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Current limiting device, robot system, and current limiting method

Abstract

A current limiting device includes a current limiter to limit a current to be carried to a drive within a range of a limit value. The limit value is set to change according to a speed of the drive.

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Background/Summary

TECHNICAL FIELD

(1) The present disclosure relates to a current limiting device, a robot system, and a current limiting method, and more particularly, it relates to a current limiting device, a robot system, and a current limiting method that each limit a current to be carried to a motor.

BACKGROUND ART

(2) Conventionally, a robot in which an upper limit is set for a current to be carried to a motor is known. Such a robot is disclosed in Japanese Patent Laid-Open No. 2008-073790, for example.

(3) Japanese Patent Laid-Open No. 2008-073790 discloses a robot including a robot main body in which a plurality of links are connected to each other via joints, motors provided at the joints of the robot main body, and speed reducers that slow rotation of the motors. This robot includes current measuring means that measure currents being carried to the motors. When the robot main body is stationary, upper limits are set for the currents to be carried to the motors based on current values measured by the current measuring means. Specifically, when the robot is stationary, constant upper limits of currents are set according to the torques of the motors required to maintain a predetermined posture. Thus, it is possible to appropriately limit driving torques applied to the joints according to the posture of the robot.

PRIOR ART

Patent Document

(4) Patent Document 1: Japanese Patent Laid-Open No. 2008-073790

SUMMARY OF THE INVENTION

(5) In a conventional robot including speed reducers that slow rotation of motors as described in Japanese Patent Laid-Open No. 2008-073790, the torque losses of the speed reducers increase as the rotation speeds of the speed reducers increase. In general, torques generated by motors decrease as the rotation speeds of the motors increase. Thus, as described in Japanese Patent Laid-Open No. 2008-073790, when the constant upper limits are set for the currents to be carried to the motors, desired torques cannot be output from the speed reducers due to an increase in the torque losses of the speed reducers with an increase in the rotation speeds of the motors and a decrease in the torques generated by the motors (drives).

(6) The present disclosure is intended to solve the above problem. The present disclosure aims to provide a current limiting device and a current limiting method capable of outputting a desired force or moment from a drive force transmitter even when the speed of a drive increases in a configuration in which an upper limit is set for a current to be carried to the drive.

(7) In order to attain the aforementioned object, a current limiting device according to a first aspect of the present disclosure limits a current to be carried to a drive that generates a force or moment when the current is carried to the drive and transmits a drive force via a drive force transmitter, and includes a current limiter to limit the current to be carried to the drive within a range of a limit value. The limit value is set to change according to a speed of the drive.

(8) In the current limiting device according to the first aspect of the present disclosure, as described above, the limit value of the current to be carried to the drive is set to change according to the speed of the drive. Accordingly, the limit value can be changed according to the loss of the drive force transmitter that changes according to the speed of the drive and a decrease in the force or moment generated by the drive. Consequently, in a configuration in which an upper limit is set for the current to be carried to the drive, a desired force or moment can be output from the drive force transmitter even when the speed of the drive increases.

(9) A robot system according to a second aspect of the present disclosure includes a robot, and a robot controller configured or programmed to control the robot. The robot includes a joint, a motor provided at the joint, and a speed reducer to slow rotation of the motor. The robot controller includes a current limiter to limit a current to be carried to the motor within a range of a limit value, and the limit value is set to change according to a speed of the motor.

(10) In the robot system according to the second aspect of the present disclosure, as described above, the limit value of the current to be carried to the motor is set to change according to the speed of the motor. Accordingly, the limit value can be changed according to the loss of the drive force transmitter that changes according to the speed of the motor and a decrease in the force or moment generated by the motor. Consequently, it is possible to provide the robot system capable of outputting a desired force or moment from the drive force transmitter even when the speed of the motor increases in a configuration in which an upper limit is set for the current to be carried to the motor.

(11) A current limiting method according to a third aspect of the present disclosure is for limiting a current to be carried to a drive that generates a force or moment when the current is carried to the drive and transmits a drive force via a drive force transmitter, and includes acquiring a speed of the drive, setting a limit value of the current to be carried to the drive based on the acquired speed of the drive, and carrying the current to the drive within a range of the set limit value.

(12) As described above, the current limiting method according to the third aspect of the present disclosure includes setting the limit value of the current to be carried to the drive based on the acquired speed of the drive. Accordingly, the limit value can be changed according to the loss of the drive force transmitter that changes according to the speed of the drive and a decrease in the force or moment generated by the drive. Consequently, it is possible to provide the current limiting method capable of outputting a desired force or moment from the drive force transmitter even when the speed of the drive increases in a configuration in which an upper limit is set for the current to be carried to the drive.

(13) According to the present disclosure, as described above, it is possible to output a desired force or moment from the drive force transmitter even when the speed of the drive increases in the configuration in which an upper limit is set for the current to be carried to the drive.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
(1) FIG. **1** is a diagram showing the configuration of a robot system according to an embodiment of the present disclosure.
(2) FIG. **2** is a block diagram of a robot controller according to the embodiment of the present disclosure.
(3) FIG. **3** is a control block diagram of the robot controller according to the embodiment of the present disclosure.
(4) FIG. **4** is a diagram showing a relationship between the rotation speed of a motor and the torque loss of a speed reducer.
(5) FIG. **5** is a diagram showing a relationship between the rotation speed of the motor and a torque generated from the motor.
(6) FIG. **6** is a diagram showing limit values that are constant regardless of the rotation speed of the motor.
(7) FIG. **7** is a diagram showing limit values for forward efficiency and for reverse efficiency that are constant regardless of the rotation speed of the motor.
(8) FIG. **8** is a diagram showing limit values for the forward efficiency and for the reverse efficiency that vary according to the rotation speed of the motor.

(9) FIG. **9** is a diagram showing limit values for the forward efficiency and for the reverse efficiency when the motor rotates in a positive direction.

(10) FIG. **10** is a diagram showing limit values for the forward efficiency and for the reverse efficiency when the motor rotates in a negative direction.

(11) FIG. **11** is a flowchart for illustrating a current limiting method according to the embodiment of the present disclosure.

(12) FIG. **12** is a diagram showing the configuration of a medical robot according to a modified example.

(13) FIG. **13** is a block diagram (**1**) showing the configuration of a robot controller according to a modified example.

(14) FIG. **14** is a block diagram (**2**) showing the configuration of a robot controller according to a modified example.

MODES FOR CARRYING OUT THE INVENTION

(15) An embodiment embodying the present disclosure is hereinafter described on the basis of the drawings.

(16) The configuration of a robot system **100** according to this embodiment is now described with reference to FIGS. **1** to **11**.

(17) As shown in FIG. **1**, the robot system **100** includes a robot **10** and a robot controller **20** that controls the robot **10**. The robot **10** is a six-axis robot, for example. Furthermore, the robot **10** is an industrial robot, for example.

(18) As shown in FIG. **1**, the robot **10** includes an arm **11**. The arm **11** includes joints **12**. A plurality of joints **12** are provided. For example, six joints **12** (joints **12***a* to **12***f*) are provided. The arm **11** is attached to a base **13**. The joint **12***a* is rotatable about an axis L**1** extending in a vertical direction. The joint **12***b* is rotatable about an axis L**2** extending in a horizontal direction. The joint **12***c* is rotatable about an axis L**3** extending parallel to the axis L**2**.

(19) The joint **12***d* is rotatable about an axis L**4** perpendicular to the axis L**3**. The joint **12***e* is rotatable about an axis L**5** perpendicular to the axis L**4**. The joint **12***f* is rotatable about an axis L**6** perpendicular to the axis L**5**.

(20) As shown in FIG. **2**, motors **14***a* to **14***f* are provided at the joints **12***a* to **12***f*, respectively. Speed reducers **15***a* to **15***f* that transmit the drive forces of the motors **14***a* to **14***f* are provided at the motors **14***a* to **14***f*, respectively. Each of the motors **14***a* to **14***f* generates a force or moment (torque in this embodiment) when a current is carried to the motor, and transmit a drive force via the corresponding speed reducer **15***a*, **15***b*, **15***c*, **15***d*, **15***e*, or **15***f*. The speed reducers **15***a* to **15***f* slow rotation of the motors **14***a* to **14***f* and transmit the rotation of the motors **14***a* to **14***f*, respectively. Thus, the joints **12***a* to **12***f* rotate. The motors **14***a* to **14***f* may be collectively referred to as a motor **14** below. In addition, the speed reducers **15***a* to **15***f* may be collectively referred to as a speed reducer **15** below. The motor **14** (**14***a* to **14***f*) is an example of a drive. The speed reducer **15** (**15***a* to **15***f*) is an example of a drive force transmitter.

(21) Encoders **16***a* to **16***f* are provided at the motors **14***a* to **14***f*, respectively. The encoders **16***a* to **16***f* detect the angular positions of output shafts **17***a* to **17***f* of the motors **14***a* to **14***f*, respectively. The detected angular positions of the output shafts **17***a* to **17***f* are transmitted to a position/speed controller **22** described below. The encoders **16***a* to **16***f* may be collectively referred to as an encoder **16** below. In addition, the output shafts **17***a* to **17***f* may be collectively referred to as an output shaft **17** below.

(22) The robot controller **20** includes a current limiting device **21** that limits a current to be carried to the motor **14** that transmits a drive force via the speed reducer **15**. The current limiting device **21** includes the position/speed controller **22** and a current limiter **23** that limits the current to be carried to the motor **14** within a limit value range.

(23) The position/speed controller **22** is electrically connected to each of the motors **14***a* to **14***f*, and carries a current to each of the motors **14***a* to **14***f* to control a torque output from each of the motors

14*a* to 14*f*. The position/speed controller 22 includes a position controller 22*a* (see FIG. 3) and a speed controller 22*b* (see FIG. 3). A storage 24 is connected to the position/speed controller 22. The storage 24 stores a program for driving each of the motors 14*a* to 14*f*.

(24) The current limiter 23 includes current limiters 23*a* to 23*f* provided for a plurality of motors 14*a* to 14*f*, respectively. Amplifiers 25*a* to 25*f* are provided between the current limiters 23*a* to 23*f* and the motors 14*a* to 14*f*, respectively. The amplifiers 25*a* to 25*f* may be collectively referred to as an amplifier 25 below.

(25) Control of the torque of the motor 14 is now described with reference to FIG. 3.

(26) The position/speed controller 22 acquires a position command value (time history command position) of the joint 12 from the storage 24 (upper command device). Then, the position controller 22*a* calculates a deviation between the acquired position command value and the angular position (actual angular position) obtained from the encoder 16 of the joint 12. Then, the position controller 22*a* multiplies the calculated deviation by a position gain. The position controller 22*a* also differentiates the position command value to calculate a speed command value, which is the target speed of the joint 12.

(27) Then, the speed controller 22*b* adds the deviation multiplied by the position gain and the generated speed command value and subtracts the actual angular speed obtained by differentiating the actual angular position from the added value to calculate a speed deviation. Then, the speed controller 22*b* multiplies the calculated speed deviation by a speed gain. Thus, the speed controller 22*b* generates a target current value corresponding to a target torque output from the motor 14.

(28) Then, the speed controller 22*b* transmits the generated target current value to the current limiter 23. When the transmitted target current value is within a current limit value range, the current limiter 23 directly transmits the target current value to the amplifier 25. On the other hand, when the transmitted target current value is outside the current limit value range, the current limiter 23 limits the target current value to a value within the current limit value range and transmits the target current value to the amplifier 25.

(29) In this embodiment, the limit value of the current to be carried to the motor 14 is set to change according to the speed of the motor 14 (see FIG. 8). One of the reasons for setting the current limit value is to make the torque output by the motor 14 equal to or less than an allowable torque of a drive system (such as a torque to reduce or prevent damage to the speed reducer 15).

(30) On the other hand, as shown in FIG. 4, as the rotation speed (horizontal axis) of the speed reducer 15 increases, the torque loss (vertical axis) of the speed reducer 15 increases. Specifically, in the speed reducer 15, Coulomb friction and viscous friction occur. The Coulomb friction is proportional to a force applied to the speed reducer 15. The viscous friction is caused by the viscosity of grease or oil contained in the speed reducer 15 and increases as the rotation speed of the speed reducer 15 increases.

(31) As shown in FIG. 5, the torque (vertical axis) generated by the motor 14 decreases as the rotation speed (horizontal axis) of the motor 14 increases. This is because as the rotation speed (number of rotations) of the motor 14 increases, a back electromotive force generated in the motor 14 increases, and it becomes difficult for a current to flow through the motor 14.

(32) As shown in FIG. 6, when the current limit value is constant regardless of the rotation speed of the motor 14, in a region in which the rotation speed of the motor 14 is relatively high, the torque loss of the speed reducer 15 increases and the torque generated by the motor 14 decreases, and thus a desired torque cannot be generated from the speed reducer 15.

(33) Therefore, in this embodiment, as shown in FIG. 8, the absolute value of the limit value is set to increase (in the case of forward efficiency described below) or decrease (in the case of reverse efficiency described below) as the speed (rotation speed) of the motor 14 increases. Furthermore, the absolute value of the limit value is set to gradually increase or decrease as the rotation speed of the motor 14 increases. When the torque loss of the speed reducer 15 is caused only by friction, the absolute value of the limit value gradually increases or decreases as the rotation speed of the motor

14 increases. However, depending on the control of the motor **14**, the absolute value of the limit value may be decreased according to the rotation speed of the motor **14**, and the absolute value may be increased after a certain rotation speed.

(34) As shown in FIG. **4**, the rate of increase in the torque loss of the speed reducer **15** increases as the rotation speed of the speed reducer **15** increases. As shown in FIG. **5**, the rate of decrease in the torque generated by the motor **14** increases as the rotation speed of the speed reducer **15** increases. Therefore, in this embodiment, the rate of change of the limit value is set to increase as the speed (rotation speed) of the motor **14** increases. The rate of change of the limit value in FIG. **8** is an example, and the rate of change of the limit value may not increase as the speed (rotation speed) of the motor **14** increases. That is, the rate of change of the limit value is set to follow a change in the torque loss of the speed reducer **15**.

(35) A case in which the driving direction (rotating direction) of the motor **14** and the direction of the force or moment (torque in this embodiment) output from the motor **14** are the same as each other is referred to as the forward efficiency. In other words, in the case of the forward efficiency, a torque is transmitted from the motor **14** side to the speed reducer **15** side in the motor **14** and the speed reducer **15**. The forward efficiency corresponds to a case in which the rotation of the joint **12** is accelerated by the motor **14**, for example. At the time of forward efficiency, the torque loss of the speed reducer **15** contributes negatively to the torque generated by the motor **14**.

(36) A case in which the driving direction (rotating direction) of the motor **14** and the direction of the force or moment (torque in this embodiment) output from the motor **14** are opposite to each other is referred to as the reverse efficiency. In other words, in the case of the reverse efficiency, a torque is transmitted from the output side of the speed reducer **15** to the motor **14** side. The reverse efficiency corresponds to a case in which the deceleration of the motor **14** is large, for example. At the time of reverse efficiency, the torque loss of the speed reducer **15** contributes positively to the torque generated by the motor **14**. Thus, the contribution of the torque loss of the speed reducer **15** to the torque generated by the motor **14** differs between the forward efficiency and the reverse efficiency.

(37) Therefore, in this embodiment, as shown in FIG. **8**, the current limit value includes a limit value for the forward efficiency in which the driving direction (rotating direction) of the motor **14** and the direction of the force or moment (torque in this embodiment) output from the motor **14** are the same as each other, and a limit value for the reverse efficiency having a value different from the limit value for the forward efficiency, in which the driving direction (rotating direction) of the motor **14** and the direction of the force or moment (torque in this embodiment) output from the motor **14** are opposite to each other. The limit value for the forward efficiency and the limit value for the reverse efficiency are set to change according to the speed (rotation speed) of the motor **14**. The absolute value of the limit value for the forward efficiency is greater than the absolute value of the limit value for the reverse efficiency.

(38) As shown in FIG. **7**, when the limit value for the forward efficiency is constant regardless of the rotation speed of the motor **14**, the torque loss of the speed reducer **15**, which contributes negatively, increases as the rotation speed of the motor **14** increases, and the torque on the output side of the speed reducer **15** decreases. When the limit value for the reverse efficiency is constant regardless of the rotation speed of the motor **14**, the torque loss of the speed reducer **15**, which contributes positively, increases as the rotation speed of the motor **14** increases, and a relatively large torque is applied to the speed reducer **15**. Therefore, the speed reducer **15** may be damaged, a bolt of the speed reducer **15** may be loosened, and the load (stress) on the arm may increase during deceleration.

(39) Therefore, in this embodiment, as shown in FIG. **8**, the absolute value of the limit value for the forward efficiency is set to increase as the rotation speed of the motor **14** increases, and the absolute value of the limit value for the reverse efficiency is set to decrease as the rotation speed of motor **14** increases.

(40) As described above, the rate of increase in the torque loss of the speed reducer **15** increases as the rotation speed of the speed reducer **15** increases (see FIG. **4**). Furthermore, the rate of decrease in the torque generated by the motor **14** increases as the rotation speed of the motor **14** increases (see FIG. **5**). Therefore, in this embodiment, the rate of increase in the limit value for the forward efficiency and the rate of decrease in the limit value for the reverse efficiency are set to increase as the rotation speed of the motor **14** increases.

(41) Specifically, as shown in FIG. **9**, when a current is carried to the motor **14** in a positive direction (the current command value is positive) and the motor **14** rotates is in the positive direction (forward efficiency), the limit value for the forward efficiency is positive, and increases as the rotation speed of the motor **14** increases. When a current is carried to the motor **14** in the positive direction (the current command value is positive) and the motor **14** rotates in a negative direction (reverse efficiency), the limit value for the reverse efficiency is positive, and decreases as the rotation speed of the motor **14** increases.

(42) As shown in FIG. **10**, when a current is carried to the motor **14** in the negative direction (the current command value is negative) and the motor **14** rotates in the negative direction (forward efficiency), the limit value for the forward efficiency is negative, and decreases (its absolute value increases) as the rotation speed of the motor **14** increases. When a current is carried to the motor **14** in the negative direction (the current command value is negative) and the motor **14** rotates in the positive direction (reverse efficiency), the limit value for the reverse efficiency is negative, and increases (its absolute value decreases) as the rotation speed of the motor **14** increases.

(43) In this embodiment, the limit value is set to reduce or prevent damage to the speed reducer **15** due to the force or moment (torque in this embodiment) generated by the motor **14** and maintain the force or moment (torque in this embodiment) on the output side of the speed reducer **15** at a constant value. Specifically, the limit value for the forward efficiency is set such that the torque on the output side of the speed reducer **15** is maintained constant even when the rotation speed of the motor **14** increases. In other words, the limit value for the forward efficiency is set to compensate for the torque loss of the speed reducer **15** and a decrease in the torque generated by the motor **14** (and to reduced or prevent damage to the speed reducer **15**). The limit value for the reverse efficiency is set to reduce or prevent damage to the speed reducer **15** due to an increase in the torque loss of the speed reducer **15** even when the rotation speed of the motor **14** increases. The motor **14** is actually driven, and the torque loss of the speed reducer **15** and the decrease in the torque of the motor **14** are measured such that the limit value for the forward efficiency and the limit value for the reverse efficiency are acquired based on the results of these measurements.

(44) A current limiting method for limiting the current to be carried to the motor **14** that transmits a drive force via the speed reducer **15** is now described with reference to FIG. **11**.

(45) In step S**1**, the current limiting device **21** acquires the speed (rotation speed) of the motor **14**. Specifically, the speed (command speed) is acquired by differentiating the time history command position from the upper command device. The rotation speed of the motor **14** may be acquired based on the angular position of the output shaft **17** of the motor **14** acquired from the encoder **16**.

(46) In step S**2**, the current limiter **23** sets the limit value of the current to be carried to the motor **14** based on the acquired speed (rotation speed) of the motor **14**.

(47) In step S**3**, the current limiter **23** carries a current to the motor **14** within the set limit value range. The operations in step S**1** to step S**3** are repeated while the motor **14** is in operation.

Advantages of this Embodiment

(48) According to this embodiment, the following advantages are achieved.

(49) According to this embodiment, as described above, the limit value of the current to be carried to the motor **14** is set to change according to the rotation speed of the motor **14**. Accordingly, the limit value can be changed according to the loss of the speed reducer **15** that changes according to the rotation speed (speed) of the motor **14** and the decrease in the torque generated by the motor **14**. Consequently, in a configuration in which an upper limit is set for the current to be carried to the

motor **14**, the desired torque can be output from the speed reducer **15** even when the rotation speed of the motor **14** increases.

(50) According to this embodiment, as described above, the absolute value of the limit value is set to increase or decrease as the rotation speed of the motor **14** increases. The loss of the speed reducer **15** may contribute positively (reverse efficiency) or negatively (forward efficiency) to the torque generated by the motor **14**. Therefore, when the loss of the speed reducer **15** contributes negatively to the force generated by the motor **14**, the limit value for the forward efficiency is increased as the rotation speed of the motor **14** increases such that the current to be carried to the motor **14** can be adjusted so as to compensate for the decrease in the torque generated by the motor **14** and the loss of the speed reducer **15**. When the loss of the speed reducer **15** contributes positively to the force generated by the motor **14**, the limit value for the reverse efficiency is decreased as the rotation speed of the motor **14** increases such that the current to be carried to the motor **14** can be adjusted so as to remove an amount by which the loss of the speed reducer **15** contributes positively. Consequently, the current to be carried to the motor **14** can be appropriately adjusted both when the loss of the speed reducer **15** contributes positively and when it contributes negatively.

(51) According to this embodiment, as described above, the rate of change of the limit value is set to increase as the rotation speed of the motor **14** increases. Accordingly, the rate of change of the loss of the speed reducer **15** and the rate of change of the decrease in the torque generated by the motor **14** increase as the rotation speed of the motor **14** increases, and thus the rate of change of the limit value is set to increase as the rotation speed of the motor **14** increases such that the current to be carried to the motor **14** can be more appropriately adjusted. Consequently, the torque of the motor **14** can be appropriately adjusted.

(52) According to this embodiment, as described above, the current limit value includes the limit value for the forward efficiency in which the driving direction (rotating direction) of the motor **14** and the direction of the force or moment (torque in this embodiment) output from the motor **14** are the same as each other, and the limit value for the reverse efficiency having a value different from the limit value for the forward efficiency, in which the driving direction (rotating direction) of the motor **14** and the direction of the force or moment (torque in this embodiment) output from the motor **14** are opposite to each other. Furthermore, the limit value for the forward efficiency and the limit value for the reverse efficiency are set to change according to the rotation speed of the motor **14**. The loss of the speed reducer **15** contributes negatively to the force generated by the motor **14** in the case of the forward efficiency, and the loss of the speed reducer **15** contributes positively to the force generated by the motor **14** in the case of the reverse efficiency. Therefore, as described above, the limit value includes the limit value for the forward efficiency and the limit value for the reverse efficiency having a value different from the limit value for the forward efficiency such that in both cases of the forward efficiency and the reverse efficiency, the current to be carried to the motor **14** can be appropriately adjusted.

(53) According to this embodiment, as described above, the absolute value of the limit value for the forward efficiency is set to increase as the rotation speed of the motor **14** increases, and the absolute value of the limit value for the reverse efficiency is set to decrease as the rotation speed of the motor **14** increases. Accordingly, in the case of the forward efficiency, the loss of the speed reducer **15** contributes negatively to the torque generated by the motor **14**, and thus the absolute value of the limit value for the forward efficiency is set to increase as the rotation speed of the motor **14** increases such that the current to be carried to the motor **14** can be appropriately adjusted to compensate for the decrease in the torque generated by the motor **14** and the loss of the speed reducer **15**. In the case of the reverse efficiency, the loss of the speed reducer **15** contributes positively to the torque generated by the motor **14**, and thus the absolute value of the limit value for the reverse efficiency is set to decrease as the rotation speed of the motor **14** increases such that damage to the speed reducer **15** due to application of an excessive torque to the speed reducer **15**

can be reduced or prevented.

(54) According to this embodiment, as described above, the rate of increase in the limit value for the forward efficiency and the rate of decrease in the limit value for the reverse efficiency are set to increase as the rotation speed of the motor **14** increases. Accordingly, the rate of increase in the loss of the speed reducer **15** and the rate of decrease in the torque generated by the motor **14** increase as the rotation speed of the motor **14** increases, and thus the rate of increase in the limit value for the forward efficiency and the rate of decrease in the limit value for the reverse efficiency are set to increase as the rotation speed of the motor **14** increases such that the current to be carried to the motor **14** can be more appropriately adjusted.

(55) According to this embodiment, as described above, the limit value is set to change according to the rotation speed of the motor **14**. Accordingly, the limit value can be changed according to the torque loss of the speed reducer **15** that changes according to the rotation speed of the motor **14** and the decrease in the torque generated by the motor **14**. Consequently, when the rotation speed of the motor **14** increases, the current to be carried to the motor **14** can be adjusted to account for the loss of the speed reducer **15** and the decrease in the torque generated by the motor **14**, and thus a desired torque can be output from the speed reducer **15** even when the rotation speed of the motor **14** increases.

(56) According to this embodiment, as described above, the limit value is set to reduce or prevent damage to the speed reducer **15** due to the torque generated by the motor **14** and to maintain the torque on the output side of the speed reducer **15** at a constant value. Accordingly, a desired torque can be output from the speed reducer **15** while damage to the speed reducer **15** is reduced or prevented.

(57) According to this embodiment, as described above, the motor **14** is provided at the joint **12** of the robot **10**. Accordingly, even when the rotation speed of the motor **14** provided at the joint **12** of the robot **10** increases, a desired torque can be output from the speed reducer **15**.

MODIFIED EXAMPLES

(58) The embodiment disclosed this time must be considered as illustrative in all points and not restrictive. The scope of the present disclosure is not shown by the above description of the embodiment but by the scope of claims for patent, and all modifications (modified examples) within the meaning and scope equivalent to the scope of claims for patent are further included.

(59) For example, while the example in which the present disclosure is applied to the industrial robot **10** has been shown in the aforementioned embodiment, the present disclosure is not limited to this. For example, as shown in FIG. **12**, the present disclosure may be applied to a medical robot **30**. The robot **30** includes a positioner **31** (articulated robot), an arm base **32**, and a plurality of arms **33**. A surgical instrument **34** is attached to the tip end of each of the plurality of arms **33**. The current limiting device of the present disclosure limits a current to be carried to the positioner **31** (articulated robot) and motors at joints of the arms **33**, for example. Thus, in the medical robot **30**, even when the speed (rotation speed) of the motor **14** increases, a desired torque can be output from the speed reducer **15**.

(60) In particular, the medical robot **30** has a limited space for arranging the medical robot **30**, includes many joints, and needs to have a low drive voltage to reduce the impact at the time of collision, for example, and thus a low-output motor **14** may be used with a high reduction ratio. In this case, the influence of the friction of a drive system increases, and thus it is particularly effective to change the current limit value according to the rotation speed of the motor **14** as in the present disclosure.

(61) While the example in which the motor **14** is applied as the "drive" of the present disclosure has been shown in the aforementioned embodiment, the present disclosure is not limited to this. For example, an actuator such as a proportional solenoid, a linear motor, a voice coil, or a spherical actuator may be applied as the "drive" of the present disclosure. Alternatively, a powder clutch/brake or a hysteresis clutch/brake may be applied as the "drive" of the present disclosure.

(62) While the example in which the speed reducer **15** is applied as the "drive force transmitter" of the present disclosure has been shown in the aforementioned embodiment, the present disclosure is not limited to this. For example, when the motor is a linear motor that moves linearly, the drive force transmitter transmits a force of linear movement of the linear motor. Furthermore, the limit value is set to change according to the linear movement speed of the linear motor.

(63) While the example in which the absolute value of the limit value for the forward efficiency is set to gradually increase as the rotation of the motor **14** increases, and the absolute value of the limit value for the reverse efficiency is set to gradually decrease as the rotation of the motor **14** increases has been shown in the aforementioned embodiment, the present disclosure is not limited to this. For example, the absolute value of the limit value for the forward efficiency may be set to increase stepwise as the rotation of the motor **14** increases, and the absolute value of the limit value for the reverse efficiency may be set to decrease stepwise as the rotation of the motor **14** increases.

(64) While the example in which the rate of change of the limit value is set to increase as the speed of the motor increases has been shown in the aforementioned embodiment, the present disclosure is not limited to this. For example, when the rate of change of a decrease in the torque generated by the motor **14** is small (close to linear) with the torque loss of the speed reducer **15** or an increase in the rotation speed of the motor **14**, the rate of change of the limit value may be constant.

(65) While the example in which the limit value for the forward efficiency and the limit value for the reverse efficiency are set has been shown in the aforementioned embodiment, the present disclosure is not limited to this. For example, when a difference between the limit value for the forward efficiency and the limit value for the reverse efficiency is small, a common limit value may be set for both the forward efficiency and the reverse efficiency.

(66) While the example in which the absolute value of the limit value for the reverse efficiency is set to decrease as the rotation speed of the motor **14** increases has been shown in the aforementioned embodiment, the present disclosure is not limited to this. For example, depending on the control of the motor **14**, the absolute value of the limit value for the reverse efficiency may be set to decrease as the rotation speed of the motor **14** increases in a high-speed range of the rotation speed of the motor **14**.

(67) While the example in which the position/speed controller **22** is provided in common (one) for the motors **14***a* to **14***f* has been shown in the aforementioned embodiment, the present disclosure is not limited to this. For example, as shown in FIG. **13**, position/speed controllers **122***a* to **122***f* may be provided individually for motors **14***a* to **14***f*.

(68) While the example in which the position/speed controller **22** is provided separately from the current limiter **23***a* to **23***f* has been shown in the aforementioned embodiment, the present disclosure is not limited to this. For example, as shown in FIG. **14**, one controller **26** including a position/speed controller and a current limiter may be provided.

(69) While the example in which the current limiter **23** is provided upstream of the amplifier **25** has been shown in the aforementioned embodiment, the present disclosure is not limited to this. In the present disclosure, the current limiter **23** is only required to be provided somewhere (such as on the output side of the amplifier **25** or in a line fed back from the encoder **16**) in a line that connects the position/speed controller **22** to the motor **14**.

DESCRIPTION OF REFERENCE NUMERALS

(70) **10**: robot **12**, **12***a* to **12***f*: joint **14**, **14***a* to **14***f*: motor (drive) **15**, **15***a* to **15***f*: speed reducer (drive force transmitter) **20**: robot controller **21**: current limiting device **23**, **23***a* to **23***f*: current limiter **30**: robot (medical robot) **100**: robot system

Claims

1. A current limiting device to limit a current to be carried to a drive that generates a force or moment when the current is carried to the drive and transmits a drive force via a drive force

transmitter, the current limiting device comprising: a current limiter to limit the current to be carried to the drive within a range of a limit value; wherein the limit value is set to change according to a speed of the drive; the limit value includes a limit value for forward efficiency in which a driving direction of the drive and a direction of the force or moment output from the drive are the same as each other, and a limit value for reverse efficiency having a value different from the limit value for the forward efficiency, in which the driving direction of the drive and the direction of the force or moment output from the drive are opposite to each other; and the limit value for the forward efficiency and the limit value for the reverse efficiency are set to linearly change according to a value of the speed of the drive.

2. The current limiting device according to claim 1, wherein an absolute value of the limit value is set to increase or decrease as the speed of the drive increases.

3. The current limiting device according to claim 2, wherein a rate of change of the limit value is set to increase as the speed of the drive increases.

4. The current limiting device according to claim 1, wherein an absolute value of the limit value for the forward efficiency is set to increase as the speed of the drive increases; and an absolute value of the limit value for the reverse efficiency is set to decrease as the speed of the drive increases.

5. The current limiting device according to claim 4, wherein a rate of increase in the limit value for the forward efficiency and a rate of decrease in the limit value for the reverse efficiency are set to increase as the speed of the drive increases.

6. The current limiting device according to claim 1, wherein the drive includes a motor; the drive force transmitter includes a speed reducer to slow rotation of the motor and transmit the rotation; and the limit value is set to change according to a rotation speed of the motor.

7. The current limiting device according to claim 1, wherein the limit value is set to reduce or prevent damage to the drive force transmitter due to the force or moment generated by the drive and to maintain a force or moment on an output side of the drive force transmitter at a constant value.

8. The current limiting device according to claim 1, wherein the drive includes a motor provided at a joint of a robot.

9. The current limiting device according to claim 8, wherein the robot includes a medical robot.

10. A robot system comprising: a robot; and a robot controller configured or programmed to control the robot; wherein the robot includes: a joint; a motor provided at the joint; and a speed reducer to slow rotation of the motor; the robot controller includes a current limiter to limit a current to be carried to the motor within a range of a limit value; the limit value is set to change according to a speed of the motor; the limit value includes a limit value for forward efficiency in which a driving direction of the motor and a direction of the force or moment output from the motor are the same as each other, and a limit value for reverse efficiency having a value different from the limit value for the forward efficiency, in which the driving direction of the motor and the direction of the force or moment output from the motor are opposite to each other; and the limit value for the forward efficiency and the limit value for the reverse efficiency are set to linearly change according to a value of the speed of the motor.

11. A current limiting method for limiting a current to be carried to a drive that generates a force or moment when the current is carried to the drive and transmits a drive force via a drive force transmitter, the current limiting method comprising: acquiring a speed of the drive; setting a limit value of the current to be carried to the drive based on the acquired speed of the drive; and carrying the current to the drive within a range of the set limit value, wherein the limit value includes a limit value for forward efficiency in which a driving direction of the drive and a direction of the force or moment output from the drive are the same as each other, and a limit value for reverse efficiency having a value different from the limit value for the forward efficiency, in which the driving direction of the drive and the direction of the force or moment output from the drive are opposite to

each other; and the limit value for the forward efficiency and the limit value for the reverse efficiency are set to linearly change according to a value of the speed of the drive.