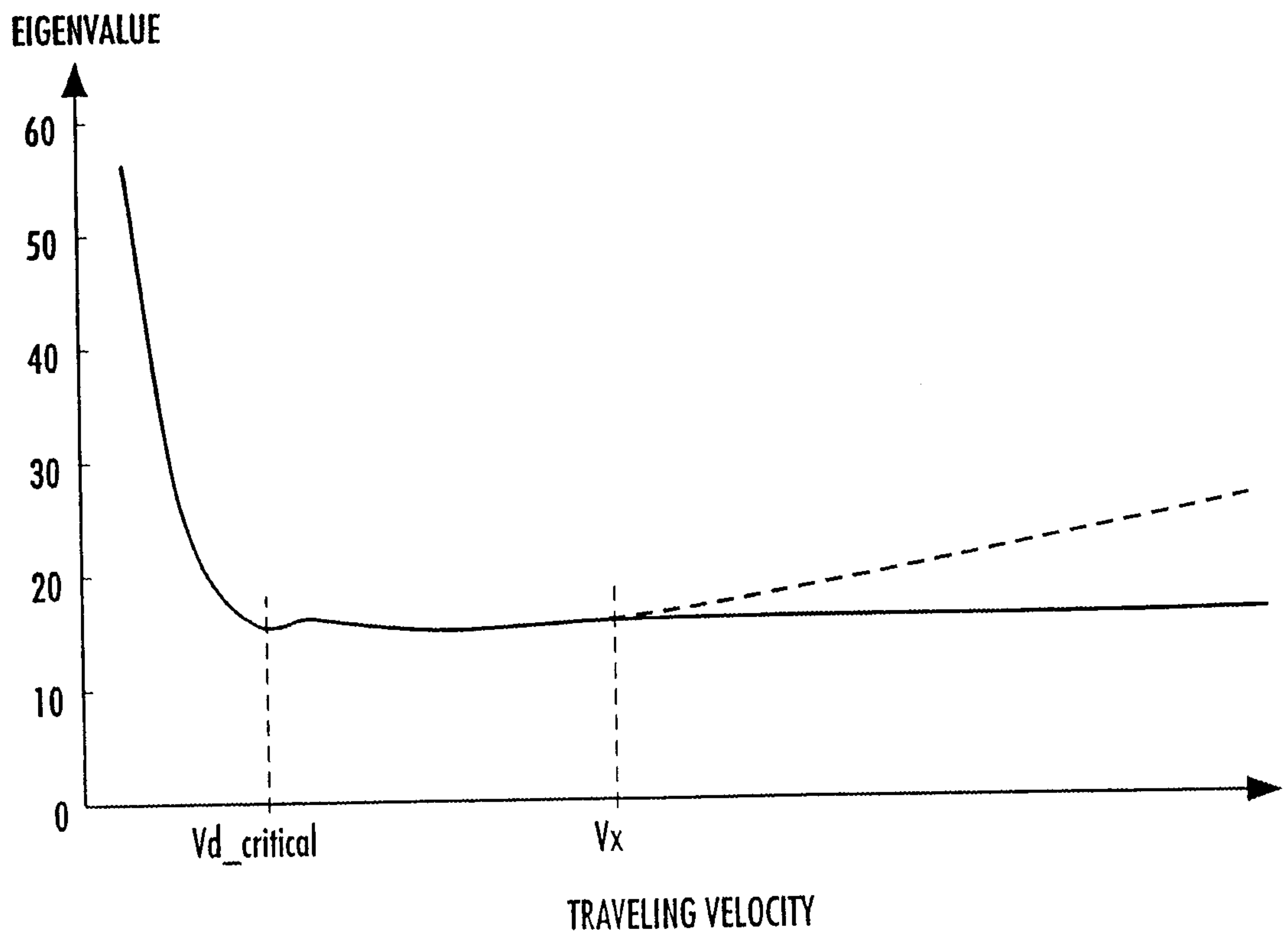


FIG.24(a)

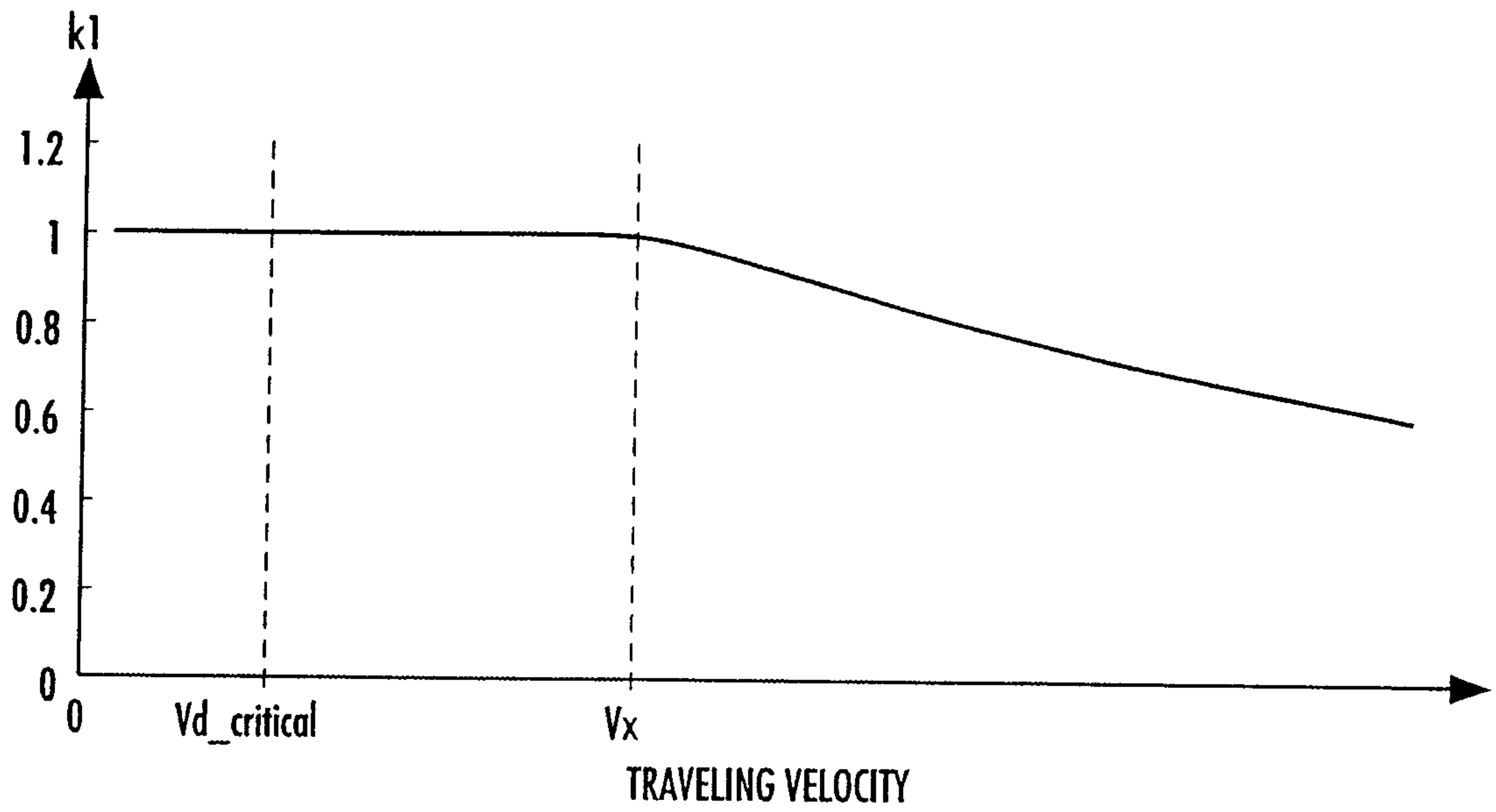


FIG.24(b)

