



(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
07.10.2026 Bulletin 2026/41

(51) International Patent Classification (IPC):
E02F 3/38^(2006.01) E02F 9/20^(2006.01)

(21) Application number: **26161600.7**

(52) Cooperative Patent Classification (CPC):
E02F 3/384; E02F 9/207

(22) Date of filing: **02.03.2026**

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC ME MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA
Designated Validation States:
GE KH LA MA MD TN

(72) Inventors:
• **Komori, Etsuro**
Chiyoda-ku, Tokyo, 102-0093 (JP)
• **Nishimura, Kazuyoshi**
Chiyoda-ku, Tokyo, 102-0093 (JP)
• **Akami, Toshiya**
Chiyoda-ku, Tokyo, 102-0093 (JP)

(30) Priority: **03.04.2025 JP 2025061854**

(74) Representative: **Grünecker Patent- und Rechtsanwälte**
PartG mbB
Leopoldstraße 4
80802 München (DE)

(71) Applicant: **NABTESCO CORPORATION**
Chiyoda-ku
Tokyo 102-0093 (JP)

(54) **DRIVE SYSTEM FOR WORK MACHINE, CONTROL DEVICE FOR WORK MACHINE, CONTROL METHOD FOR WORK MACHINE, CONTROL PROGRAM FOR WORK MACHINE, AND WORK MACHINE**

(57) One object is to reduce a moment load acting on an electric actuator that drives an attachment. An excavator includes: a swing bracket rotatable about a swing axis relative to an upper body; a swing actuator configured to rotate the swing bracket; an electric actuator mounted to the swing bracket and configured to output a torque about an axis intersecting the swing axis; an attachment driven by the electric actuator; and a control

device configured to perform specific control in which the swing actuator is controlled so as to maintain a constant rotational position of the swing bracket. When a load torque, which is a torque about the swing axis acting on the swing bracket during the specific control, has reached or exceeded a critical torque, the control device controls the swing actuator so as to reduce the load torque.

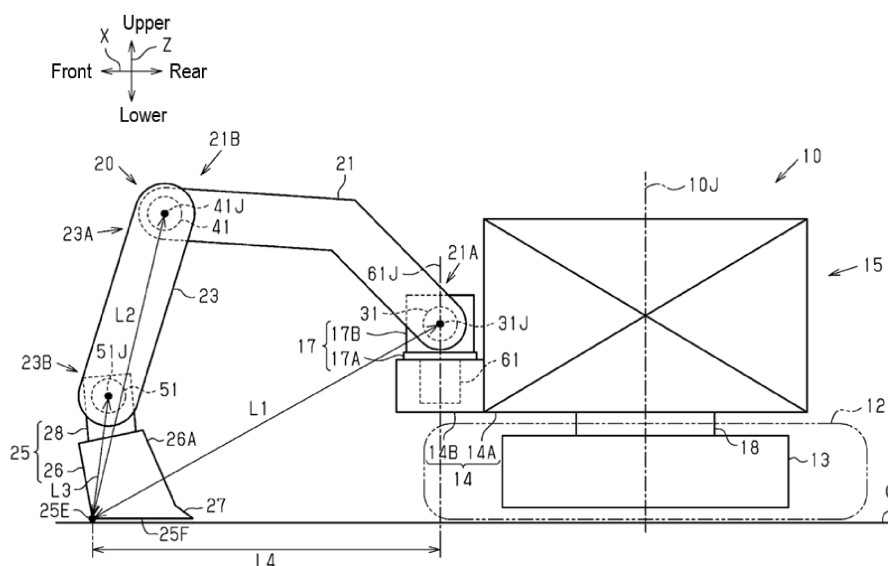


Fig. 1

Description

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application is based on and claims the benefit of priority from Japanese Patent Application Serial No. 2025-061854 (filed on April 3, 2025), the contents of which are hereby incorporated by reference in their entirety.

TECHNICAL FIELD

[0002] The present disclosure relates to a drive system for a work machine, a control device for a work machine, a control method for a work machine, a control program for a work machine, and a work machine.

BACKGROUND

[0003] Japanese Patent Application Publication No. 2001-254395 ("the '395 Publication") discloses an excavator including a vehicle body, a boom, an arm, and a bucket. The boom is coupled to the front end of the vehicle body. The boom can rotate up and down relative to the vehicle body. The arm is coupled to the distal end of the boom. The arm can rotate up and down relative to the boom. The bucket is coupled to the distal end of the arm. The bucket can rotate up and down relative to the arm.

[0004] In technologies such as the one disclosed in the '395 Publication, electric actuators that output torque may be used to drive a boom, an arm, and various attachments for work such as a bucket. Simultaneously, these electric actuators may be located at joints, for example, at the coupling point between the vehicle body and the boom, or between the boom and the arm. With this type of structure, moment loads may act on the electric actuators located at the joints during works using attachments. It is desirable to reduce the burden on the electric actuators due to such moment loads. The same issue can arise not only in excavators but also in any structure where moment loads act directly on an electric actuator.

SUMMARY

[0005] A drive system for a work machine for overcoming the above drawback comprises: a slew actuator configured to rotate an upper body relative to a lower body about a rotation axis; a swing actuator configured to rotate a swing bracket relative to the upper body about a swing axis parallel to the rotation axis; an electric actuator mounted to the swing bracket, the electric actuator being configured to drive an attachment by outputting a torque about an axis intersecting the swing axis; and a control device configured to perform specific control in which the swing actuator is controlled so as to maintain a constant rotational position of the swing bracket relative to the upper body, wherein when a load torque, which is a

torque about the swing axis acting on the swing bracket during the specific control, has reached or exceeded a critical torque, the control device performs load reduction control in which at least one of the slew actuator or the swing actuator is controlled so as to reduce the load torque.

[0006] The load torque acting on the swing bracket reflects the moment load acting on the electric actuator that drives the attachment. In the above configuration, the moment load acting on the electric actuator can be reduced through the load reduction control.

[0007] The drive system for a work machine may further comprise a swing position sensor configured to sense a swing rotational position, the swing rotational position being a rotational position of the swing bracket, wherein the swing actuator has an electric motor serving as a drive source, wherein in the specific control, the control device may repeat: a first process to obtain the swing rotational position; a second process to perform feedback control of the electric motor so as to eliminate a gap between the swing rotational position obtained and the swing rotational position at start of the specific control, and to obtain a current value of power supplied to the electric motor during the feedback control; and a third process to calculate the load torque based on the current value obtained in the second process, and wherein when the load torque calculated in the third process has reached or exceeded the critical torque, the control device may end the second process, and in the load reduction control, the control device may control the power supplied to the electric motor so that the current value of the power supplied to the electric motor is closer to zero than at point of time at which the load torque reached the critical torque.

[0008] In the drive system for a work machine, the swing actuator may include: a hydraulic cylinder to and from which hydraulic oil is supplied and discharged; and a piston rod protruding from inside to outside of the hydraulic cylinder and mounted to the swing bracket, the piston rod having different protruding lengths from the hydraulic cylinder in response to supply and discharge of the hydraulic oil to and from the hydraulic cylinder, wherein the drive system may further comprise: a hydraulic circuit configured to adjust supply and discharge of the hydraulic oil to and from the hydraulic cylinder; and an oil pressure sensor configured to sense an internal oil pressure of the hydraulic cylinder, and wherein in the specific control, the control device may perform: a first process to control supply and discharge of the hydraulic oil to and from the hydraulic cylinder so as to maintain a position of the piston rod at start of the specific control; and a second process to repeat, during the first process, obtaining the internal oil pressure and calculating the load torque based on the internal oil pressure obtained, wherein when the load torque calculated has reached or exceeded the critical torque, the control device may end the first process, and in the load reduction control, the control device may control supply and discharge of the

hydraulic oil such that the piston rod moves from a position of the piston rod at point of time at which the load torque reached the critical torque.

[0009] In the drive system for a work machine, supposing that the electric actuator is a first electric actuator, and the attachment is a first attachment, the drive system may further comprise: a second electric actuator mounted to the first attachment, the second electric actuator being configured to drive a second attachment by outputting a torque about a second axis parallel to a first axis, the first axis being an axis of the first electric actuator; and a third electric actuator mounted to the second attachment, the third electric actuator being configured to drive a third attachment by outputting a torque about a third axis parallel to the first axis, wherein the control device may stores in advance a first allowable moment load, which is a maximum moment load allowed for the first electric actuator, a second allowable moment load, which is a maximum moment load allowed for the second electric actuator, and a third allowable moment load, which is a maximum moment load allowed for the third electric actuator, and wherein during the specific control, the control device may perform a calculation process to calculate the critical torque so that a moment load acting on the first electric actuator is less than or equal to the first allowable moment load, a moment load acting on the second electric actuator is less than or equal to the second allowable moment load, and a moment load acting on the third electric actuator is less than or equal to the third allowable moment load.

[0010] The drive system for a work machine may further comprise: a first position sensor configured to sense a first rotational position, the first rotational position being a rotational position of the first attachment; a second position sensor configured to sense a second rotational position, the second rotational position being a rotational position of the second attachment; and a third position sensor configured to sense a third rotational position, the third rotational position being a rotational position of the third attachment, wherein the control device may store in advance: first relationship information expressing a relationship between the second and third rotational positions and a first distance, the first distance being a distance from a specific region of the third attachment to the first axis in a specific plan view toward a direction along the first axis; second relationship information expressing a relationship between the third rotational position and a second distance, the second distance being a distance from the specific region of the third attachment to the second axis in the specific plan view; a third distance from the specific region of the third attachment to the third axis in the specific plan view; and fourth relationship information expressing a relationship between the first, second, and third rotational positions and a fourth distance, the fourth distance being a distance from the specific region of the third attachment to the swing axis with respect to a direction along an axis orthogonal to both the swing axis and the first axis, and

wherein in the calculation process, the control device may perform: a first calculation process to obtain the first rotational position, the second rotational position, and the third rotational position; a second calculation process to calculate the first distance by applying the second and third rotational positions obtained to the first relationship information, and to calculate a first allowable lateral force by dividing the first allowable moment load by the first distance calculated; a third calculation process to calculate the second distance by applying the third rotational position obtained to the second relationship information, and to calculate a second allowable lateral force by dividing the second allowable moment load by the second distance calculated; a fourth calculation process to calculate a third allowable lateral force by dividing the third allowable moment load by the third distance; a fifth calculation process to calculate the fourth distance by applying the first, second, and third rotational positions obtained to the fourth relationship information; and a sixth calculation process to calculate the critical torque at a value less than or equal to a product of smallest of the first, second, and third allowable lateral forces calculated and the fourth distance.

[0011] In the drive system for a work machine, in the specific control, the control device may control the slew actuator so that the upper body rotates relative to the lower body. In the drive system for a work machine, in the load reduction control, the control device may control the slew actuator so that a rotational speed of the upper body is lower than at point of time at which the load torque reached the critical torque.

[0012] In the drive system for a work machine, supposing that the electric actuator is a first electric actuator, and the attachment is a first attachment, the drive system may further comprise: a second electric actuator mounted to the first attachment, the second electric actuator being configured to drive a second attachment by outputting a torque about a second axis parallel to a first axis, the first axis being an axis of the first electric actuator; a third electric actuator mounted to the second attachment, the third electric actuator being configured to drive a third attachment by outputting a torque about a third axis parallel to the first axis; a first position sensor configured to sense a first rotational position, the first rotational position being a rotational position of the first attachment; a second position sensor configured to sense a second rotational position, the second rotational position being a rotational position of the second attachment; and a third position sensor configured to sense a third rotational position, the third rotational position being a rotational position of the third attachment, wherein the control device may: store, in advance, facing distance information that expresses a relationship between the first, second, and third rotational positions and an estimated facing distance, the estimated facing distance being an estimated shortest distance from a specific region of the third attachment to a ground surface; perform pre-processing to obtain the first, second, and third

rotational positions and calculate the estimated facing distance by applying the first, second, and third rotational positions obtained to the facing distance information; and perform the specific control on a condition that the estimated facing distance is less than or equal to a proximity distance predetermined.

[0013] In the drive system for a work machine, when the load torque has reached or exceeded a handling torque set at a value smaller than the critical torque during the specific control, the control device may perform handling control in which one or more of the first, second, and third electric actuators are controlled so that the specific region is moved upward of a position of the specific region at point of time at which the load torque reached the handling torque.

[0014] A control device for a work machine for overcoming the above drawback is applied to a work machine including: an upper body rotatable about a rotation axis relative to a lower body; a slew actuator configured to rotate the upper body relative to the lower body; a swing bracket coupled to the upper body and rotatable about a swing axis parallel to the rotation axis relative to the upper body; a swing actuator configured to rotate the swing bracket relative to the upper body; an electric actuator mounted to the swing bracket, the electric actuator being configured to output a torque about an axis intersecting the swing axis; and an attachment mounted to the electric actuator and driven by the electric actuator, the control device being configured to: perform specific control in which the swing actuator is controlled so as to maintain a constant rotational position of the swing bracket relative to the upper body; and when a load torque, which is a torque about the swing axis acting on the swing bracket during the specific control, has reached or exceeded a critical torque, perform load reduction control in which at least one of the slew actuator or the swing actuator is controlled so as to reduce the load torque.

[0015] A control method for a work machine for overcoming the above drawback, the work machine including: an upper body rotatable about a rotation axis relative to a lower body; a slew actuator configured to rotate the upper body relative to the lower body; a swing bracket coupled to the upper body and rotatable about a swing axis parallel to the rotation axis relative to the upper body; a swing actuator configured to rotate the swing bracket relative to the upper body; an electric actuator mounted to the swing bracket, the electric actuator being configured to output a torque about an axis intersecting the swing axis; and an attachment mounted to the electric actuator and driven by the electric actuator, a control device applied to the work machine being configured to: perform specific control in which the swing actuator is controlled so as to maintain a constant rotational position of the swing bracket relative to the upper body; and when a load torque, which is a torque about the swing axis acting on the swing bracket during the specific control, has reached or exceeded a critical torque, perform load reduction control in which at least one of the slew

actuator or the swing actuator is controlled so as to reduce the load torque.

[0016] A control program for a work machine, the work machine including: an upper body rotatable about a rotation axis relative to a lower body; a slew actuator configured to rotate the upper body relative to the lower body; a swing bracket coupled to the upper body and rotatable about a swing axis parallel to the rotation axis relative to the upper body; a swing actuator configured to rotate the swing bracket relative to the upper body; an electric actuator mounted to the swing bracket, the electric actuator being configured to output a torque about an axis intersecting the swing axis; and an attachment mounted to the electric actuator and driven by the electric actuator, the control program causing a control device applied to the work machine to: perform specific control in which the swing actuator is controlled so as to maintain a constant rotational position of the swing bracket relative to the upper body; and when a load torque, which is a torque about the swing axis acting on the swing bracket during the specific control, has reached or exceeded a critical torque, perform load reduction control in which at least one of the slew actuator or the swing actuator is controlled so as to reduce the load torque.

[0017] The load torque acting on the swing bracket reflects the moment load acting on the electric actuator that drives the attachment. The above control device, control method, and control program for a work machine can reduce the moment load acting on the electric actuator through the load reduction control.

[0018] A work machine for overcoming the above drawback comprises: an upper body rotatable about a rotation axis relative to a lower body; a slew actuator configured to rotate the upper body relative to the lower body; a swing bracket coupled to the upper body and rotatable about a swing axis parallel to the rotation axis relative to the upper body; a swing actuator configured to rotate the swing bracket relative to the upper body; an electric actuator mounted to the swing bracket, the electric actuator being configured to output a torque about an axis intersecting the swing axis; an attachment mounted to the electric actuator and driven by the electric actuator; and a control device configured to perform specific control in which the swing actuator is controlled so as to maintain a constant rotational position of the swing bracket relative to the upper body, wherein when a load torque, which is a torque about the swing axis acting on the swing bracket during the specific control, has reached or exceeded a critical torque, the control device performs load reduction control in which at least one of the slew actuator or the swing actuator is controlled so as to reduce the load torque.

[0019] The load torque acting on the swing bracket reflects the moment load acting on the electric actuator that drives the attachment. In the above work machine, the moment load acting on the electric actuator can be reduced through the load reduction control.

ADVANTAGEOUS EFFECTS

[0020] The above technical idea can reduce the moment load acting on the electric actuator that drives the attachment.

BRIEF DESCRIPTION OF THE DRAWINGS

[0021]

Fig. 1 is a side view schematically showing an excavator.

Fig. 2 is a plan view schematically showing the excavator.

Fig. 3 shows the electric configuration and the power transmission path of the excavator.

Fig. 4 shows processing of specific control.

Fig. 5 is a flowchart showing a procedure of a swing process.

Fig. 6 is a flowchart showing a procedure of a calculation process.

Fig. 7 is a flowchart showing a procedure of a load reduction routine.

Fig. 8 schematically illustrates a bucket and a third actuator.

Fig. 9 shows a modification example of a swing actuator.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0022] A construction machine is hereinafter used as an example for describing an embodiment of a drive system for a work machine, a control device for a work machine, a control method for a work machine, a control program for a work machine, and a work machine. For simplicity and clarity of explanation, the components shown in the drawings are not necessarily drawn to a fixed scale.

<Overall Configuration>

[0023] As shown in Fig. 1, an excavator 10, serving as a construction machine, includes a lower body 13 and an upper body 14. The upper body 14 is located on the opposite side to the ground surface G with respect to the lower body 13. In this embodiment, when viewed from the lower body 13, the upper body 14 is located in the upper direction, and the direction opposite thereto is the lower direction. A specific one of the directions orthogo-

nal to the upper direction is the front direction, and the direction opposite thereto is the rear direction. Furthermore, the direction that is orthogonal to both of the upper and front directions faces the left and right directions, which are opposite to each other. The front and rear directions may be collectively referred to as X direction. The left and right directions may be collectively referred to as Y direction. The upper and lower directions may be collectively referred to as Z direction.

[0024] The lower body 13 and the upper body 14 constitute a vehicle body 15. The lower body 13 is shaped like a rectangular parallelepiped, for example. The upper body 14 includes a case main portion 14A and a case front portion 14B. The case main portion 14A is shaped like a rectangular parallelepiped, for example. The interior of the case main portion 14A constitutes a hollow housing space. The housing space houses various devices for operating the excavator 10. The case front portion 14B is positioned frontward of the case main portion 14A. The case front portion 14B is positioned substantially in the middle of the case main portion 14A in the Y direction. The case front portion 14B is fixed to the front surface of the case main portion 14A. The case front portion 14B is shaped like a rectangular parallelepiped, for example, smaller than the case main portion 14A. The interior of the case front portion 14B is hollow. Although not shown in the drawings, the upper body 14 includes a cabin for the operator. The cabin is integrally fixed to the case main portion 14A. The upper body 14 may be herein referred to as a slewable upper structure.

[0025] As shown in Fig. 1, the excavator 10 includes a slewing bearing 18. The slewing bearing 18 is interposed between the lower body 13 and the upper body 14. In Fig. 1, the width of the slewing bearing 18 in the top-to-bottom direction is shown in an exaggerated manner in the Z direction. As shown in Fig. 2, the slewing bearing 18 has an annular inner race 18A, an annular outer race 18B, and a plurality of rolling elements. Fig. 2 does not show the rolling elements. The outer diameter of the inner race 18A is smaller than the inner diameter of the outer race 18B. A slewing axis 10J, which is the central axis of the inner race 18A, substantially coincides with the central axis of the outer race 18B. The slewing axis 10J extends in the upper and lower directions relative to the vehicle body 15, or in the Z direction. As shown in Fig. 1, the slewing axis 10J extends in the top-to-bottom direction through both the upper body 14 and the lower body 13. The rolling elements are interposed between the inner race 18A and the outer race 18B. The rolling elements support the inner race 18A and the outer race 18B such that they can rotate relative to each other. The outer race 18B is thus rotatable about the slewing axis 10J relative to the inner race 18A. The inner race 18A is fixed to the lower body 13. The outer race 18B is fixed to the case main portion 14A of the upper body 14. Accordingly, the upper body 14 is rotatable about the slewing axis 10J relative to the lower body 13. The slewing axis 10J is the rotation axis about which the upper body 14 rotates

relative to the lower body 13.

[0026] As shown in Figs. 1 and 2, the excavator 10 includes a pair of traveling units 12. The traveling units 12 are provided at the left and right sides of the lower body 13. Each of the traveling units 12 is connected to the lower body 13. The traveling units 12 each include a traveling crawler, an operating mechanism for circulating the crawler, among other components. The crawler is shaped like an endless belt. The crawler is open on both the left and right sides. The lower surface of the crawler is in contact with the ground surface G. The excavator 10 travels as the crawler circulates. The traveling units 12 and the lower body 13 may be collectively referred to as an undercarriage.

[0027] As shown in Figs. 1 and 2, the excavator 10 includes a swing bracket 17. The swing bracket 17 is positioned frontward of the case main portion 14A of the upper body 14. The swing bracket 17 includes a first swing wall 17A and a second swing wall 17B. The first swing wall 17A is located on the upper surface of the case front portion 14B in the upper body 14. The first swing wall 17A is shaped like a circular plate, for example. The first swing wall 17A is connected to the case front portion 14B. The first swing wall 17A can rotate about a swing axis 61J relative to the case front portion 14B. The swing axis 61J is substantially parallel to the slewing axis 10J. The swing axis 61J will be further described below. The second swing wall 17B protrudes upward from the upper surface of the first swing wall 17A. The second swing wall 17B is shaped like a rectangular plate. The excavator 10 includes a drive system. The drive system includes the swing bracket 17 and the upper body 14.

<Attachments>

[0028] As shown in Fig. 1, the excavator 10 includes a work unit 20. The work unit 20 includes a boom 21, an arm 23, and a bucket 25. The boom 21 is a first attachment. The arm 23 is a second attachment. The bucket 25 is a third attachment. The work unit 20 is included in the components of the drive system.

[0029] As shown in Fig. 1, the boom 21 is positioned frontward of the case main portion 14A of the upper body 14. The boom 21 is shaped like an elongated plate or column. As shown in Fig. 2, the first end portion 21A of the boom 21 in its longitudinal direction is aligned with the second swing wall 17B in the direction along a first axis 31J. The first axis 31J is an imaginary axis that is substantially orthogonal to the swing axis 61J. The first axis 31J will be further described below. The first end portion 21A of the boom 21 is rotatably coupled to the second swing wall 17B of the swing bracket 17.

[0030] As shown in Fig. 1, the arm 23 extends from a second end portion 21B of the boom 21 that is opposite the first end portion 21A. The arm 23 is shaped like an elongated plate or column. As shown in Fig. 2, a first end portion 23A of the arm 23 in its longitudinal direction is aligned with the second end portion 21B of the boom 21 in

the direction along a second axis 41J. The second axis 41J is an imaginary axis that is substantially parallel to the first axis 31J. The second axis 41J will be further described below. The first end portion 23A of the arm 23 is rotatably coupled to the second end portion 21B of the boom 21.

[0031] As shown in Fig. 1, the bucket 25 is located near a second end portion 23B of the arm 23 that is opposite the first end portion 23A. The bucket 25 includes a bucket body 26, a plurality of teeth 27, and a bucket coupling wall 28. The bucket body 26 is shaped like a box. Specifically, the bucket body 26 includes a rectangular bottom wall and four peripheral walls rising from the four edges of the bottom wall. The four peripheral walls are connected to one another. One of the four peripheral walls is a specific wall 25F, and the boundary between the specific wall 25F and the bottom wall constitutes a specific region 25E of this embodiment. As shown in Fig. 2, the ends of the four peripheral walls opposite to the bottom wall define an opening 26A. The teeth 27 protrude from the end of the specific wall 25F opposite to the bottom wall. The bucket coupling wall 28 protrudes from one of the four peripheral walls of the bucket body 26 that is opposed to the specific wall 25F. The bucket coupling wall 28 is aligned with the second end portion 23B of the arm 23 in the direction along a third axis 51J. The third axis 51J is an imaginary axis that is substantially parallel to both the first axis 31J and the second axis 41J. The third axis 51J will be further described below. The bucket coupling wall 28 is rotatably coupled to the second end portion 23B of the arm 23.

<Actuators>

[0032] As shown in Fig. 3 the work unit 20 includes a first actuator 31, a second actuator 41, and a third actuator 51. The excavator 10 also includes a first inverter 35, a second inverter 45, a third inverter 55, and a battery 19 as components related to the work unit 20. Although not shown in the drawings, the first inverter 35, the second inverter 45, the third inverter 55, and the battery 19 are housed in the case main portion 14A of the upper body 14.

[0033] As shown in Fig. 2, the first actuator 31 is located between the second swing wall 17B of the swing bracket 17 and the first end portion 21A of the boom 21. As shown in Fig. 3, the first actuator 31 includes a first electric motor 32 and a first speed reducer 33. The first electric motor 32 is a three-phase AC motor. The first electric motor 32 is electrically connected to the battery 19 via the first inverter 35. The first electric motor 32 has a housing 32A and an output shaft 32B that can rotate relative to the housing 32A. The housing 32A is mounted to the second swing wall 17B of the swing bracket 17. The output shaft 32B protrudes from the inside of the housing 32A to the outside. The output shaft 32B is shaped like a circular column. The output shaft 32B can rotate about its own central axis, or the first axis 31J, relative to the housing 32A. In other words, the output shaft 32B outputs torque about the first axis 31J. The output shaft 32B is rotatable

in both forward and reverse directions about the first axis 31J. As shown in Fig. 2, the first axis 31J extends through both the second swing wall 17B of the swing bracket 17 and the first end portion 21A of the boom 21.

[0034] As shown in Fig. 3, the first speed reducer 33 includes a housing 33A, a reduction mechanism 33B, and an output member 33C. The housing 33A is mounted to the housing 32A of the first electric motor 32. The reduction mechanism 33B is located inside the housing 33A. The reduction mechanism 33B receives torque input from the output shaft 32B of the first electric motor 32. The reduction mechanism 33B amplifies the torque from the first electric motor 32 at a predetermined ratio and outputs the amplified torque to the output member 33C. The reduction mechanism 33B may be of, for example, an eccentric oscillation gear type or planetary gear type. The output member 33C is shaped like a circular column. The central axis of the output member 33C substantially coincides with the first axis 31J. The output member 33C is rotatable relative to the housing 33A. The output member 33C rotates about the first axis 31J in response to the rotation of the output shaft 32B of the first electric motor 32. The output member 33C is mounted to the first end portion 21A of the boom 21. Thus, the output member 33C inputs torque to the boom 21. When acted upon by this torque, the boom 21 rotates about the first axis 31J. Thus, the boom 21 is driven by the first actuator 31. As described above, the first actuator 31 can be electrically driven by the first electric motor 32. The first actuator 31 constitutes the first electric actuator.

[0035] As shown in Fig. 2, the second actuator 41 is located between the second end portion 21B of the boom 21 and the first end portion 23A of the arm 23. The configuration of the second actuator 41 is basically the same as that of the first actuator 31, except for details such as dimensions, reduction ratio, and output. Therefore, the configuration of the second actuator 41 is briefly described below.

[0036] As shown in Fig. 3, the second actuator 41 includes a second electric motor 42 and a second speed reducer 43. The second electric motor 42 is electrically connected to the battery 19 via the second inverter 45. The housing 42A of the second electric motor 42 is mounted to the second end portion 21B of the boom 21. An output shaft 42B of the second electric motor 42 outputs torque about its own central axis, or the second axis 41J. As shown in Fig. 2, the second axis 41J extends through both the second end portion 21B of the boom 21 and the first end portion 23A of the arm 23. The output member 43C of the second speed reducer 43 is mounted to the first end portion 23A of the arm 23. As shown in Fig. 3, the output member 43C outputs torque about the second axis 41J. The arm 23 rotates about the second axis 41J in response to the torque from the output member 43C. Thus, the arm 23 is driven by the second actuator 41. As described above, the second actuator 41 can be electrically driven by the second electric motor 42. The second actuator 41 constitutes the second electric

actuator. A housing 43A and a reduction mechanism 43B of the second speed reducer 43 have the same function as the housing 33A and reduction mechanism 33B of the first speed reducer 33.

[0037] As shown in Fig. 2, the third actuator 51 is located between the second end portion 23B of the arm 23 and the bucket coupling wall 28 of the bucket 25. The configuration of the third actuator 51 is basically the same as that of the first actuator 31, except for details such as dimensions, reduction ratio, and output. Therefore, the configuration of the third actuator 51 is briefly described below.

[0038] As shown in Fig. 3, the third actuator 51 includes a third electric motor 52 and a third speed reducer 53. The third electric motor 52 is electrically connected to the battery 19 via the third inverter 55. The housing 52A of the third electric motor 52 is mounted to the second end portion 23B of the arm 23. An output shaft 52B of the third electric motor 52 outputs torque about its own central axis, or the third axis 51J. As shown in Fig. 2, the third axis 51J extends through both the second end portion 23B of the arm 23 and the bucket coupling wall 28. The output member 53C of the third speed reducer 53 is mounted to the bucket coupling wall 28. As shown in Fig. 3, the output member 53C outputs torque about the third axis 51J. The bucket 25 rotates about the third axis 51J in response to the torque from the output member 53C. Thus, the bucket 25 is driven by the third actuator 51. As described above, the third actuator 51 can be electrically driven by the third electric motor 52. The third actuator 51 constitutes the third electric actuator. A housing 53A and a reduction mechanism 53B of the third speed reducer 53 have the same function as the housing 33A and reduction mechanism 33B of the first speed reducer 33.

[0039] As shown in Fig. 3, the excavator 10 includes a swing actuator 61 and a fourth inverter 65. The swing actuator 61 is included in the components of the drive system. As shown in Fig. 1, the swing actuator 61 is housed in the case front portion 14B of the upper body 14. Although not shown, the fourth inverter 65 is housed in the case main portion 14A of the upper body 14. The configuration of the swing actuator 61 is basically the same as that of the first actuator 31, except for details such as dimensions, reduction ratio, and output. The configuration of the swing actuator 61 is therefore only briefly described below.

[0040] As shown in Fig. 3, the swing actuator 61 has a fourth electric motor 62, serving as a drive source, and a fourth speed reducer 63. The fourth electric motor 62 is electrically connected to the battery 19 via the fourth inverter 65. The fourth electric motor 62 has a housing 62A mounted to the case main portion 14A of the upper body 14. An output shaft 62B of the fourth electric motor 62 outputs torque about its own central axis, or the swing axis 61J. An output member 63C of the fourth speed reducer 63 is mounted to the first swing wall 17A of the swing bracket 17. The output member 63C outputs torque about the swing axis 61J. The swing bracket 17

rotates about the swing axis 61J in response to the torque from the output member 63C. In other words, the swing actuator 61 rotates the swing bracket 17 relative to the upper body 14. A housing 63A and a reduction mechanism 63B of the fourth speed reducer 63 have the same function as the housing 33A and reduction mechanism 33B of the first speed reducer 33.

[0041] The swing actuator 61 includes a brake device 64. The brake device 64 applies braking torque to the output shaft 62B of the fourth electric motor 62 or the output member 63C of the fourth speed reducer 63. The magnitude of the braking torque is adjustable. Although not shown in the drawings, other actuators also include a brake device similar to that of the swing actuator 61.

[0042] As shown in Fig. 3, the excavator 10 includes a slew actuator 71 and a fifth inverter 75. The slew actuator 71 is included in the components of the drive system. The slew actuator 71 and the fifth inverter 75 are housed in the case main portion 14A of the upper body 14. The configuration of the slew actuator 71 is basically the same as that of the first actuator 31, except for details such as dimensions, reduction ratio, and output. The configuration of the slew actuator 71 is therefore only briefly described below.

[0043] As shown in Fig. 3, the slew actuator 71 has a fifth electric motor 72 and a fifth speed reducer 73. The fifth electric motor 72 is electrically connected to the battery 19 via the fifth inverter 75. The fifth electric motor 72 has a housing 72A mounted to the case main portion 14A of the upper body 14. An output member 73C of the fifth speed reducer 73 has a plurality of teeth. The teeth mesh with the teeth of the inner race 18A of the slewing bearing 18. The output member 73C outputs torque about an axis aligned with the central axis 71J of the output shaft 72B of the fifth electric motor 72. This torque causes the upper body 14 to rotate with the housing 72A of the fifth electric motor 72, relative to the inner race 18A and thus the lower body 13. In other words, the slew actuator 71 causes the upper body 14 to rotate relative to the lower body 13. A housing 73A and a reduction mechanism 73B of the fifth speed reducer 73 have the same function as the housing 33A and reduction mechanism 33B of the first speed reducer 33.

<Sensors>

[0044] As shown in Fig. 3, the excavator 10 includes a first position sensor 38, a second position sensor 48, a third position sensor 58, and a swing position sensor 68. The first position sensor 38, second position sensor 48, third position sensor 58, and swing position sensor 68 are included in the components of the drive system.

[0045] The first position sensor 38 senses a rotational position 38S of the first electric motor 32. The rotational position of the first electric motor 32 is strictly the rotational position of the output shaft 32B of the first electric motor 32. For the other electric motors, their rotational positions are similarly described without referring to their

output shafts. The second position sensor 48 senses a rotational position 48S of the second electric motor 42. The third position sensor 58 senses a rotational position 58S of the third electric motor 52. The swing position sensor 68 senses a rotational position 68S of the fourth electric motor 62. The rotational positions sensed by the position sensors are represented by values in the range of 0 to 360 degrees, with a predetermined reference position defined as 0 degrees. In other words, the rotational positions represent the absolute angles of the respective electric motors. The position sensors repeatedly transmit signals corresponding to the sensed information to a control device 100, which will be described below.

[0046] The excavator 10 includes an inclination sensor 81 and a current sensor 82. The inclination sensor 81 and the current sensor 82 are included in the components of the drive system. The inclination sensor 81 is mounted to the vehicle body 15. For example, the inclination sensor 81 is mounted to the case main portion 14A of the upper body 14. The inclination sensor 81 senses the inclination 81S of the upper body 14 and thus the vehicle body 15 relative to the horizontal plane. The current sensor 82 senses a swing current value SC, which indicates the current value of the power supplied to the fourth electric motor 62. The swing current value SC takes positive and negative values depending on the direction of rotation of the output shaft 62B of the fourth electric motor 62. The inclination sensor 81 and the current sensor 82 repeatedly transmit signals corresponding to the sensed information to the control device 100, which will be described below.

[0047] The excavator 10 includes various operating devices 90. The various operating devices 90 are located in the cabin, for example. The various operating devices 90 include a lever and a switch that can be operated by the operator. Fig. 3 shows the various operating devices 90 as a single unit. The various operating devices 90 transmit signals 90S in accordance with the operator's operations to the control device 100 described below. The various operating devices 90 are included in the components of the drive system.

<Control Device>

[0048] As shown in Fig. 3, the excavator 10 includes a control device 100. The control device 100 is included in the components of the drive system. The control device 100 is a computer with a processing circuit. The processing circuit includes a CPU 101 as an execution unit and a memory 102 as a storage unit. The memory 102 includes three types of storage media: a RAM, a ROM, and an electrically rewritable nonvolatile memory. In this embodiment, these three types of storage media are collectively referred to as the memory 102. The memory 102 stores in advance various control programs 102A that describe the processes to be executed by the CPU 101. The memory 102 stores in advance various control data

102B necessary for the CPU 101 to execute the control programs 102A. The processing circuit includes a communication circuit for wireless communication with an external device.

[0049] The CPU 101 receives sensing signals from the various sensors mounted on the excavator 10. For example, the CPU 101 receives sensing signals from the inclination sensor 81 and the current sensor 82. The CPU 101 also receives a sensing signal from the swing position sensor 68. When receiving a sensing signal from the swing position sensor 68, the CPU 101 converts the received rotational position 68S of the fourth electric motor 62 to a swing rotational position SW. The swing rotational position SW is the rotational position of the swing bracket 17 relative to a predetermined swing reference position. For example, the swing reference position is a rotational position of the swing bracket 17 where both of the main surfaces of the plate-shaped second swing wall 17B face the Y direction. The CPU 101 converts the rotational position 68S of the fourth electric motor 62 to the swing rotational position SW based on the reduction ratio of the fourth speed reducer 63 and the history of the rotation of the fourth electric motor 62. Calculation of the swing rotational position SW by such conversion is equivalent to obtaining the swing rotational position SW. Although a repeated explanation is omitted, the calculation of other rotational positions that will be described later is equivalent to obtaining the respective rotational positions. The swing rotational position SW can be regarded as the rotational position of the swing bracket 17 relative to the upper body 14. As can be seen from the conversion of the rotational position 68S of the fourth electric motor 62 to the swing rotational position SW, the swing position sensor 68 that senses the rotational position 68S of the fourth electric motor 62 can be said to sense the swing rotational position SW in effect.

[0050] The CPU 101 receives a sensing signal from the first position sensor 38. When receiving a sensing signal from the first position sensor 38, the CPU 101 converts the received rotational position 38S of the first electric motor 32 to a first rotational position 21W. The first rotational position 21W is the rotational position of the boom 21 relative to a first reference position predetermined. The first reference position is defined in the view of the excavator 10 as seen in the direction along the first axis 31J. An example of the first reference position is a rotational position at which both the first end portion 21A and the second end portion 21B of the boom 21 are positioned in an imaginary straight line orthogonal to both the first axis 31J and the swing axis 61J. In this example of the first reference position, the second end portion 21B of the boom 21 is positioned opposite the upper body 14 across the first axis 31J. The first rotational position 21W can also be regarded as the rotational position of the boom 21 relative to the swing bracket 17. Like the swing position sensor 68, the first position sensor 38, which senses the rotational position 38S of the first electric motor 32, senses the first rotational position 21W in effect.

[0051] The CPU 101 receives a sensing signal from the second position sensor 48. As in the case of other position sensors, when receiving a sensing signal from the second position sensor 48, the CPU 101 converts the received rotational position 48S of the second electric motor 42 to a second rotational position 23W. The second rotational position 23W is the rotational position of the arm 23 relative to a second reference position predetermined. The second reference position is defined in the view of the excavator 10 as seen in the direction along the second axis 41J. An example of the second reference position is a rotational position at which both the first end portion 23A and the second end portion 23B of the arm 23 are positioned in an imaginary straight line passing through the first axis 31J and the second axis 41J. In this example of the second reference position, the second end portion 23B of the arm 23 is positioned opposite the first axis 31J across the second axis 41J. The second rotational position 23W can also be regarded as the rotational position of the arm 23 relative to the boom 21. Like other position sensors, the second position sensor 48, which senses the rotational position 48S of the second electric motor 42, senses the second rotational position 23W in effect.

[0052] The CPU 101 receives a sensing signal from the third position sensor 58. As in the case of other position sensors, when receiving a sensing signal from the third position sensor 58, the CPU 101 converts the received rotational position 58S of the third electric motor 52 to a third rotational position 25W. The third rotational position 25W is the rotational position of the bucket 25 relative to a third reference position predetermined. The third reference position is defined in the view of the excavator 10 as seen in the direction along the third axis 51J. An example of the third reference position is a rotational position at which the distal end of the teeth 27 of the bucket 25 is positioned in an imaginary straight line passing through the second axis 41J and the third axis 51J. In this example of the third reference position, the distal end of the teeth 27 of the bucket 25 is positioned opposite the second axis 41J across the third axis 51J. The third rotational position 25W can also be regarded as the rotational position of the bucket 25 relative to the arm 23. Like other position sensors, the third position sensor 58, which senses the rotational position 58S of the third electric motor 52, senses the third rotational position 25W in effect.

[0053] After calculating the first rotational position 21W, the second rotational position 23W, and the third rotational position 25W, the CPU 101 calculates two information items indicating the positional relationship between the bucket 25 and the ground surface G. The two information items are the estimated facing distance 25M and the attitude index 25N.

[0054] The estimated facing distance 25M is an estimate of the shortest distance from the specific region 25E of the bucket 25 to the ground surface G. The memory 102 stores facing distance information in advance, which represents the relationship among the first rotational

position 21W, the second rotational position 23W, and the third rotational position 25W, the inclination 81S of the vehicle body 15, and the estimated facing distance 25M. The facing distance information includes, for example, a table, graph, or formula. The facing distance information is generated, for example, by simulation using a model replicating the excavator 10. The facing distance information is a type of control data 102B stored on the memory 102. The CPU 101 calculates the latest estimated facing distance 25M based on the facing distance information. Thus, after obtaining the latest first rotational position 21W, the latest second rotational position 23W, the latest third rotational position 25W, and the latest inclination 81S of the vehicle body 15, the CPU 101 applies these obtained information items to the facing distance information. The CPU 101 thus calculates the estimated facing distance 25M in accordance with the current posture of the work unit 20 and the inclination 81S of the vehicle body 15. The CPU 101 repeats the calculation of the estimated facing distance 25M. The process in which the CPU 101 repeats the calculation of the estimated facing distance 25M is the first pre-processing.

[0055] The attitude index 25N is an index indicating the attitude of the bucket 25. The attitude index 25N can take either the first or second value. The first value indicates that the specific wall 25F of the bucket 25 is estimated to be substantially parallel to the ground surface G. The second value indicates that the specific wall 25F of the bucket 25 is estimated to be not parallel to the ground surface G. The memory 102 stores bucket attitude information in advance, which represents the relationship among the first rotational position 21W, the second rotational position 23W, and the third rotational position 25W, the inclination 81S of the vehicle body 15, and the attitude index 25N. The bucket attitude information includes, for example, a table, graph, or formula. The bucket attitude information is generated, for example, by simulation using a model replicating the excavator 10. The bucket attitude information is a type of control data 102B stored on the memory 102. The CPU 101 calculates the latest attitude index 25N based on the bucket attitude information. Thus, after obtaining the latest first rotational position 21W, the latest second rotational position 23W, the latest third rotational position 25W, and the latest inclination 81S of the vehicle body 15, the CPU 101 applies these obtained information items to the bucket attitude information. The CPU 101 thus calculates the attitude index 25N in accordance with the current posture of the work unit 20 and the inclination 81S of the vehicle body 15. The CPU 101 repeats the calculation of the attitude index 25N. The process in which the CPU 101 repeats the calculation of the attitude index 25N is the second pre-processing.

[0056] As mentioned above, the CPU 101 takes into account the inclination 81S of the vehicle body 15 for calculating the estimated facing distance 25M and the attitude index 25N. This is for the following reasons. At the work site of the excavator 10, for example, the ground

surface G on which the vehicle body 15 is located may be inclined with respect to the horizontal plane, while the ground surface G in front of the vehicle body, which is the object of work of the work unit 20, may be horizontal, or vice versa. When considering such a work site, the inclination 81S of the vehicle body 15 should be taken into account for the calculation of the estimated facing distance 25M and attitude index 25N, so as to obtain the estimated facing distance 25M and attitude index 25N appropriately.

<Control>

[0057] The CPU 101 receives an operation signal 90S transmitted from the operating device 90. The CPU 101 controls the slew actuator 71, the swing actuator 61, and each actuator of the work unit 20 in accordance with the operation signal 90S from the operating device 90. In controlling these actuators, the CPU 101 controls, in effect, the respective electric motors and, moreover, the inverters connected to the electric motors. The CPU 101 can be said to control the supply of power to the electric motors through the control of the inverters.

[0058] The CPU 101 can perform specific control as part of the control related to the slew actuator 71, the swing actuator 61, and each actuator of the work unit 20. In the specific control, the CPU 101 controls the swing actuator 61 to maintain the swing rotational position SW constant. Simultaneously, in the specific control, the CPU 101 controls the slew actuator 71 so that the upper body 14 rotates relative to the lower body 13. As a precondition for the specific control, the CPU 101 determines whether or not the execution condition for the specific control is satisfied. The execution condition is that all three of the following requirements (A1), (A2), and (A3) are fulfilled. (A1) The estimated facing distance 25M is less than or equal to a proximity distance GM. (A2) The attitude index 25N is at the first value. In other words, the specific wall 25F of the bucket 25 is substantially parallel to the ground surface G. (A3) An operation signal 90S for rotating the upper body 14 has been received.

[0059] As to the requirement (A1), the proximity distance GM is predetermined as the distance at which the specific region 25E of the bucket 25 is likely to contact the ground surface G. The proximity distance GM is, for example, 30 cm. As can be seen from the setting of the proximity distance GM, when the requirements (A1) and (A2) are fulfilled, the entire specific wall 25F of the bucket 25, including the specific region 25E, is located close to the ground surface G. In the specific control, the CPU 101 performs a ground leveling work in which the bucket 25 is slewed along the ground surface G in such a proximity state.

[0060] The CPU 101 repeats the determination on whether or not the execution condition is satisfied based on the latest values of the parameters related to the requirements (A1), (A2), and (A3). The CPU 101 then performs the specific control when the execution condi-

tion is satisfied, i.e., the three requirements are fulfilled. The CPU 101 continues the specific control while the execution condition is satisfied. The CPU 101 can be said to automatically determine that there is a request for performing the ground leveling work when the execution condition is satisfied.

<Details of Specific Control>

[0061] As shown in Fig. 4, the specific control includes slew process Q1, attachment process Q2, swing process Q3, and calculation process Q4. The calculation process Q4 may be treated as a process separate from the specific control, not as part of the specific control.

[0062] The slew process Q1 is the process for rotating the upper body 14 relative to the lower body 13. In the slew process Q1, the CPU 101 controls the slew actuator 71 so that the upper body 14 rotates at a set rotational speed. The set rotational speed may be predetermined at a single value suitable for ground leveling work, or it may be predetermined at multiple stepwise values. If the set rotational speed is predetermined at multiple stepwise values, the CPU 101 should select the value that corresponds to the operation signal 90S from the operating device 90.

[0063] The attachment process Q2 is for adjusting the first rotational position 21W, second rotational position 23W, and third rotational position 25W. The ground leveling work is basically performed with the first rotational position 21W, the second rotational position 23W, and the third rotational position 25W maintained constant. In some cases, however, the operator may wish to fine-tune the first rotational position 21W, second rotational position 23W, and third rotational position 25W. In the attachment process Q2, the CPU 101 controls one or more of the first actuator 31, the second actuator 41, and the third actuator 51 in accordance with the operation signal 90S from the operating device 90.

<Swing Process>

[0064] The swing process Q3 is for controlling the swing actuator 61 so as to maintain the swing rotational position SW constant. The swing process Q3 is also for calculating a load torque FU. The load torque FU is the torque about the swing axis 61J acting on the swing bracket 17 from the work unit 20. Specifically, the load torque FU is the torque acting on the swing bracket 17 in response to the force acting on the specific region 25E of the bucket 25 in the direction along the third axis 51J.

[0065] As shown in Fig. 5, the CPU 101 first performs step S11 in the swing process Q3. In step S11, the CPU 101 obtains the latest swing rotational position SW. The process in step S11 constitutes a first process. When the CPU 101 performs the process in step S11 for the first time after the start of the specific control and thus the swing process Q3, the obtained swing rotational position SW is stored on the memory 102 as the initial position

SWA. After performing the process in step S11, the CPU 101 proceeds to step S12.

[0066] In step S12, the CPU 101 performs feedback control of the fourth electric motor 62 in the swing actuator 61. Specifically, the CPU 101 performs feedback control of the fourth electric motor 62 so as to eliminate the gap between the swing rotational position SW obtained in step S11 and the initial position SWA. More specifically, the CPU 101 calculates a target current value required to eliminate the difference between the swing rotational position SW and the initial position SWA. The target current value takes positive and negative values in accordance with the direction of rotation of the output shaft 62B of the fourth electric motor 62. Therefore, the target current value reflects both the amount and direction of current supplied to the fourth electric motor 62. After calculating the target current value, the CPU 101 supplies power to the fourth electric motor 62 so that the current flows at the target current value. The CPU 101 performs the feedback control of the fourth electric motor 62 over a predetermined control time. The control time is, for example, less than 1 second. After performing the process in step S12, the CPU 101 proceeds to step S13. The process in step S12 constitutes a second process.

The CPU 101 calculating the target current value is equivalent to the CPU 101 obtaining the swing current value SC during the feedback control described above. The CPU 101 may obtain the actual swing current value SC from the current sensor 82 while performing step S12.

[0067] In step S13, the CPU 101 calculates the load torque FU. Specifically, the CPU 101 converts the swing current value SC obtained in step S12 into the torque output by the fourth electric motor 62. Furthermore, the CPU 101 converts the converted torque into the torque acting on the swing bracket 17 from the output member 63C of the fourth speed reducer 63, taking into account the reduction ratio of the fourth speed reducer 63. The CPU 101 treats the absolute value of this torque as the load torque FU. Thus, the CPU 101 calculates the load torque FU based on the swing current value SC obtained in step S12. The memory 102 stores in advance as control data 102B various information necessary in the process of converting the swing current value SC into the load torque FU. After performing the process in step S13, the CPU 101 returns to step S11. The CPU 101 then quickly performs the process in step S11. Thus, in the swing process Q3, the CPU 101 repeats steps S11, S12, and S13. The process in step S13 constitutes a third process.

[0068] The following describes the relationship between the swing current value SC and the load torque FU in relation to the process in step S13. Suppose that a certain magnitude of load torque FU is acting on the swing bracket 17 while step S12 is performed. As described above, in step S12, the CPU 101 performs the feedback control of the fourth electric motor 62 so as to maintain the rotational position of the swing bracket 17 at the initial position SWA. The torque of the swing actuator

61 required to maintain the rotational position of the swing bracket 17 constant has the same magnitude as the load torque FU, but is in the opposite direction. Therefore, if the torque of the swing actuator 61 is known, the load torque FU is known. Also, as is well known, the torque of the swing actuator 61, and thus the torque of the fourth electric motor 62, reflects the swing current value SC. Because of this relationship, the CPU 101 can calculate the load torque FU from the swing current value SC in step S13.

<Calculation Process>

[0069] The calculation process Q4 is for calculating a critical torque FK. The critical torque FK is the reference value for the magnitude of the load torque FU.

[0070] As shown in Fig. 6, the CPU 101 first performs step S51 in the calculation process Q4. In step S51, the CPU 101 obtains the latest first rotational position 21W, the latest second rotational position 23W, and the latest third rotational position 25W. The CPU 101 then proceeds to step S52. The process in step S51 constitutes a first calculation process.

[0071] In step S52, the CPU 101 calculates a first allowable lateral force FH1. The first allowable lateral force FH1 will be described below, along with the second and third allowable lateral forces FH2 and FH3 mentioned below. In calculating the first allowable lateral force FH1, the CPU 101 first calculates a first distance L1. As shown in Fig. 1, the plan view of the excavator 10 as seen in the direction along the first axis 31J is referred to as the specific plan view. The first distance L1 is the distance from the specific region 25E of the bucket 25 to the first axis 31J in the specific plan view. The memory 102 stores in advance first relationship information related to the first distance L1. The first relationship information represents the relationship between the second and third rotational positions 23W and 25W and the first distance L1. Specifically, the first relationship information represents the first distance L1 for each combination of different values of the second and third rotational positions 23W and 25W. The first relationship information includes, for example, a table, graph, or formula. The first relationship information is generated, for example, by simulation using a model replicating the excavator 10. The first relationship information is a type of control data 102B stored on the memory 102. The CPU 101 applies the second rotational position 23W and the third rotational position 25W obtained in step S51 to the first relationship information to calculate the first distance L1 according to the current posture of the work unit 20. After calculating the first distance L1, the CPU 101 calculates the first allowable lateral force FH1 by dividing a first allowable moment load M1 by the first distance L1 calculated. The memory 102 stores in advance the first allowable moment load M1 as the control data 102B. The first allowable moment load M1 is the maximum moment load allowed for the first actuator 31. The moment load will be described below. As

shown in Fig. 6, after calculating the first allowable lateral force FH1, the CPU 101 proceeds to step S53. The process in step S52 constitutes a second calculation process.

[0072] In step S53, the CPU 101 calculates a second allowable lateral force FH2. In calculating the second allowable lateral force FH2, the CPU 101 first calculates a second distance L2. As shown in Fig. 1, the second distance L2 is the distance from the specific region 25E of the bucket 25 to the second axis 41J in the specific plan view. The memory 102 stores in advance second relationship information related to the second distance L2. The second relationship information represents the relationship between the third rotational position 25W and the second distance L2. Specifically, the second relationship information represents the second distance L2 for different values of the third rotational position 25W. The second relationship information includes, for example, a table, graph, or formula. The second relationship information is generated, for example, by simulation using a model replicating the excavator 10. The second relationship information is a type of control data 102B stored on the memory 102. The CPU 101 applies the third rotational position 25W obtained in step S51 to the second relationship information to calculate the second distance L2 according to the current posture of the work unit 20. After calculating the second distance L2, the CPU 101 calculates the second allowable lateral force FH2 by dividing a second allowable moment load M2 by the second distance L2 calculated. The memory 102 stores in advance the second allowable moment load M2 as the control data 102B. The second allowable moment load M2 is the maximum moment load allowed for the second actuator 41. As shown in Fig. 6, after calculating the second allowable lateral force FH2, the CPU 101 proceeds to step S54. The process in step S53 constitutes a third calculation process.

[0073] In step S54, the CPU 101 calculates a third allowable lateral force FH3. In calculating the third allowable lateral force FH3, the CPU 101 refers to two information items stored on the memory 102 as the control data 102B. One of the two information items is a third distance L3. As shown in Fig. 1, the third distance L3 is the distance from the specific region 25E of the bucket 25 to the third axis 51J in the specific plan view. The other of the two information items is a third allowable moment load M3. The third allowable moment load M3 is the maximum moment load allowed for the third actuator 51. In step S54, the CPU 101 calculates the third allowable lateral force FH3 by dividing the third allowable moment load M3 by the third distance L3. As shown in Fig. 6, after calculating the third allowable lateral force FH3, the CPU 101 proceeds to step S55. The process in step S54 constitutes a fourth calculation process.

[0074] In step S55, the CPU 101 calculates a fourth distance L4. As shown in Fig. 1, the fourth distance L4 is the distance from the specific region 25E of the bucket 25 to the swing axis 61J with respect to the direction ortho-

gonal to both the swing axis 61J and the first axis 31J. The memory 102 stores in advance fourth relationship information related to the fourth distance L4. The fourth relationship information represents the relationship between the first, second, and third rotational positions 21W, 23W, and 25W and the fourth distance L4. Specifically, the fourth relationship information represents the fourth distance L4 for each combination of different values of the first, second, and third rotational positions 21W, 23W, and 25W. The fourth relationship information includes, for example, a table, graph, or formula. The fourth relationship information is generated, for example, by simulation using a model replicating the excavator 10. The fourth relationship information is a type of control data 102B stored on the memory 102. The CPU 101 applies the first, second, and third rotational positions 21W, 23W, and 25W obtained in step S51 to the fourth relationship information to calculate the fourth distance L4 according to the current posture of the work unit 20. As shown in Fig. 6, the CPU 101 proceeds to step S56 after calculating the fourth distance L4. The process in step S55 constitutes a fifth calculation process.

[0075] In step S56, the CPU 101 calculates the critical torque FK. Specifically, the CPU 101 selects, as the minimum lateral force, the smallest among the first allowable lateral force FH1 calculated in step S52, the second allowable lateral force FH2 calculated in step S53, and the third allowable lateral force FH3 calculated in step S54. The CPU 101 then calculates the product of the minimum lateral force and the fourth distance L4 calculated in step S55 as a provisional value FKA. The CPU 101 calculates the critical torque FK by multiplying the provisional value FKA by a set percentage. An example of the set percentage is 90%. The set percentage is predetermined so as to provide a slight margin to the critical torque FK for satisfying the requirements (B1), (B2), and (B3) described below. The CPU 101 may calculate the provisional value FKA as the critical torque FK. The critical torque FK can have any value less than or equal to the provisional value FKA. Upon calculating the critical torque FK, the CPU 101 ends the process in step S56. The CPU 101 then returns to step S51. The CPU 101 then quickly performs the process in step S51. In this way, the CPU 101 repeats the processes in steps S51 to S56 in the calculation process Q4. The process in step S56 constitutes a sixth process.

[0076] As described above, in this embodiment, various types of information and calculation methods for calculating the critical torque FK are predetermined. This configuration is also encompassed by the notion that the critical torque FK is predetermined. In other words, the notion that the critical torque FK is predetermined does not mean that it must be predetermined solely as a fixed value.

<Load Reduction Routine>

[0077] The CPU 101 performs the load reduction rou-

tine shown in Fig. 7 while performing the specific control. When the CPU 101 starts the specific control, it starts the load reduction routine in parallel. If the CPU 101 ends the specific control, it simultaneously ends the load reduction routine.

[0078] In the load reduction routine, the CPU 101 first performs step S101. In step S101, the CPU 101 compares the latest load torque FU calculated in step S13 of the swing process Q3 with the latest critical torque FK calculated in step S56 of the calculation process Q4. If the load torque FU is less than the critical torque FK (step S101: NO), the CPU 101 performs step S101 again. The CPU 101 repeats the process in step S101 while the load torque FU remains less than the critical torque FK. When the load torque FU reaches or exceeds the critical torque FK (Step S101: YES), the CPU 101 proceeds to step S102.

[0079] In step S102, the CPU 101 performs load reduction control. In the load reduction control, the CPU 101 controls the swing actuator 61 so that the load torque FU is lower than at the point of time at which the load torque FU is determined to have reached or exceeded the critical torque FK. The timing at which the load torque FU is determined to have reached or exceeded the critical torque FK is referred to as the determination timing. The timing at which the load torque FU reaches the critical torque FK is referred to as the reaching timing. The determination timing is substantially the same as the reaching timing. In other words, the determination timing can be regarded as the reaching timing. The swing current value SC at the reaching timing is referred to as the critical current value. In the load reduction control, the CPU 101 controls the supply of power to the fourth electric motor 62 so that the current value of the power supplied to the fourth electric motor 62 is closer to zero than is the critical current value. Thus, the CPU 101 controls the swing actuator 61 so that the load torque FU is reduced. In this embodiment, the CPU 101 sets the current value of the power supplied to the fourth electric motor 62 to zero. The CPU 101 continues the process in step S102 until the predetermined ending condition is satisfied. An example of the ending condition is an operation signal 90S from the operating device 90. For example, in step S102, the CPU 101 performs a process to inform the operator that the load acting on the work unit 20 has increased, in parallel with the load reduction control. Specifically, the CPU 101 provides voice guidance through the speaker in the cabin or indicates on the display in the cabin that the load is high. When the worker operates the operating device 90 in response to this notification, the ending condition is satisfied. The ending condition may be that a predetermined period of time has elapsed since the start of the load reduction control. When performing the load reduction control, the CPU 101 cancels the swing process Q3 of the specific control. When the ending condition is satisfied, the CPU 101 ends the process in step S102. Simultaneously, the CPU 101 ends the load reduction routine.

<Significance of Parameters Calculated in Calculation Process>

[0080] First, a description is given of the moment loads acting on the actuators of the work unit 20. Of the three actuators, the third actuator 51 is taken here as an example.

[0081] As shown in Fig. 8, the force acting on the bucket body 26 in the direction along the third axis 51J is referred to as the lateral force FH. When the lateral force FH acts on the bucket body 26, the lateral force FH acts as a moment load M on the third actuator 51 via the bucket coupling wall 28. The moment load M acting on the third actuator 51 is the force that acts to bend the output member 53C of the third speed reducer 53 and the output shaft 52B of the third electric motor 52 in the third actuator 51 with respect to the third axis 51J. For example, when the lateral force FH acts on the specific region 25E of the bucket 25, the moment load M is given as the product of the lateral force FH and the third distance L3. The third allowable moment load M3 used in step S54 of the calculation process is the maximum moment load M that the third actuator 51 can withstand. As described with Fig. 1, the third distance L3 is the distance from the specific region 25E of the bucket 25 to the third axis 51J in the specific plan view. Fig. 8 shows a simplified example of the third distance L3.

[0082] When a moment load M acts on the third actuator 51, the third actuator 51 receives this load mainly at the bearing 53D in the third speed reducer 53 that supports the output member 53C. Although only one bearing 53D is shown in Fig. 8, there are actually two bearings 53D in the direction along the third axis 51J. The third allowable moment load M3 is defined based on the limit of the magnitude of the force that these bearings 53D can withstand. The third allowable moment load M3 can be said to be defined by the standard of the third actuator 51. Like the third allowable moment load M3, the first allowable moment load M1 is the maximum moment load M that the first actuator 31 can withstand. The second allowable moment load M2 is the maximum moment load M that the second actuator 41 can withstand.

[0083] Next, a description is given of the significance of the first allowable lateral force FH1, second allowable lateral force FH2, and third allowable lateral force FH3. As described above, the lateral force FH is a force acting on the bucket body 26 in the direction along the third axis 51J. Each allowable lateral force is the maximum lateral force FH that can be withstood by the corresponding actuator. For example, as shown in Fig. 8, the third allowable lateral force FH3 is the maximum lateral force FH that the third actuator 51 can withstand in relation to the third allowable moment load M3. The lateral force FH acting on the bucket body 26 also generates a moment load M on the second actuator 41 via the bucket 25, the third actuator 51, and the arm 23. With such a force transmission path, the second allowable lateral force FH2 is the maximum lateral force FH that can be with-

stood by the second actuator 41 in relation to the second allowable moment load M2. Similarly, the first allowable lateral force FH1 is the maximum lateral force FH that the first actuator 31 can withstand in relation to the first allowable moment load M1.

[0084] Next, a description is given of the significance of the critical torque FK. As described above, in step S56 of the calculation process Q4, the critical torque FK is calculated in relation to the smallest among the first allowable lateral force FH1, the second allowable lateral force FH2, and the third allowable lateral force FH3. Now, consider the first situation where the smallest lateral force, the smallest among these three allowable lateral forces, is the third allowable lateral force FH3. In the first situation, suppose that the lateral force FH actually acting on the bucket 25 gradually increases from less than the smallest lateral force to eventually reach the smallest lateral force. At this time, if the lateral force FH acting on the bucket 25 is quickly reduced, no force exceeding the third allowable moment load M3 will act on the third actuator 51, which is subject to the third allowable lateral force FH3. Also, in the first situation, the first allowable lateral force FH1 and the second allowable lateral force FH2 are greater than the third allowable lateral force FH3, which is the smallest lateral force. Therefore, if the lateral force FH acting on the bucket 25 is quickly reduced when the lateral force FH reaches the smallest lateral force, no force exceeding the respective allowable moment loads will act on the other two electric actuators. Thus, the smallest lateral force is set so that the moment loads acting on the three actuators do not exceed their respective allowable moment loads. The critical torque FK is the value obtained by converting the smallest lateral force into a torque acting on the swing actuator 61. Thus, the critical torque FK is calculated to fulfill the following requirements (B1), (B2), and (B3). (B1) The moment load acting on the first actuator 31 is less than or equal to the first allowable moment load M1. (B2) The moment load acting on the second actuator 41 is less than or equal to the second allowable moment load M2. (B3) The moment load acting on the third actuator 51 is less than or equal to the third allowable moment load M3.

<Operation of Embodiment>

[0085] In ground leveling work, the work unit 20 and thus the bucket 25 are slewed together with the upper body 14 while the swing rotational position SW is maintained constant. During such ground leveling work, there may be obstacles such as clods or stones in the path of the bucket body 26. When the bucket body 26 collides with this obstacle, a lateral force FH acts on the bucket body 26. Simultaneously, the load torque FU acting on the work unit 20 and thus on the swing bracket 17 can be increased. As a result, the moment loads acting on the actuators in the work unit 20 may exceed their respective allowable moment loads.

[0086] Therefore, the CPU 101 in this embodiment

performs the load reduction control when the load torque FU reaches or exceeds the critical torque FK during the ground leveling work. Specifically, the CPU 101 ends the ongoing feedback control of the fourth electric motor 62 and sets the power supplied to the fourth electric motor 62 to zero. Accordingly, the swing bracket 17 is allowed to rotate. Since the swing bracket 17 is allowed to rotate, the force acting on the entire work unit 20, including the bucket 25, is released. This prevents forces exceeding the respective allowable moment loads from acting on the actuators of the work unit 20.

<Advantageous Effects of Embodiment>

[0087]

(1) As described in Operation of Embodiment, the CPU 101 controls the swing actuator 61 so that the load torque FU is reduced when the load torque FU has reached or exceeded the critical torque FK. This prevents excessive burden on the actuators in the work unit 20.

(2) In the specific control, the CPU 101 performs the feedback control of the fourth electric motor 62 so as to maintain the rotational position of the swing bracket 17 constant. At this time, the current value of the power supplied to the fourth electric motor 62 reflects the load torque FU. Therefore, the CPU 101 can accurately calculate the load torque FU based on the swing current value SC during the feedback control. Also, in the load reduction control, the CPU 101 reduces the current value of the power supplied to the fourth electric motor 62. This allows the swing bracket 17 to rotate, as described above in Operation of Embodiment. Thus, the moment loads acting on the actuators of the work unit 20 can be reduced.

(3) In the calculation process Q4, the CPU 101 calculates the critical torque FK so as not to exceed the respective allowable moment loads of the three actuators in the work unit 20. Since the critical torque FK thus calculated is used as the reference for determining whether to perform the load reduction control, each of the three actuators can be prevented from being subjected to a moment load exceeding the allowable value.

(4) The allowable lateral force of each actuator in the work unit 20 varies in accordance with the posture of the work unit 20. In this embodiment, the CPU 101 calculates, in the calculation process Q4, the critical torque FK based on the latest first rotational position 21W, the latest second rotational position 23W, and the latest third rotational position 25W. In other words, the CPU 101 calculates the critical torque FK in accordance with the real-time posture of the

work unit 20. Since the critical torque FK thus calculated is used as the reference for determining whether to perform the load reduction control, the three actuators can be prevented at any time from being subjected to a moment load exceeding the allowable value.

(5) During the slewing of the upper body 14, the direction of movement of the work unit 20 can be approximate to the direction along the third axis 51J of the third actuator 51. Because of this direction of movement, when the bucket 25 collides with an obstacle while the upper body 14 is slewing, an impact tends to act as a lateral force FH on the bucket 25. Thus, during the slewing of the upper body 14, lateral forces FH act on the bucket 25 more frequently. Simultaneously, during the slewing of the upper body 14, moment loads act on the actuators of the work unit 20 more frequently. Performing the load reduction control under such a situation is particularly effective in controlling the loads acting on the actuators of the work unit 20.

(6) In addition to (5), in the ground leveling work, the bucket 25 passes through a position close to the ground surface G, and therefore, moment loads act on the actuator of the work unit 20 particularly frequently. Performing the load reduction control under such a situation is highly effective in controlling the loads acting on the actuators of the work unit 20.

<Modification Examples>

[0088] The above embodiments can be modified as described below. The above embodiments and the following modifications can be implemented in combination to the extent where they are technically consistent with each other.

[0089] The details of the load reduction control are not limited to the example in the above embodiment. In the load reduction control, when the load torque FU has reached or exceeded the critical torque FK, at least one of the swing actuator 61 or the slew actuator 71 may be controlled in any manner so that the load torque FU is lower than at the point of time at which the load torque FU reached the critical torque FK. For example, in the load reduction control, the slew actuator 71 may be controlled so that the rotational speed of the upper body 14 is lower than at the point of time at which the load torque FU reached the critical torque FK, instead of or in addition to the configuration of the above embodiment. For example, the upper body 14 may be stopped. Any appropriate method of reducing the load torque FU may be employed in the load reduction control, in conjunction with the process for maintaining the swing rotational position SW constant in the specific control.

[0090] The process for maintaining the swing rotational position SW constant in the specific control is not limited

to the example in the above embodiment. For example, the swing process Q3 may be replaced with a process for controlling the brake device 64 of the swing actuator 61. In addition, the swing rotational position SW may be maintained constant by this process for controlling the brake device 64. In maintaining the swing rotational position SW constant by using the brake device 64, for example, the following configuration may be employed. The CPU 101 obtains the latest critical torque FK calculated in the calculation process Q4. The CPU 101 then controls the brake device 64 so that a braking torque of the same magnitude as this critical torque FK but in the opposite direction than the critical torque FK acts on the swing bracket 17. By repeating these processes, the swing rotational position SW can be maintained constant. When the swing rotational position SW is maintained constant in this manner, the load torque FU may be calculated separately using the method in the modification example described below, and the load reduction control may be configured as follows. When the load torque FU has reached or exceeded the critical torque FK, the CPU 101 reduces the braking torque to a lower value than at that point of time. The CPU 101 may set the braking torque to zero. This allows the swing bracket 17 to rotate, thereby reducing the load torque FU.

[0091] The method of calculating the load torque FU is not limited to the example in the above embodiment. Any method is acceptable as long as the load torque FU can be calculated appropriately. For example, a strain sensor may be installed in the work unit 20, and the load torque FU may be calculated based on the sensing value of the strain sensor. The strain sensor should preferably be installed at a location where strain is likely to occur in response to the lateral force FH acting on the bucket 25. Examples of such locations include the location where the first actuator 31 is mounted to the boom 21, the location where the second actuator 41 is mounted to the arm 23, and the location where the third actuator 51 is mounted to the bucket 25.

[0092] The swing actuator can be configured in any other manners than described in the above embodiment. For example, the swing actuator may include a hydraulic motor instead of an electric motor as a drive source. Also, the swing actuator may be of a direct-acting type instead of a rotating type.

[0093] The following describes an example employing a direct-acting swing actuator with reference to Fig. 9. As a prerequisite, the swing bracket 17 shown in Fig. 9 includes a first support shaft 17C and a second support shaft 17D in addition to the first swing wall 17A and the second swing wall 17B. Fig. 9. does not show the second swing wall 17B. The first support shaft 17C protrudes downward from the lower surface of the first swing wall 17A. The first support shaft 17C is shaped like a circular column. The central axis of the first support shaft 17C extends in the Z direction. The central axis of the first support shaft 17C substantially coincides with the central axis of the first swing wall 17A. The central axis of the first

support shaft 17C constitutes a swing axis. Although not shown in the drawing, the first support shaft 17C is rotatably supported on the case front portion 14B of the upper body 14. The first swing wall 17A can rotate about the swing axis together with the first support shaft 17C. The second support shaft 17D protrudes upward from the upper surface of the first swing wall 17A. The second support shaft 17D is located closer to the periphery of the first swing wall 17A. The second support shaft 17D is shaped like a circular column. The central axis of the second support shaft 17D extends in the Z direction.

[0094] As shown in Fig. 9, a swing actuator 130 includes a hydraulic cylinder 131 and a piston rod 132. The hydraulic cylinder 131 is housed in the case main portion 14A of the upper body 14. The hydraulic cylinder 131 is shaped like a hollow column. For example, the hydraulic cylinder 131 as a whole is shaped like a circular column. The interior of the hydraulic cylinder 131 constitutes a hydraulic chamber for containing a hydraulic fluid which is supplied into and discharged out of the hydraulic chamber. The central axis of the hydraulic cylinder 131 extends in a direction substantially orthogonal to the Z direction.

[0095] The piston rod 132 includes a rod body 132A and a piston 132B. The rod body 132A is shaped like a rod. The rod body 132A protrudes from the inside of the hydraulic cylinder 131 to the outside. The central axis of the rod body 132A substantially coincides with the central axis of the hydraulic cylinder 131. The rod body 132A can reciprocate in the direction along the central axis of the hydraulic cylinder 131. The protruding end portion of the rod body 132A, which is the distal end portion protruding from the hydraulic cylinder 131, is rotatably coupled to the first swing wall 17A of the swing bracket 17. The protruding end of the rod body 132A has a receiving portion formed of a hole or depression that receives the second support shaft 17D. With the second support shaft 17D received in the receiving portion, the rod body 132A is mounted to the first swing wall 17A. The rod body 132A can rotate relative to the second support shaft 17D and thus the first swing wall 17A.

[0096] The piston 132B is located inside the hydraulic cylinder 131. The piston 132B is connected to the end of the rod body 132A opposite to the protruding end portion. The piston 132B is shaped like a circular plate. The piston 132B divides the interior of the hydraulic cylinder 131 into two sections. As a result of the piston 132B dividing the interior of the hydraulic cylinder 131 into two sections, the interior of the hydraulic cylinder 131 is partitioned into a first oil chamber 131A and a second oil chamber 131B. In the example shown in Fig. 9, the first oil chamber 131A is located on the side from which the piston rod 132 protrudes, relative to the second oil chamber 131B.

[0097] The excavator 10 includes a hydraulic circuit 140 for driving the swing actuator 130. The hydraulic circuit 140 includes a tank 142, a pump 144, and a control valve 145. The tank 142 stores the hydraulic oil. The pump 144 pumps the hydraulic oil from the tank 142

toward the control valve 145. The pump 144 is driven by an electric motor. The control valve 145 includes, for example, an electromagnetic proportional valve and a spool operated by the pilot pressure generated by the electromagnetic proportional valve. The control valve 145 adjusts the supply and discharge of the hydraulic oil to and from the first oil chamber 131A and the second oil chamber 131B under the control of the CPU 101. Specifically, the CPU 101 adjusts the flow rate of the hydraulic oil flowing into each of the first oil chamber 131A and the second oil chamber 131B, and switches the direction of flow of the hydraulic oil. In response to the supply and discharge of the hydraulic oil to the first and second oil chambers 131A and 131B, the piston 132B and thus the rod body 132A reciprocate in the direction along the central axis thereof. Simultaneously, the protruding length of the piston rod 132 from the hydraulic cylinder 131 is varied. With the variation in the protruding length of the piston rod 132, the swing bracket 17 rotates about the swing axis. Fig. 9 shows the hydraulic circuit 140 in a schematic manner.

[0098] The excavator 10 includes a first oil pressure sensor 181 and a second oil pressure sensor 182 as components related to the swing actuator 130. The hydraulic cylinder 131 has internal oil pressure. The first oil pressure sensor 181 senses the oil pressure in the first oil chamber 131A as a first pressure, and the second oil pressure sensor 182 senses the oil pressure in the second oil chamber 131B as a second pressure. The first oil pressure sensor 181 and the second oil pressure sensor 182 repeatedly transmit signals corresponding to the sensed information to the control device 100. The first oil pressure sensor 181, the second oil pressure sensor 182, and the hydraulic circuit 140 are included in the components of the drive system of the excavator 10, together with the swing actuator 130.

[0099] With the swing actuator 130 described above, the CPU 101 performs the following first and second processes as the swing process Q3 to maintain the swing rotational position SW constant. In the first process, the CPU 101 controls the supply and discharge of the hydraulic oil to and from the hydraulic cylinder 131 to maintain the position of the piston rod 132 at the start of the specific control. For example, when the CPU 101 starts the specific control, it controls the control valve 145 to shut off the flow of hydraulic oil to both the first oil chamber 131A and the second oil chamber 131B. Specifically, the CPU 101 shuts off the supply of the hydraulic oil from the pump 144, and also shuts off the discharge of the hydraulic oil to the tank 142, for both the first oil chamber 131A and the second oil chamber 131B. The CPU 101 maintains the shutoff of the hydraulic oil flow to both the first oil chamber 131A and the second oil chamber 131B. As to the first process, the CPU 101 may obtain the latest swing rotational position SW repeatedly and adjust the flow rate or switch the flow path so that the latest swing rotational position SW coincides with the swing rotational position SW at the start of the specific

control. Instead of using the swing rotational position SW, the excavator 10 may include a sensor that senses the protruding length of the piston rod 132 relative to the hydraulic cylinder 131, or the position of the piston rod 132 in the direction along the central axis of the piston rod 132. Based on the information sensed by this sensor, the hydraulic circuit 140 may be controlled so that the latest position of the piston rod 132 coincides with the position of the piston rod 132 at the start of the specific control.

[0100] The CPU 101 continues the first process described above while performing the second process in parallel with the first process. In the second process, the CPU 101 obtains the latest internal oil pressure, i.e., the latest first pressure and the latest second pressure. The CPU 101 then calculates the latest load torque FU based on the first and second pressures obtained. During the first process, the CPU 101 repeatedly obtains the latest internal oil pressure and calculate the latest load torque FU based on the internal oil pressure obtained. The memory 102 stores relationship information that represents the relationship between the internal oil pressure and the load torque FU. In this relationship information, the load torque FU is larger as the internal oil pressure is larger. The CPU 101 calculates the load torque FU by applying the internal oil pressure obtained in the second process to this relationship information. For example, the CPU 101 selects the larger of the obtained first and second pressures as the subject oil pressure. The CPU 101 then applies the subject oil pressure to the relationship information to calculate the load torque FU. When the load torque FU is acting on the swing bracket 17, the load torque FU is the force to move the piston rod 132. This results in a difference between the first pressure and the second pressure. For example, when the load torque FU acts to push the piston rod 132 deeper into the hydraulic cylinder 131, the second pressure can be higher than the first pressure. The deeper side of the hydraulic cylinder 131 is opposite to the side of the hydraulic cylinder 131 from which the piston rod 132 protrudes. On the other hand, when the load torque FU acts to pull the piston rod 132 back from the hydraulic cylinder 131, the first pressure can be higher than the second pressure. Based on this relationship, the CPU 101 can calculate the load torque FU from the subject oil pressure. In the swing process Q3, the CPU 101 continues the first and second processes described above.

[0101] With the swing actuator 130 and swing process Q3 described above, the CPU 101 controls, in the load reduction control, the supply and discharge of the hydraulic oil to and from the first oil chamber 131A and the second oil chamber 131B so that the subject oil pressure is lower than at the point of time at which the load torque FU reached the critical torque FK. For example, the CPU 101 controls the control valve 145 so that the hydraulic oil in the subject oil chamber, which is the oil chamber in which the subject oil pressure is to be sensed, flows to the tank 142. It can be said that the CPU 101 controls the control valve 145 to allow the piston rod 132 to move in

accordance with the load torque FU. Thus, in the second process, the CPU 101 controls the supply and discharge of the hydraulic oil to and from the first oil chamber 131A and the second oil chamber 131B so that the piston rod 132 moves from the position of the piston rod 132 at the time the load torque FU reached the critical torque FK. When performing the load reduction control described above, the CPU 101 cancels the swing process Q3.

[0102] The details of the load reduction routine are not limited to the example in the above embodiment. For example, in the load reduction routine, the CPU 101 may perform handling control in a step before performing the load reduction control. The handling control is for reducing the load torque FU in a step before performing the load reduction control. When the handling control is incorporated into the load reduction routine, the CPU 101 first determines, in the load reduction routine, whether or not the load torque FU has reached or exceeded a handling torque. The handling torque is, for example, 70% of the latest critical torque FK. Thus, the handling torque is set at a value smaller than the critical torque FK. The handling torque may have any value indicating that interim measures to reduce the load torque FU are necessary. The CPU 101 performs the handling control when the load torque FU has reached or exceeded the handling torque. Specifically, in the handling control, the CPU 101 controls one or more of the three actuators in the work unit 20 so that the specific region 25E of the bucket 25 moves upward by a handling distance. The CPU 101 increases the handling distance as the current estimated facing distance 25M is shorter. The handling distance is predetermined in association with the estimated facing distance 25M so as to fulfill the requirement (A1) of the execution condition for the specific control. The memory 102 stores, in advance, information representing the relationship between the estimated facing distance 25M and the handling distance as the control data 102B. The CPU 101 calculates the handling distance based on this information. For example, it is possible that the ground surface G on which the ground leveling work is to be performed is locally raised. In the handling control, the bucket 25 is moved to the top side of the rise of the ground surface G at such a location. The CPU 101 performs the load reduction control when the load torque FU is still large even after the handling control. Specifically, after performing the handling control, the CPU 101 proceeds to step S101 described for the above embodiment.

[0103] A camera may be used in determining whether or not the requirements (A1) and (A2) of the execution condition for the specific control are satisfied. Specifically, a camera is mounted on the excavator 10, and the area around the bucket 25 is imaged by the camera. Then, the captured images may be analyzed to determine whether the requirements (A1) and (A2) are satisfied.

[0104] The execution condition for the specific control and the processes performed in the specific control are

not limited to the examples in the above embodiments. For example, the requirements (A1) and (A2) may be eliminated from the execution condition for the specific control. In other words, the specific control may be performed for purposes other than the ground leveling work. Furthermore, the specific control may be performed for purposes other than the works in which the upper body 14 is slewed. For example, the specific control may be performed for purposes of excavation works performed with the upper body 14 maintaining its rotational position. The specific control should include a process to maintain the swing rotational position SW. The execution condition for the specific control may be determined as appropriate in accordance with the purposes for which the specific control is to be performed.

[0105] The way to set the critical torque FK is not limited to the example in the above embodiment. If the critical torque FK can be determined so as to fulfill the requirements (B1), (B2), and (B3), not only in the example of the calculation process Q4 in the above embodiment, then the actuators of the work unit 20 can be prevented from being subjected to moment loads exceeding the allowable values.

[0106] The critical torque FK may be a predetermined fixed value. Depending on the works to be performed with the excavator 10, the moment loads that would act on the actuators of the work unit 20 can be known in advance through experiments. In these cases, it is possible to set the critical torque FK as a fixed value. Any appropriate critical torque FK can be set so that the actuators of the work unit 20 are not overloaded.

[0107] The first actuator 31 can be configured in any other manners than described in the above embodiment. The first actuator 31 may be configured in any manner as long as it includes an electric motor and can output torque about an axis intersecting the swing axis. For example, the first actuator 31 may be embodied without the first speed reducer 33. Like the first actuator 31, the second actuator 41 may be configured in any manner as long as it includes the electric motor and can output torque about an axis intersecting the swing axis. The same applies to the third actuator 51.

[0108] The first actuator 31 can be mounted in any other manners than described in the above embodiment. The first actuator 31 may be configured in any manner as long as it can rotate the first attachment relative to the swing bracket 17. For example, the first actuator 31 may be oriented reversely between the second swing wall 17B of the swing bracket 17 and the first attachment. Specifically, the housing 32A of the first electric motor 32 may be mounted to the first attachment, and the output member 33C of the first speed reducer 33 may be mounted to the second swing wall 17B. Like the first actuator 31, the second actuator 41 can be mounted in any other manners than described in the above embodiment. The second actuator 41 may be configured in any manner as long as it can rotate the second attachment relative to the first attachment. Similarly, the third actuator 51 can be

mounted in any other manners than described in the above embodiment. The third actuator 51 may be configured in any manner as long as it can rotate the third attachment relative to the second attachment.

[0109] The specific region 25E of the bucket 25 is not limited to the example in the above embodiment. For example, in a work in which the work unit 20 is slewed, such as the ground leveling work, a region where the lateral force FH tends to act on the bucket 25 may be treated as a specific region 25E as appropriate. Similarly, the specific wall 25F of the bucket 25 is not limited to the example in the above embodiment. A wall to be used for the ground leveling work and other works may be treated as a specific wall 25F as appropriate.

[0110] The shape of the bucket 25 is not limited to the example in the above embodiment. The bucket 25 may be shaped in any manner as long as it has the opening 26A and it can hold dirt and other materials inside. For example, the bottom wall of the bucket 25 may have a polygonal shape other than a rectangle. It is possible that the bucket 25 does not have a wall defined as a bottom wall.

[0111] The third attachment is not limited to the bucket 25. Depending on the nature of the work, any suitable device, mechanism, or tool may be employed as the third attachment. When a non-rotational component is employed as the third attachment, the third actuator 51 may be eliminated, and the third attachment may be directly coupled to the arm 23.

[0112] The third attachment may be eliminated. Simultaneously, the third actuator 51 may be eliminated. The second attachment is not limited to the arm 23. If the second attachment is a long member, it is effective in enlarging the working range of the work unit 20.

[0113] The second attachment may be eliminated. Simultaneously, the second actuator 41 may be eliminated. The first attachment is not limited to the boom 21. If the first attachment is a long member, it is effective in enlarging the working range of the work unit 20.

[0114] Various position sensors such as the first position sensor 38, second position sensor 48, third position sensor 58, and swing position sensor 68 are not required. If the specific control and the load reduction control can be accomplished without these sensors, the various sensors may be eliminated as appropriate. For example, if the critical torque FK is set as a fixed value, as described in the above modification example, it is not necessary to provide the position sensors for the purpose of calculating the critical torque FK. As with the position sensors, the current sensor 82 and the inclination sensor 81 are not required. For example, if the inclination of the vehicle body 15 is not taken into account in calculating the estimated facing distance 25M and the attitude index 25N, the inclination sensor 81 may be eliminated.

[0115] The swing bracket 17 may be configured in any other manners than described in the above in relation with the embodiment. For example, the shape of the second swing wall 17B can be a polygon other than a

rectangle. The swing bracket 17 may be configured in any manner as long as it is coupled to the vehicle body 15 so as to be rotatable about an axis extending upwards and downwards with respect to the vehicle body 15. Simultaneously, the swing bracket 17 may be configured in any manner as long as it allows coupling of the first attachment so as to be rotatable about an axis that intersects the swing axis. Depending on the configuration of the swing bracket 17 and the swing actuator 61, the swing bracket 17 and the swing actuator 61 may be coupled to each other in different manners. Thus, the coupling between the swing bracket 17 and the swing actuator 61 can be configured in any other manners than described in the above embodiment.

[0116] The swing bracket 17 may be coupled to the vehicle body 15 in any other manners than described in the above embodiment. For example, the shape of the case front portion 14B may be other than a rectangle. The case front portion 14B can be eliminated if the swing bracket 17 can be coupled to the vehicle body 15 without the use of a wall defined as the case front portion 14B.

[0117] The configuration of the upper body 14 is not limited to the example in the above embodiment. For example, the cabin may be eliminated from the upper body 14. The upper body 14 may have other shape than a rectangular parallelepiped shape. The upper body 14 can be configured in any manner as long as it can provide the required functions of, for example, housing the various devices.

[0118] In conjunction with eliminating the cabin from the upper body 14 as in the above modification example, the operating device 90 may be eliminated from the upper body 14. Simultaneously, the operation signal 90S may be configured to be transmitted via wireless communication from a device external to the vehicle body 15. In other words, the source device of the operation signal 90S is not limited to those provided on the vehicle body 15.

[0119] The components of the drive system are not limited to the example in the above embodiment. The components of the drive system can be changed in accordance with the various modifications described in the above modification examples. The drive system may be configured in any manner as long as it includes a slew actuator 71, a swing actuator 61, the electric actuators for driving the attachments, and the control device 100.

[0120] It is not required that the upper body 14 be rotatable relative to the lower body 13. In other words, the slewing bearing 18 and the slew actuator 71 may be eliminated. A specific control to maintain the swing rotational position SW constant may be performed in an excavator 10 in which the upper body 14 is not rotatable relative to the lower body 13. If the load torque FU increases during this specific control, the load reduction control may be performed to reduce the load torque FU.

[0121] The overall configuration of the vehicle body 15 and thus the excavator 10 is not limited to the example of the above embodiments. For example, the vehicle body 15 may have a different overall shape than in the above

illustrative embodiments, in accordance with the different shape of the upper body 14 described in the above modification example. The excavator 10 as a whole may have any configuration to accomplish the required work, for example, the ground leveling or excavation work.

[0122] The work machine is not limited to the excavator 10. The work machine may be a construction machine other than the excavator 10. Furthermore, the work machine is not limited to a construction machine. Examples of work machines other than construction machines include machines used in forestry, quarrying, industrial waste disposal, and agriculture.

[0123] The processing circuit of the control device 100 should have any one of the following configurations (a) to (c). (a) The processing circuit has one or more processors that perform various processes according to a computer program. The processors include a CPU 101 and a memory 102 such as a RAM or a ROM. The memory 102 stores program codes or instructions configured to cause the CPU 101 to perform processes. The memory 102, or a computer-readable medium, encompasses any kind of available media accessible by a general-purpose or dedicated computer.

[0124] (b) The processing circuit includes one or more dedicated hardware circuits that perform various processes. The dedicated hardware circuits can be, for example, application-specific integrated circuits, i.e., ASICs or FPGAs.

[0125] (c) The processing circuit includes a processor that performs part of the various processes according to a computer program and a dedicated hardware circuit that performs the rest of the various processes.

[0126] The foregoing embodiment describes a plurality of physically separate constituent parts. They may be combined into a single part, and any one of them may be divided into a plurality of physically separate constituent parts. Irrespective of whether or not the constituent parts are integrated, they are acceptable as long as they are configured to solve the problems.

[0127] According to the foregoing embodiments, a plurality of functions are distributively provided. Some or all of the functions may be integrated. Any one of the functions may be partly or entirely segmented into a plurality of functions, which are distributively provided. Irrespective of whether the functions are integrated or distributed, they are acceptable as long as they are configured to attain the object of the invention.

Claims

1. A drive system for a work machine, the drive system comprising:

a slew actuator configured to rotate an upper body relative to a lower body about a rotation axis;

a swing actuator configured to rotate a swing bracket relative to the upper body about a swing axis parallel to the rotation axis;
an electric actuator mounted to the swing bracket, the electric actuator being configured to drive an attachment by outputting a torque about an axis intersecting the swing axis; and
a control device configured to perform specific control in which the swing actuator is controlled so as to maintain a constant rotational position of the swing bracket relative to the upper body, wherein when a load torque, which is a torque about the swing axis acting on the swing bracket during the specific control, has reached or exceeded a critical torque, the control device performs load reduction control in which at least one of the slew actuator or the swing actuator is controlled so as to reduce the load torque.

2. The drive system for a work machine according to claim 1, further comprising a swing position sensor configured to sense a swing rotational position, the swing rotational position being a rotational position of the swing bracket,

wherein the swing actuator has an electric motor serving as a drive source,
wherein in the specific control, the control device repeats:

a first process to obtain the swing rotational position;
a second process to perform feedback control of the electric motor so as to eliminate a gap between the swing rotational position obtained and the swing rotational position at start of the specific control, and to obtain a current value of power supplied to the electric motor during the feedback control; and
a third process to calculate the load torque based on the current value obtained in the second process, and
wherein when the load torque calculated in the third process has reached or exceeded the critical torque, the control device ends the second process, and in the load reduction control, the control device controls the power supplied to the electric motor so that the current value of the power supplied to the electric motor is closer to zero than at point of time at which the load torque reached the critical torque.

3. The drive system for a work machine according to claim 1,
wherein the swing actuator includes:

a hydraulic cylinder to and from which hydraulic

oil is supplied and discharged; and
 a piston rod protruding from inside to outside of
 the hydraulic cylinder and mounted to the swing
 bracket, the piston rod having different protrud-
 ing lengths from the hydraulic cylinder in re-
 sponse to supply and discharge of the hydraulic
 oil to and from the hydraulic cylinder,
 wherein the drive system further comprises:

a hydraulic circuit configured to adjust sup-
 ply and discharge of the hydraulic oil to and
 from the hydraulic cylinder; and
 an oil pressure sensor configured to sense
 an internal oil pressure of the hydraulic cy-
 linder, and
 wherein in the specific control, the control
 device performs:

a first process to control supply and
 discharge of the hydraulic oil to and
 from the hydraulic cylinder so as to
 maintain a position of the piston rod
 at start of the specific control; and
 a second process to repeat, during the
 first process, obtaining the internal oil
 pressure and calculating the load tor-
 que based on the internal oil pressure
 obtained,
 wherein when the load torque calcu-
 lated has reached or exceeded the crit-
 ical torque, the control device ends the
 first process, and in the load reduction
 control, the control device controls sup-
 ply and discharge of the hydraulic oil
 such that the piston rod moves from a
 position of the piston rod at point of time
 at which the load torque reached the
 critical torque.

4. The drive system for a work machine according to
 claim 1,
 wherein supposing that the electric actuator is a first
 electric actuator, and the attachment is a first attach-
 ment, the drive system further comprises:

a second electric actuator mounted to the first
 attachment, the second electric actuator being
 configured to drive a second attachment by out-
 putting a torque about a second axis parallel to a
 first axis, the first axis being an axis of the first
 electric actuator; and
 a third electric actuator mounted to the second
 attachment, the third electric actuator being con-
 figured to drive a third attachment by outputting
 a torque about a third axis parallel to the first
 axis,
 wherein the control device stores in advance a
 first allowable moment load, which is a maxi-

mum moment load allowed for the first electric
 actuator, a second allowable moment load,
 which is a maximum moment load allowed for
 the second electric actuator, and a third allow-
 able moment load, which is a maximum moment
 load allowed for the third electric actuator, and
 wherein during the specific control, the control
 device performs a calculation process to calcu-
 late the critical torque so that a moment load
 acting on the first electric actuator is less than or
 equal to the first allowable moment load, a mo-
 ment load acting on the second electric actuator
 is less than or equal to the second allowable
 moment load, and a moment load acting on the
 third electric actuator is less than or equal to the
 third allowable moment load.

5. The drive system for a work machine according to
 claim 4, further comprising:

a first position sensor configured to sense a first
 rotational position, the first rotational position
 being a rotational position of the first attachment;
 a second position sensor configured to sense a
 second rotational position, the second rotational
 position being a rotational position of the second
 attachment; and
 a third position sensor configured to sense a
 third rotational position, the third rotational po-
 sition being a rotational position of the third attach-
 ment,
 wherein the control device stores in advance:

first relationship information expressing a
 relationship between the second and third
 rotational positions and a first distance, the
 first distance being a distance from a spe-
 cific region of the third attachment to the first
 axis in a specific plan view toward a direc-
 tion along the first axis;
 second relationship information expressing
 a relationship between the third rotational
 position and a second distance, the second
 distance being a distance from the specific
 region of the third attachment to the second
 axis in the specific plan view;
 a third distance from the specific region of
 the third attachment to the third axis in the
 specific plan view; and
 fourth relationship information expressing a
 relationship between the first, second, and
 third rotational positions and a fourth dis-
 tance, the fourth distance being a distance
 from the specific region of the third attach-
 ment to the swing axis with respect to a
 direction along an axis orthogonal to both
 the swing axis and the first axis, and
 wherein in the calculation process, the con-

trol device performs:

a first calculation process to obtain the first rotational position, the second rotational position, and the third rotational position; 5
 a second calculation process to calculate the first distance by applying the second and third rotational positions obtained to the first relationship information, and to calculate a first allowable lateral force by dividing the first allowable moment load by the first distance calculated; 10
 a third calculation process to calculate the second distance by applying the third rotational position obtained to the second relationship information, and to calculate a second allowable lateral force by dividing the second allowable moment load by the second distance calculated; 15
 a fourth calculation process to calculate a third allowable lateral force by dividing the third allowable moment load by the third distance; 25
 a fifth calculation process to calculate the fourth distance by applying the first, second, and third rotational positions obtained to the fourth relationship information; and 30
 a sixth calculation process to calculate the critical torque at a value less than or equal to a product of smallest of the first, second, and third allowable lateral forces calculated and the fourth distance. 35

6. The drive system for a work machine according to claim 1, wherein in the specific control, the control device controls the slew actuator so that the upper body rotates relative to the lower body. 40
7. The drive system for a work machine according to claim 6, wherein in the load reduction control, the control device controls the slew actuator so that a rotational speed of the upper body is lower than at point of time at which the load torque reached the critical torque. 45
8. The drive system for a work machine according to claim 6, wherein supposing that the electric actuator is a first electric actuator, and the attachment is a first attachment, the drive system further comprises: 50

a second electric actuator mounted to the first attachment, the second electric actuator being

configured to drive a second attachment by outputting a torque about a second axis parallel to a first axis, the first axis being an axis of the first electric actuator;

a third electric actuator mounted to the second attachment, the third electric actuator being configured to drive a third attachment by outputting a torque about a third axis parallel to the first axis;

a first position sensor configured to sense a first rotational position, the first rotational position being a rotational position of the first attachment; a second position sensor configured to sense a second rotational position, the second rotational position being a rotational position of the second attachment; and

a third position sensor configured to sense a third rotational position, the third rotational position being a rotational position of the third attachment,

wherein the control device:

stores, in advance, facing distance information that expresses a relationship between the first, second, and third rotational positions and an estimated facing distance, the estimated facing distance being an estimated shortest distance from a specific region of the third attachment to a ground surface;

performs pre-processing to obtain the first, second, and third rotational positions and calculate the estimated facing distance by applying the first, second, and third rotational positions obtained to the facing distance information; and

performs the specific control on a condition that the estimated facing distance is less than or equal to a proximity distance predetermined.

9. The drive system for a work machine according to claim 8, wherein when the load torque has reached or exceeded a handling torque set at a value smaller than the critical torque during the specific control, the control device performs handling control in which one or more of the first, second, and third electric actuators are controlled so that the specific region is moved upward of a position of the specific region at point of time at which the load torque reached the handling torque. 50
10. A control device for a work machine, the control device being applied to a work machine including: 55

an upper body rotatable about a rotation axis relative to a lower body;

a slew actuator configured to rotate the upper

body relative to the lower body;
 a swing bracket coupled to the upper body and
 rotatable about a swing axis parallel to the rota-
 tion axis relative to the upper body;
 a swing actuator configured to rotate the swing
 bracket relative to the upper body;
 an electric actuator mounted to the swing brack-
 et, the electric actuator being configured to out-
 put a torque about an axis intersecting the swing
 axis; and
 an attachment mounted to the electric actuator
 and driven by the electric actuator,
 the control device being configured to:

perform specific control in which the swing
 actuator is controlled so as to maintain a
 constant rotational position of the swing
 bracket relative to the upper body; and
 when a load torque, which is a torque about
 the swing axis acting on the swing bracket
 during the specific control, has reached or
 exceeded a critical torque, perform load
 reduction control in which at least one of
 the slew actuator or the swing actuator is
 controlled so as to reduce the load torque.

**11. A control method for a work machine, the work
 machine including:**

an upper body rotatable about a rotation axis
 relative to a lower body;
 a slew actuator configured to rotate the upper
 body relative to the lower body;
 a swing bracket coupled to the upper body and
 rotatable about a swing axis parallel to the rota-
 tion axis relative to the upper body;
 a swing actuator configured to rotate the swing
 bracket relative to the upper body;
 an electric actuator mounted to the swing brack-
 et, the electric actuator being configured to out-
 put a torque about an axis intersecting the swing
 axis; and
 an attachment mounted to the electric actuator
 and driven by the electric actuator,
 a control device applied to the work machine
 being configured to:

perform specific control in which the swing
 actuator is controlled so as to maintain a
 constant rotational position of the swing
 bracket relative to the upper body; and
 when a load torque, which is a torque about
 the swing axis acting on the swing bracket
 during the specific control, has reached or
 exceeded a critical torque, perform load
 reduction control in which at least one of
 the slew actuator or the swing actuator is
 controlled so as to reduce the load torque.

**12. A control program for a work machine, the work
 machine including:**

an upper body rotatable about a rotation axis
 relative to a lower body;
 a slew actuator configured to rotate the upper
 body relative to the lower body;
 a swing bracket coupled to the upper body and
 rotatable about a swing axis parallel to the rota-
 tion axis relative to the upper body;
 a swing actuator configured to rotate the swing
 bracket relative to the upper body;
 an electric actuator mounted to the swing brack-
 et, the electric actuator being configured to out-
 put a torque about an axis intersecting the swing
 axis; and
 an attachment mounted to the electric actuator
 and driven by the electric actuator,
 the control program causing a control device
 applied to the work machine to:

perform specific control in which the swing
 actuator is controlled so as to maintain a
 constant rotational position of the swing
 bracket relative to the upper body; and
 when a load torque, which is a torque about
 the swing axis acting on the swing bracket
 during the specific control, has reached or
 exceeded a critical torque, perform load
 reduction control in which at least one of
 the slew actuator or the swing actuator is
 controlled so as to reduce the load torque.

13. A work machine comprising:

an upper body rotatable about a rotation axis
 relative to a lower body;
 a slew actuator configured to rotate the upper
 body relative to the lower body;
 a swing bracket coupled to the upper body and
 rotatable about a swing axis parallel to the rota-
 tion axis relative to the upper body;
 a swing actuator configured to rotate the swing
 bracket relative to the upper body;
 an electric actuator mounted to the swing brack-
 et, the electric actuator being configured to out-
 put a torque about an axis intersecting the swing
 axis;
 an attachment mounted to the electric actuator
 and driven by the electric actuator; and
 a control device configured to perform specific
 control in which the swing actuator is controlled
 so as to maintain a constant rotational position of
 the swing bracket relative to the upper body,
 wherein when a load torque, which is a torque
 about the swing axis acting on the swing bracket
 during the specific control, has reached or ex-
 ceeded a critical torque, the control device per-

forms load reduction control in which at least one of the slew actuator or the swing actuator is controlled so as to reduce the load torque.

5

10

15

20

25

30

35

40

45

50

55

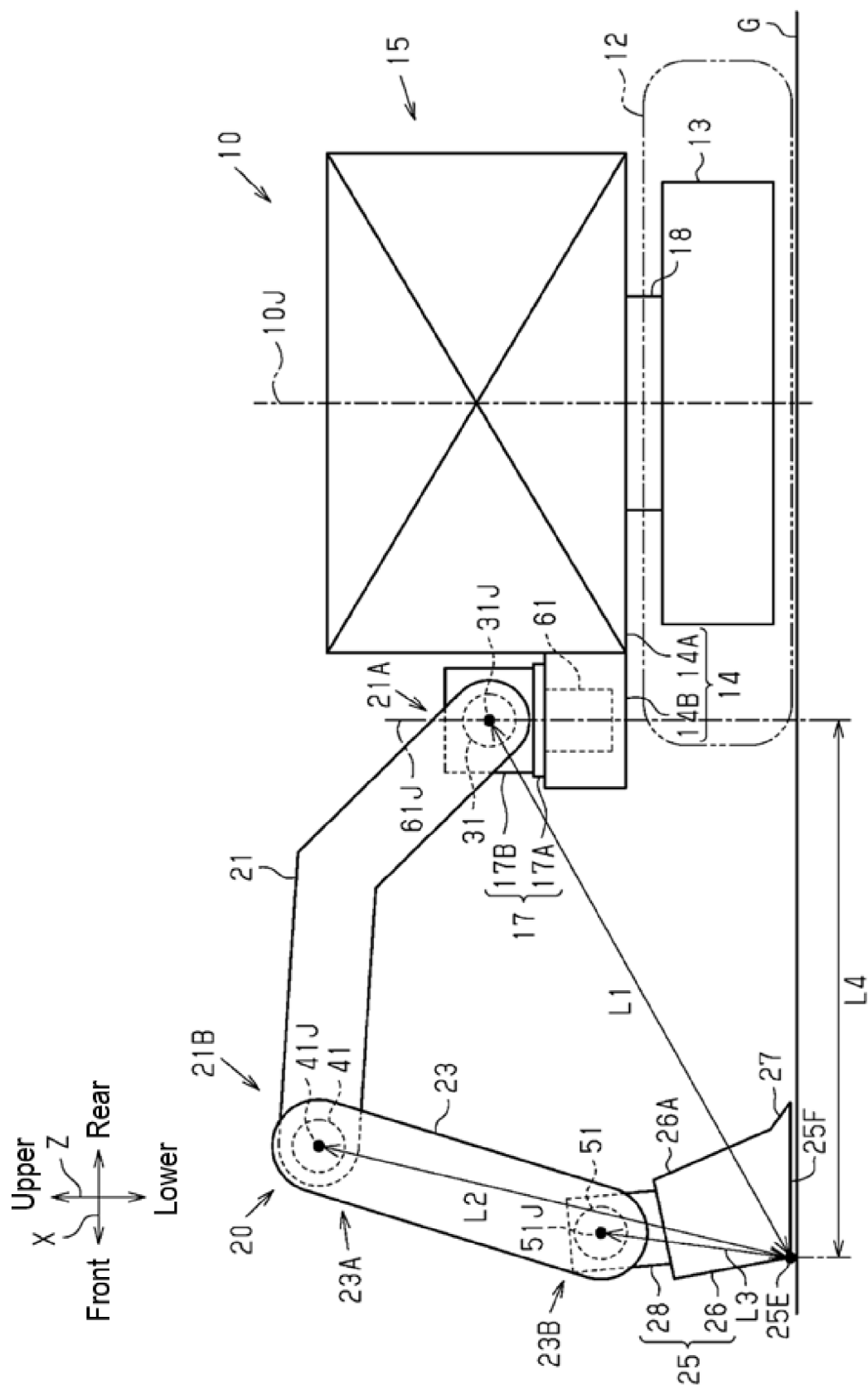


Fig. 1

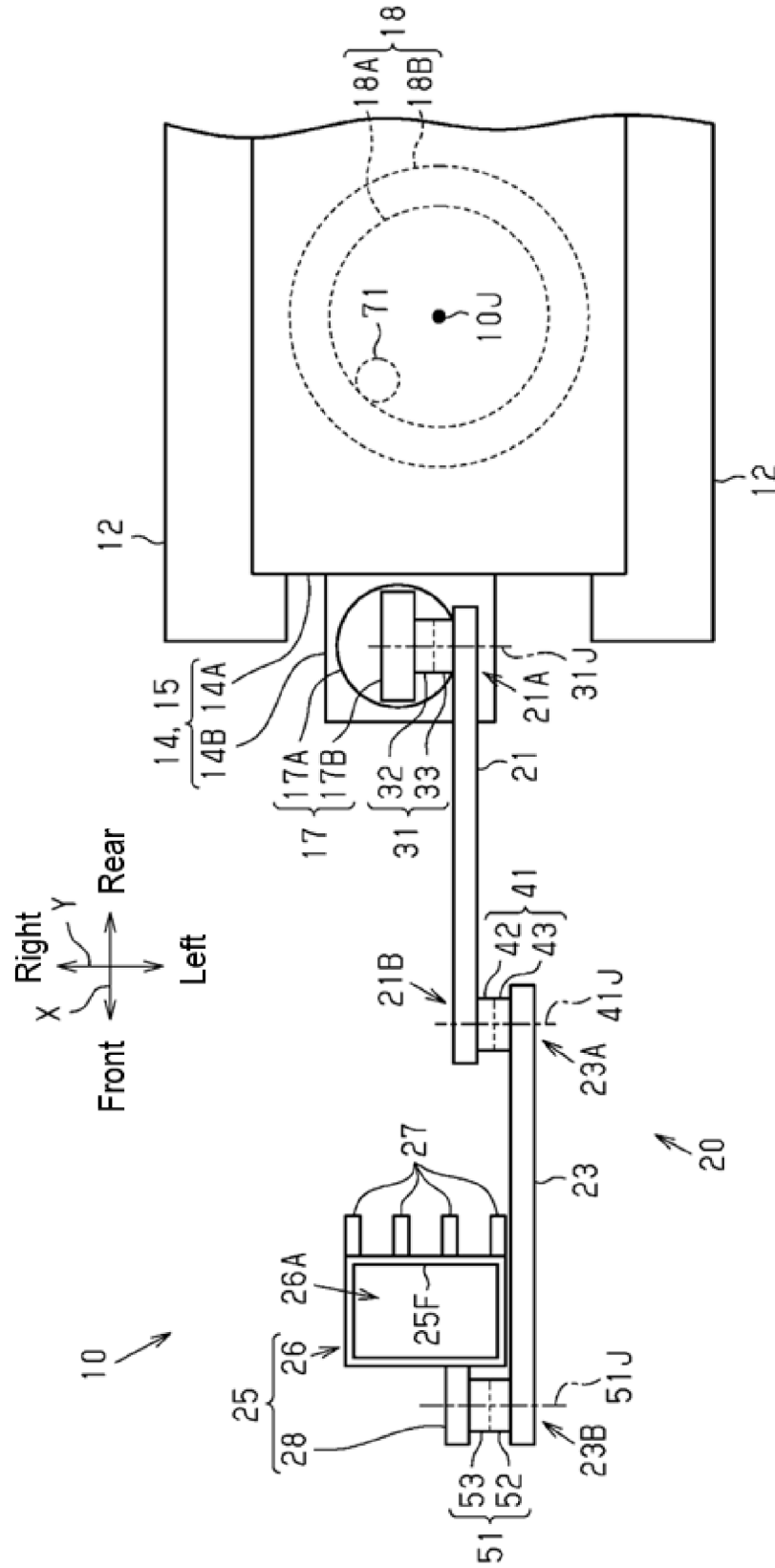


Fig. 2

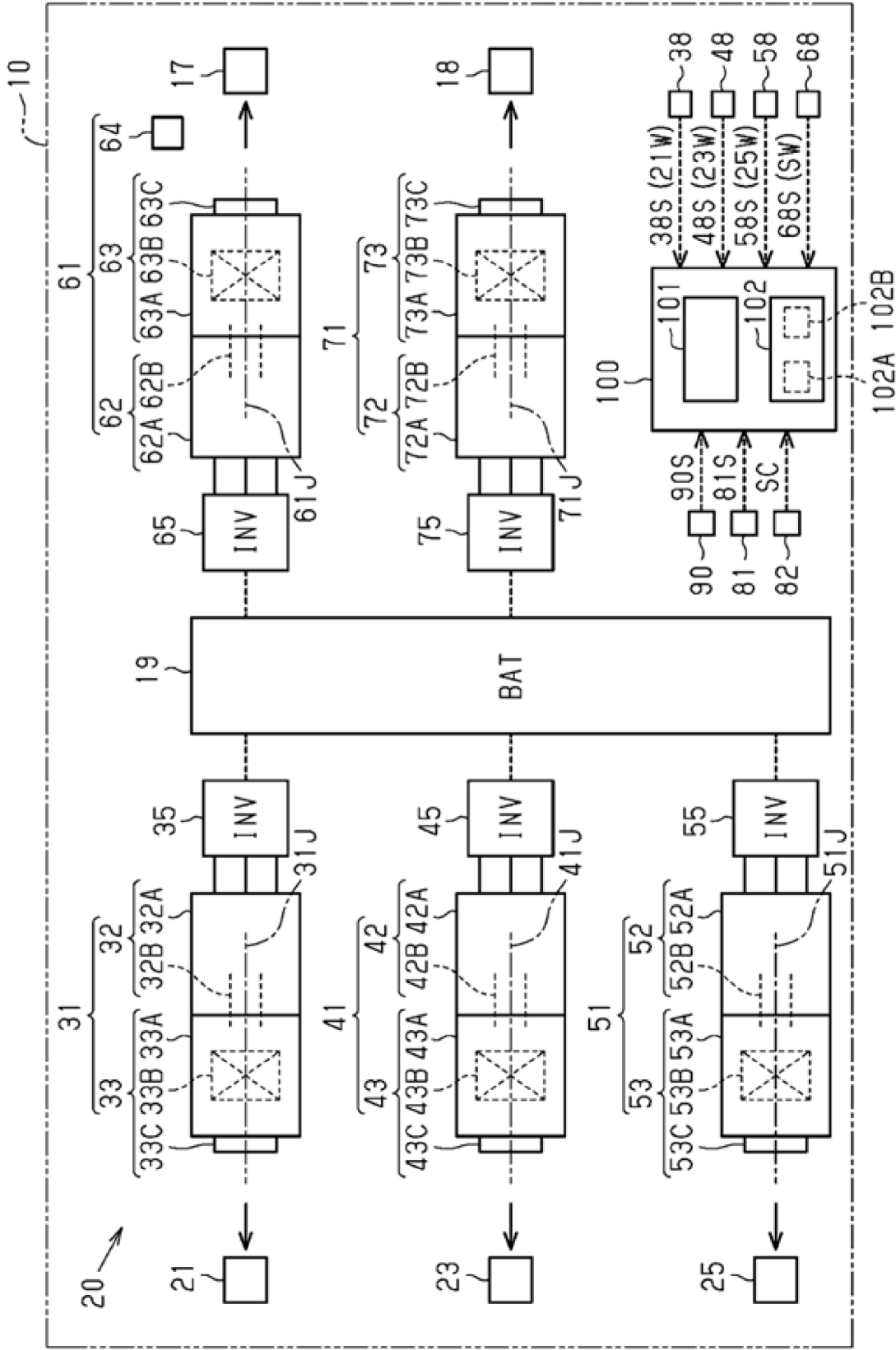


Fig. 3

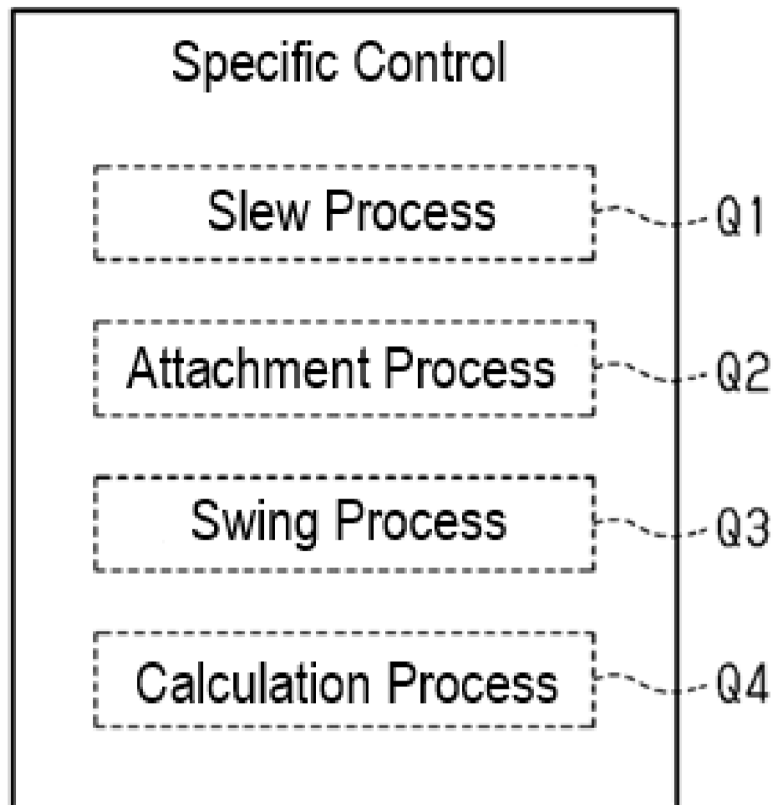


Fig. 4

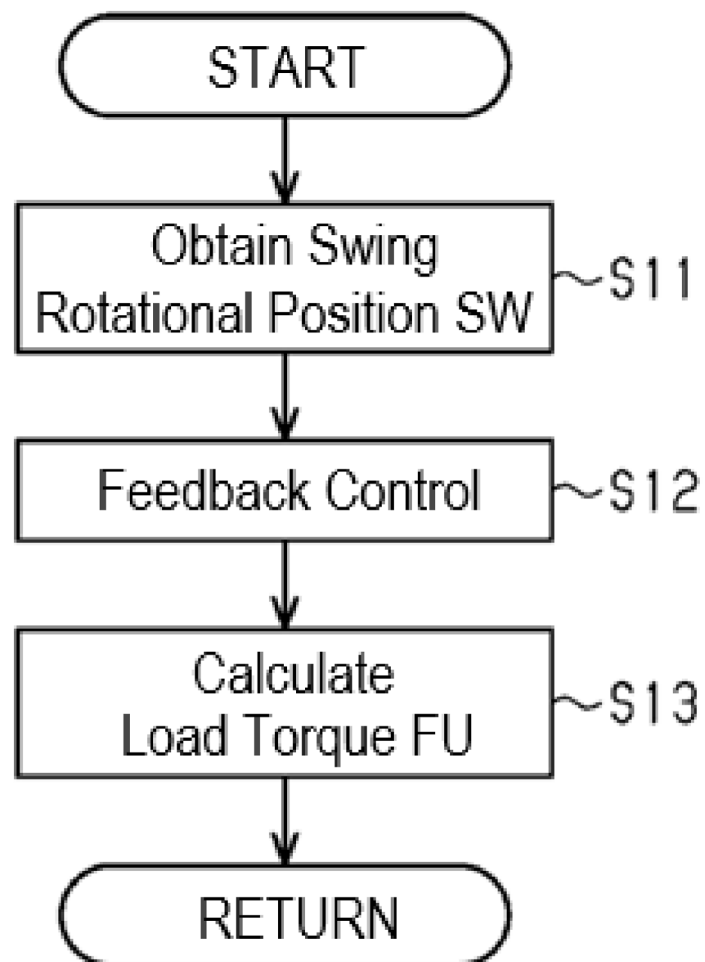


Fig. 5

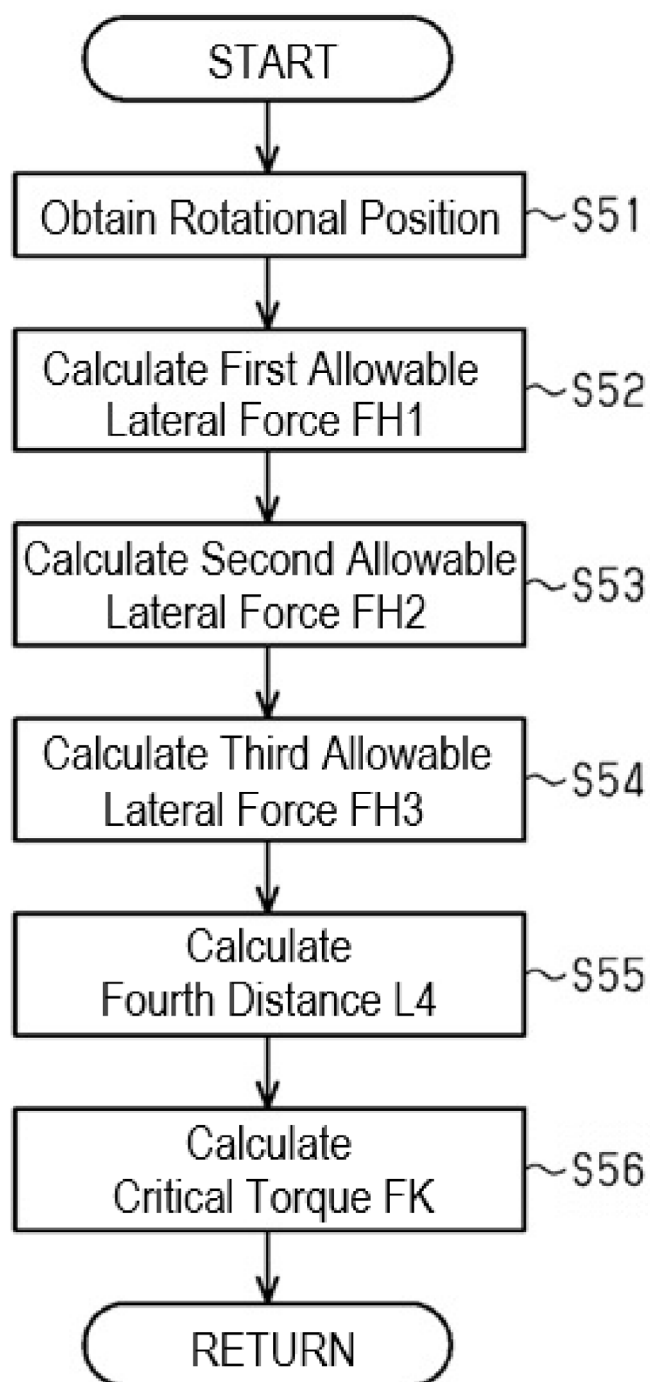


Fig. 6

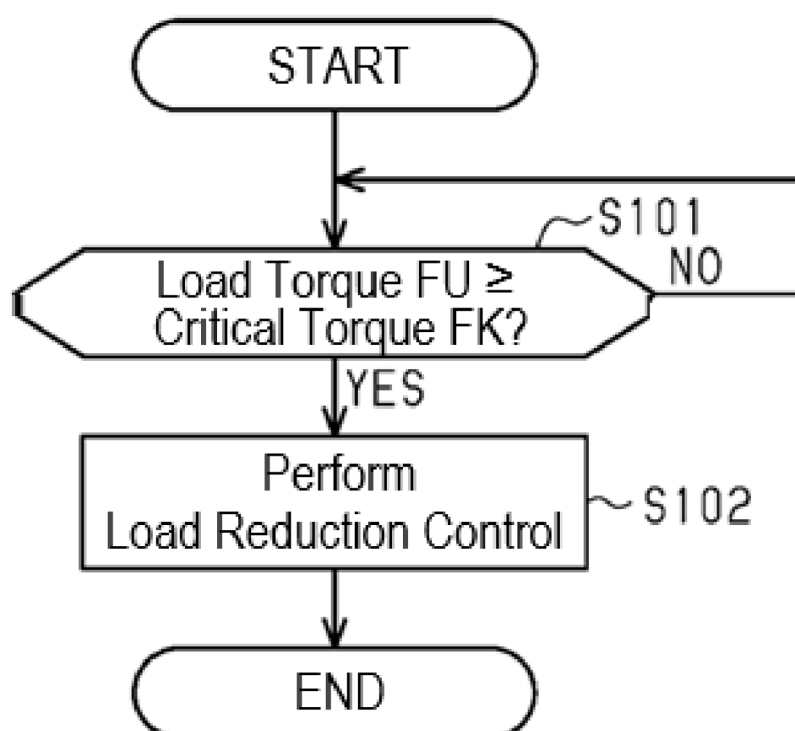


Fig. 7

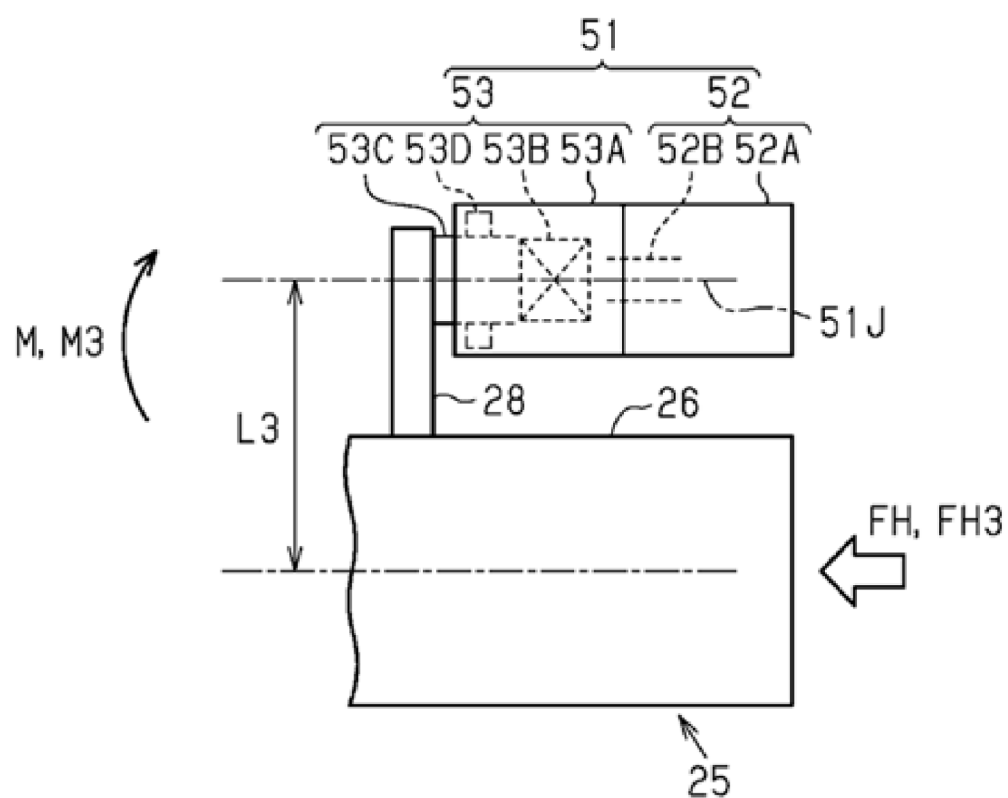


Fig. 8

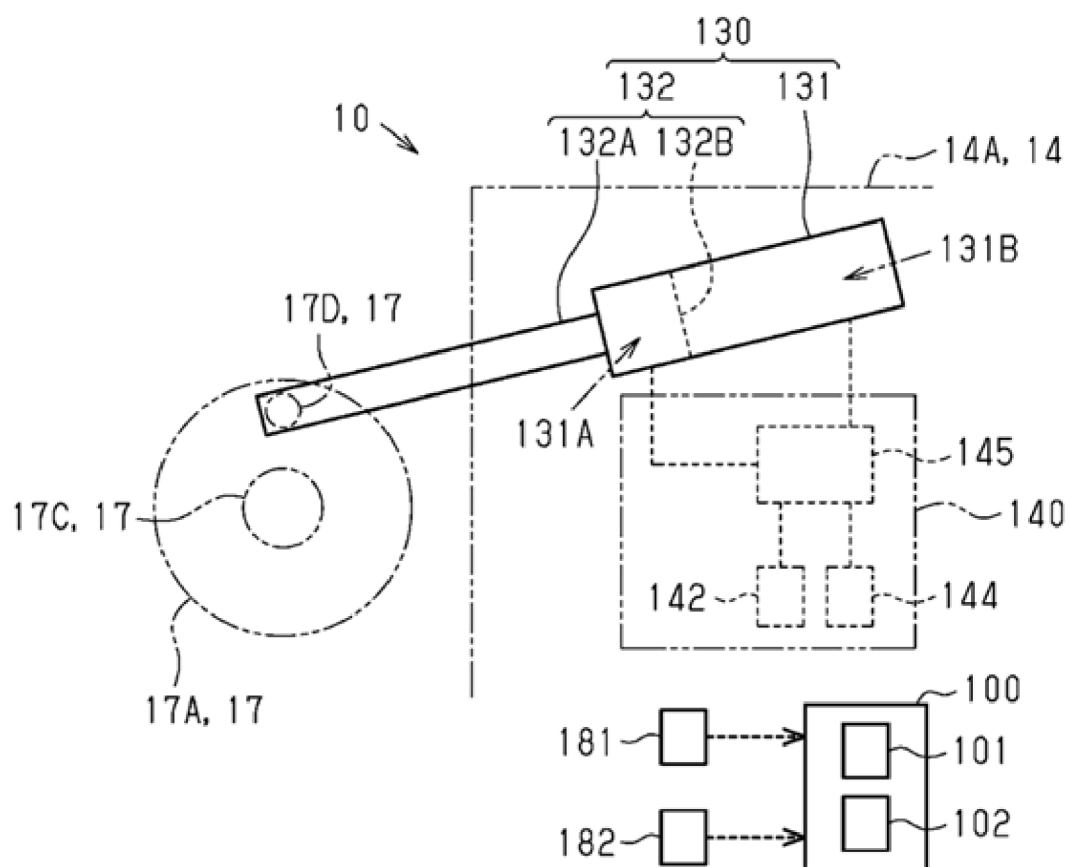


Fig. 9



EUROPEAN SEARCH REPORT

Application Number

EP 26 16 1600

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
A	EP 4 286 606 A1 (KUBOTA KK [JP]) 6 December 2023 (2023-12-06) * paragraph [0201] - paragraph [0221]; figures 1,14 *	1-13	INV. E02F3/38 E02F9/20
A	DE 20 2011 100095 U1 (KINSHOFER GMBH [DE]) 3 August 2012 (2012-08-03) * paragraph [0021] - paragraph [0022]; figures 1-3 *	1-13	
A	US 3 803 925 A (JACKSON J) 16 April 1974 (1974-04-16) * abstract; figure 1 *	1-13	
			TECHNICAL FIELDS SEARCHED (IPC)
			E02F
The present search report has been drawn up for all claims			
Place of search		Date of completion of the search	Examiner
Munich		20 August 2026	Clarke, Alister
CATEGORY OF CITED DOCUMENTS			
X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document			
T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO.

EP 26 16 1600

5

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on
The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

20-08-2026

10

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP 4286606 A1	06-12-2023	CN 115362296 A	18-11-2022
		EP 4286606 A1	06-12-2023

DE 202011100095 U1	03-08-2012	NONE	

US 3803925 A	16-04-1974	BE 803601 A	14-02-1974
		CA 976384 A	21-10-1975
		GB 1395847 A	29-05-1975
		JP S4958266 A	06-06-1974
		JP S5743700 B2	16-09-1982
		US 3803925 A	16-04-1974

15

20

25

30

35

40

45

50

55

EPO FORM P0459

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

REFERENCES CITED IN THE DESCRIPTION

This list of references cited by the applicant is for the reader's convenience only. It does not form part of the European patent document. Even though great care has been taken in compiling the references, errors or omissions cannot be excluded and the EPO disclaims all liability in this regard.

Patent documents cited in the description

- JP 2025061854 A [0001]
- JP 2001254395 A [0003]