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(54) **DRIVE SYSTEM OF WORKING MACHINE, METHOD OF CONTROLLING WORKING MACHINE, AND CONTROL PROGRAM FOR CONTROLLING A WORKING MACHINE**

(57) It is desired to reduce power consumption of electric actuators. An excavator includes a first electric actuator configured to drive a first movable member, a second electric actuator configured to drive a second movable member connected to the first movable member, a brake device configured to apply a braking force to a first output shaft of the first electric actuator, and a control device. If reaction torque acting on the first output

shaft as the second electric actuator outputs torque is greater than a threshold, the control device controls the first electric actuator such that the first output shaft outputs the torque in a direction opposite to the reaction torque. If the reaction torque is no more than the threshold, the control device causes the brake device to apply a braking force to the first output shaft and suspends power supply to the first electric actuator.

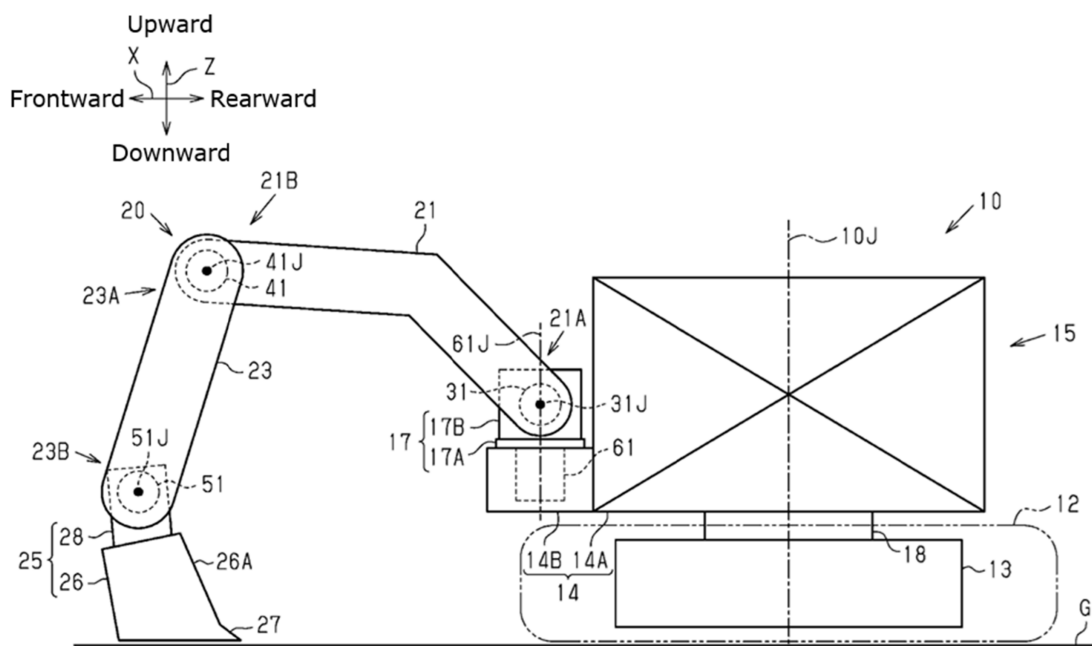


Fig. 1

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Description

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application is based on and claims the benefit of priority from Japanese Patent Application Serial No. 2025-061852 (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 of a working machine, a method of controlling a working machine, and a control program for controlling a working 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 front end of the boom. The arm can rotate up and down relative to the boom. The bucket is coupled to the front end of the arm. The bucket can rotate up and down relative to the arm.

[0004] Technologies such as the one described in the '395 Publication may employ electric actuators to rotate the moving parts such as the boom, arm, and bucket. When this type of actuator is employed, it is desirable to minimize the power consumption of each actuator. For example, during excavation work, a particular one of the moving parts may be rotated while another one is held at a substantially fixed position. In this case, the actuator for the moving part that is held at the fixed position is subjected to reaction force associated with the movement of the rotating moving part. To counteract the reaction force, the actuator may be energized to maintain the moving part at the fixed position. This may increase the power consumption of the actuator depending on the magnitude of the reaction force.

SUMMARY

[0005] To solve the above-described problem, a drive system of a working machine is provided. The drive system is applied to a working machine including a first movable member and a second movable member, the second movable member being rotatably connected to the first movable member. The drive system includes: a first electric actuator having a first output shaft configured to output torque to the first movable member; a second electric actuator attached to the first movable member, the second electric actuator having a second output shaft configured to output torque to the second movable member; a brake device configured to be switched between a

braking state in which the brake device applies braking torque to the first output shaft and a released state in which the brake device releases application of the braking torque to the first output shaft; and a control device configured to control the first electric actuator, the second electric actuator, and the brake device. When reaction torque is defined as torque of a reaction force acting on the first output shaft as the second output shaft outputs the torque, the control device performs: a first process if drive control for controlling the second electric actuator is being performed such that the second output shaft outputs the torque and if the reaction torque is greater than a predetermined threshold, the predetermined threshold being a value equal to or less than a maximum value of the braking torque the brake device is capable of applying to the first output shaft, the first process including controlling a rotation speed of the first output shaft to be equal to or less than a predetermined setting value by controlling the first electric actuator such that the first output shaft outputs the torque in a direction opposite to the reaction torque; and a second process if the drive control is being performed and if the reaction torque is equal to or less than the threshold, the second process including placing the brake device in the braking state and suspending power supply to the first electric actuator.

[0006] According to the above configuration, the power supply to the first electric actuator can be suspended until the reaction torque acting on the first output shaft exceeds the threshold value. This can result in shortening the drive duration of the first electric actuator, thereby saving the power consumption of the first electric actuator.

[0007] In the drive system of a working machine, in the first process, the control device may control the brake device and the first electric actuator such that a sum of the braking torque applied by the brake device and the torque output by the first output shaft becomes equal in magnitude to the reaction torque.

[0008] In the drive system of a working machine, the working machine may include a third movable member rotatably connected to the second movable member. The control device may perform: a third process in which positional relationship between the first output shaft and the third movable member is estimated based on a position of the second movable member relative to the first movable member and a position of the third movable member relative to the second movable member; and a fourth process in which the reaction torque is calculated based on the positional relationship estimated in the third process.

[0009] To solve the above-described problem, a drive system of a working machine is provided. The drive system is applied to a working machine including a first movable member and a second movable member, the second movable member being rotatably connected to the first movable member. The drive system includes: a first electric actuator having a first output shaft configured to output torque to the first movable member; a second

electric actuator attached to the first movable member, the second electric actuator having a second output shaft configured to output torque to the second movable member; a brake device configured to be switched between a braking state in which the brake device applies braking torque to the second output shaft and a released state in which the brake device releases application of the braking torque to the second output shaft; and a control device configured to control the first electric actuator, the second electric actuator, and the brake device. When reaction torque is defined as torque of a reaction force acting on the second output shaft as the first output shaft outputs the torque, the control device performs: a first process if drive control for controlling the first electric actuator is being performed such that the first output shaft outputs the torque and if the reaction torque is greater than a predetermined threshold, the predetermined threshold being a value equal to or less than a maximum value of the braking torque the brake device is capable of applying to the second output shaft, the first process including controlling a rotation speed of the second output shaft to be equal to or less than a predetermined setting value by controlling the second electric actuator such that the second output shaft outputs the torque in a direction opposite to the reaction torque; and a second process if the drive control is being performed and if the reaction torque is equal to or less than the threshold, the second process including placing the brake device in the braking state and suspending power supply to the second electric actuator.

[0010] According to the above configuration, the power supply to the second electric actuator can be suspended until the reaction torque acting on the second output shaft exceeds the threshold value. This can result in shortening the drive duration of the second electric actuator, thereby saving the power consumption of the second electric actuator.

[0011] In the drive system of a working machine, in the first process, the control device may control the brake device and the second electric actuator such that a sum of the braking torque applied by the brake device and the torque output by the second output shaft becomes equal in magnitude to the reaction torque.

[0012] In the drive system of a working machine, the working machine may include a third movable member rotatably connected to the second movable member. The control device may perform: a third process in which positional relationship between the second output shaft and the third movable member is estimated based on a position of the third movable member relative to the second movable member; and a fourth process in which the reaction torque is calculated based on the positional relationship estimated in the third process.

[0013] To solve the above-described problem, a method of controlling a working machine is provided. The method is applied to a working machine including: a first electric actuator having a first output shaft configured to output torque; a first movable member configured to

rotate in response to the torque from the first output shaft; a second electric actuator attached to the first movable member, the second electric actuator having a second output shaft configured to output torque; a second movable member configured to rotate in response to the torque from the second output shaft; a brake device configured to be switched between a braking state in which the brake device applies braking torque to the first output shaft and a released state in which the brake device releases application of the braking torque to the first output shaft; and a control device configured to control the first electric actuator, the second electric actuator, and the brake device. When reaction torque is defined as torque of a reaction force acting on the first output shaft as the second output shaft outputs the torque, the control device performs: a first process if drive control for controlling the second electric actuator is being performed such that the second output shaft outputs the torque and if the reaction torque is greater than a predetermined threshold, the predetermined threshold being a value equal to or less than a maximum value of the braking torque the brake device is capable of applying to the first output shaft, the first process including controlling a rotation speed of the first output shaft to be equal to or less than a predetermined setting value by controlling the first electric actuator such that the first output shaft outputs the torque in a direction opposite to the reaction torque; and a second process if the drive control is being performed and if the reaction torque is equal to or less than the threshold, the second process including placing the brake device in the braking state and suspending power supply to the first electric actuator.

[0014] According to the above method, the power supply to the first electric actuator can be suspended until the reaction torque acting on the first output shaft exceeds the threshold value. This can result in shortening the drive duration of the first electric actuator, thereby saving the power consumption of the first electric actuator.

[0015] To solve the above-described problem, a method of controlling a working machine is provided. The method is applied to a working machine including: a first electric actuator having a first output shaft configured to output torque; a first movable member configured to rotate in response to the torque from the first output shaft; a second electric actuator attached to the first movable member, the second electric actuator having a second output shaft configured to output torque; a second movable member configured to rotate in response to the torque from the second output shaft; a brake device configured to be switched between a braking state in which the brake device applies braking torque to the second output shaft and a released state in which the brake device releases application of the braking torque to the second output shaft; and a control device configured to control the first electric actuator, the second electric actuator, and the brake device. When reaction torque is defined as torque of a reaction force acting on the second

output shaft as the first output shaft outputs the torque, the control device performs: a first process if drive control for controlling the first electric actuator is being performed such that the first output shaft outputs the torque and if the reaction torque is greater than a predetermined threshold, the predetermined threshold being a value equal to or less than a maximum value of the braking torque the brake device is capable of applying to the second output shaft, the first process including controlling a rotation speed of the second output shaft to be equal to or less than a predetermined setting value by controlling the second electric actuator such that the second output shaft outputs the torque in a direction opposite to the reaction torque; and a second process if the drive control is being performed and if the reaction torque is equal to or less than the threshold, the second process including placing the brake device in the braking state and suspending power supply to the second electric actuator.

[0016] According to the above method, the power supply to the second electric actuator can be suspended until the reaction torque acting on the second output shaft exceeds the threshold value. This can result in shortening the drive duration of the second electric actuator, thereby saving the power consumption of the second electric actuator.

[0017] To solve the above-described problem, a control program for controlling a working machine is provided. The control program is applied to a working machine including: a first electric actuator having a first output shaft configured to output torque; a first movable member configured to rotate in response to the torque from the first output shaft; a second electric actuator attached to the first movable member, the second electric actuator having a second output shaft configured to output torque; a second movable member configured to rotate in response to the torque from the second output shaft; a brake device configured to be switched between a braking state in which the brake device applies braking torque to the first output shaft and a released state in which the brake device releases application of the braking torque to the first output shaft; and a control device configured to control the first electric actuator, the second electric actuator, and the brake device. When reaction torque is defined as torque of a reaction force acting on the first output shaft as the second output shaft outputs the torque, the control program causes the control device to perform: a first process if drive control for controlling the second electric actuator is being performed such that the second output shaft outputs the torque and if the reaction torque is greater than a predetermined threshold, the predetermined threshold being a value equal to or less than a maximum value of the braking torque the brake device is capable of applying to the first output shaft, the first process including controlling a rotation speed of the first output shaft to be equal to or less than a predetermined setting value by controlling the first electric actuator such that the first output shaft outputs the torque in a direction opposite to the reaction torque;

and a second process if the drive control is being performed and if the reaction torque is equal to or less than the threshold, the second process including placing the brake device in the braking state and suspending power supply to the first electric actuator.

[0018] According to the above program, the power supply to the first electric actuator can be suspended until the reaction torque acting on the first output shaft exceeds the threshold value. This can result in shortening the drive duration of the first electric actuator, thereby saving the power consumption of the first electric actuator.

[0019] To solve the above-described problem, a control program for controlling a working machine is provided. The control program is applied to a working machine including: a first electric actuator having a first output shaft configured to output torque; a first movable member configured to rotate in response to the torque from the first output shaft; a second electric actuator attached to the first movable member, the second electric actuator having a second output shaft configured to output torque; a second movable member configured to rotate in response to the torque from the second output shaft; a brake device configured to be switched between a braking state in which the brake device applies braking torque to the second output shaft and a released state in which the brake device releases application of the braking torque to the second output shaft; and a control device configured to control the first electric actuator, the second electric actuator, and the brake device. When reaction torque is defined as torque of a reaction force acting on the second output shaft as the first output shaft outputs the torque, the control program causes the control device to perform: a first process if drive control for controlling the first electric actuator is being performed such that the first output shaft outputs the torque and if the reaction torque is greater than a predetermined threshold, the predetermined threshold being a value equal to or less than a maximum value of the braking torque the brake device is capable of applying to the second output shaft, the first process including controlling a rotation speed of the second output shaft to be equal to or less than a predetermined setting value by controlling the second electric actuator such that the second output shaft outputs the torque in a direction opposite to the reaction torque; and a second process if the drive control is being performed and if the reaction torque is equal to or less than the threshold, the second process including placing the brake device in the braking state and suspending power supply to the second electric actuator.

[0020] According to the above program, the power supply to the second electric actuator can be suspended until the reaction torque acting on the second output shaft exceeds the threshold value. This can result in shortening the drive duration of the second electric actuator, thereby saving the power consumption of the second electric actuator.

ADVANTAGEOUS EFFECTS

[0021] The above-described technical concepts can reduce the power consumption of the electric actuator.

BRIEF DESCRIPTION OF THE DRAWINGS

[0022]

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

Fig. 2 is a schematic plan view of the excavator.

Fig. 3 shows the electrical configuration and power transmission paths of the excavator.

Fig. 4 is a schematic sectional view of a boom actuator and a first brake device.

Fig. 5 is a flowchart representing the steps taken to perform hold control.

Fig. 6 is a side view to describe how to calculate reaction torque acting on a first drive shaft.

Fig. 7 is a side view to describe how to calculate reaction torque acting on a second drive shaft.

Fig. 8 is a side view to describe how to calculate reaction torque acting on a third drive shaft.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

<First Embodiment>

[0023] The following now describes a first embodiment of a drive system of a working machine, a method of controlling a working machine, and a control program of a working machine, using a construction machine as an example. The drawings may show the constituent elements in an enlarged manner for the sake of better intelligibility. The ratios of the dimensions of the constituent elements may be different from those of the actual constituent elements, and among the drawings.

<Overall Configuration>

[0024] As shown in Figs. 1 and 2, an excavator 10, which is a construction machine, has 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 the present embodiment, the term "upward direction" refers to the direction in which the upper body 14 is located when viewed from the lower body 13, and the term "downward direction" refers to the opposite direction. A specific one of the directions ortho-

gonal to the upward direction is the frontward direction, and the opposite direction is the rearward direction. Furthermore, the direction that is orthogonal to both of the upward and frontward directions faces the left and right directions, which are opposite to each other. The frontward and rearward directions may be collectively referred to as the X direction. The left and right directions may be collectively referred to as the Y direction. The upward and downward directions may be collectively referred to as the Z direction.

[0025] The lower body 13 and the upper body 14 constitute a vehicle body 15. The lower body 13 has a rectangular parallelepiped shape, for example. The upper body 14 has a casing main portion 14A and a casing front portion 14B. The casing main portion 14A has a rectangular parallelepiped shape, for example. The interior of the casing main portion 14A is a hollow housing space. The housing space accommodates the various devices used to operate the excavator 10. The casing front portion 14B is located on the frontward side relative to the casing main portion 14A. The casing front portion 14B is positioned on the casing main portion 14A substantially at the middle in the Y direction. The casing front portion 14B is fixed onto the front side of the casing main portion 14A. The casing front portion 14B has a smaller rectangular parallelepiped shape than the casing main portion 14A, for example. The casing front portion 14B is hollow. Although not shown in the drawings, the upper body 14 has a cabin for accommodating an operator. The cabin is fixed as an integral part of the casing main portion 14A. The upper body 14 may be referred to as the upper revolving body.

[0026] As shown in Figs. 1 and 2, the excavator 10 has a slewing bearing 18. The slewing bearing 18 is interposed between the lower body 13 and the upper body 14. In Fig. 1, the vertical width of the slewing bearing 18 is exaggeratedly large with respect to the Z direction. As shown in Fig. 2, the slewing bearing 18 has an annular inner ring 18A, an annular outer ring 18B, and a plurality of rolling elements. The rolling elements are not shown in Fig. 2. The outer diameter of the inner ring 18A is smaller than the inner diameter of the outer ring 18B. The central axis of the inner ring 18A is referred to as a slew axis 10J, which substantially coincides with the central axis of the outer ring 18B. The slew axis 10J extends upwards and downwards relative to the vehicle body 15, i.e., in the Z direction. As shown in Fig. 1, the slew axis 10J passes vertically through both the upper body 14 and the lower body 13. The rolling elements are located between the inner ring 18A and outer ring 18B. The rolling elements support the inner ring 18A and outer ring 18B such that they can rotate relative to each other. This enables the outer ring 18B to rotate about the slew axis 10J relative to the inner ring 18A. The inner ring 18A is fixed to the lower body 13. The outer ring 18B is fixed to the casing main portion 14A of the upper body 14. In other words, the upper body 14 is rotatable about the slew axis 10J with respect to the lower body 13. Stated differently, the upper

body 14 can rotate relative to the lower body 13.

[0027] 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. Both of the traveling units 12 are 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 lower body 13 may be collectively referred to as the lower traveling body.

[0028] As shown in Figs. 1 and 2, the excavator 10 has a swing bracket 17. The swing bracket 17 is located on the forward side of the casing main portion 14A of the upper body 14. The swing bracket 17 has a first swing wall 17A and a second swing wall 17B. The first swing wall 17A is located on the upper surface of the casing front portion 14B of the upper body 14. The first swing wall 17A is, for example, shaped like a disc. The first swing wall 17A is connected to the casing front portion 14B. The first swing wall 17A can rotate, relative to the casing front portion 14B, about a fourth rotation axis 61J that extends upwards and downwards with respect to the vehicle body 15. The fourth rotation axis 61J is substantially parallel to the slew axis 10J. The second swing wall 17B protrudes upward from the upper surface of the first swing wall 17A. The second swing wall 17B is, for example, shaped like a rectangular plate.

<Working Attachment>

[0029] As shown in Figs. 1 and 2, the drive system of the excavator 10 includes a working attachment 20. The working attachment 20 has a boom 21, an arm 23, and a bucket 25.

[0030] As shown in Figs. 1 and 2, the boom 21 is located on the forward side with respect to the upper body 14. The boom 21 is shaped like an elongated plate or column. For example, the boom 21 is bent at an intermediate position in the longitudinal direction thereof. As shown in Fig. 2, a first end 21A of the boom 21 in the longitudinal direction is aligned with the second swing wall 17B of the swing bracket 17 in a direction along a first rotation axis 31J. The first rotation axis 31J is a virtual axis that intersects the fourth rotation axis 61J. Specifically, the first rotation axis 31J is substantially orthogonal to the fourth rotation axis 61J. The first end 21A of the boom 21 is rotatably connected to the second swing wall 17B. The boom 21 is equivalent to a first movable member. The first rotation axis 31J is equivalent to a first axis.

[0031] As shown in Figs. 1 and 2, the arm 23 extends from a second end 21B of the boom 21 that is opposite the first end 21A. The arm 23 is shaped like an elongated plate or column. As shown in Fig. 2, a first end 23A of the arm 23 in the longitudinal direction is aligned with the

second end 21B of the boom 21 in a direction along a second rotation axis 41J. The second rotation axis 41J is a virtual axis that is substantially parallel to the first rotation axis 31J. The first end 23A of the arm 23 is rotatably connected to the second end 21B of the boom 21. The arm 23 is equivalent to a second movable member. The second rotation axis 41J is equivalent to a second axis.

[0032] As shown in Figs. 1 and 2, the bucket 25 is located near a second end 23B of the arm 23 that is opposite the first end 23A. The bucket 25 has a bucket body 26, a plurality of teeth 27, and a bucket connecting wall 28. The bucket body 26 is shaped like a bucket. In other words, as shown in Fig. 2, the bucket body 26 has an opening 26A. The teeth 27 protrude from one of the edges of the rectangular opening of the bucket body 26. The bucket connecting wall 28 protrudes from a portion of the outer wall of the bucket body 26 that is located opposite the teeth 27 across the opening 26A. As shown in Fig. 2, the bucket connecting wall 28 is aligned with the second end 23B of the arm 23 in a direction along a third rotation axis 51J. The third rotation axis 51J is a virtual axis that is substantially parallel to both the first rotation axis 31J and the second rotation axis 41J. The bucket connecting wall 28 is rotatably connected to the second end 23B of the arm 23. The bucket 25 corresponds to a third movable member. The third rotation axis 51J is equivalent to a third axis. The tips of the teeth 27 of the bucket 25 are equivalent to a specific portion of the bucket 25.

<Electric Actuator>

[0033] As shown in Fig. 3, the drive system of the excavator 10 has a boom actuator 31, an arm actuator 41, and a bucket actuator 51. The boom actuator 31 can drive the boom 21. The arm actuator 41 can drive the arm 23. The bucket actuator 51 can drive the bucket 25. The excavator 10 includes a first inverter 35, a second inverter 45, a third inverter 55, and a battery 19. Although not shown, the first inverter 35, the second inverter 45, the third inverter 55, and the battery 19 are housed in the casing main portion 14A of the upper body 14. The boom actuator 31 is equivalent to a first electric actuator. The arm actuator 41 is equivalent to a second electric actuator.

[0034] As shown in Fig. 2, the boom actuator 31 is located between the second swing wall 17B of the swing bracket 17 and the first end 21A of the boom 21. As shown in Figs. 3 and 4, the boom actuator 31 has 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, a first drive shaft 32B, a stator 32C, and a rotor 32D. The stator 32C is located inside the housing 32A. The stator 32C is fixed to the housing 32A. The stator 32C is cylindrical. Although not shown in the drawing, a coil is

wound around the stator 32C. The coil is electrically connected to the battery 19 via the first inverter 35. The rotor 32D is located inside the stator 32C. The rotor 32D is rotatable relative to the stator 32C. The first drive shaft 32B is fixed to the rotor 32D. The first drive shaft 32B rotates together with the rotor 32D. The first drive shaft 32B protrudes from the inside of the housing 32A to the outside. The first drive shaft 32B is cylindrical. The first drive shaft 32B can rotate about its own rotation axis, that is to say, the first rotation axis 31J, relative to the housing 32A. In other words, the first drive shaft 32B outputs torque about the first rotation axis 31J. The first drive shaft 32B can rotate bi-directionally about the first rotation axis 31J. As shown in Fig. 2, the first rotation axis 31J passes through both the second swing wall 17B of the swing bracket 17 and the first end 21A of the boom 21. The first drive shaft 32B is equivalent to a first output shaft.

[0035] As shown in Figs. 3 and 4, the first speed reducer 33 has a housing 33A, a reduction mechanism 33B, and an output member 33C. The housing 33A is attached to the housing 32A of the first electric motor 32. The reduction mechanism 33B is located inside the housing 33A. Torque is input to the reduction mechanism 33B from the first drive 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, for example, an eccentric oscillating gear type or a planetary gear type. The output member 33C is cylindrical. The central axis of the output member 33C substantially coincides with the first rotation axis 31J. The output member 33C is rotatable relative to the housing 33A. The output member 33C rotates about the first rotation axis 31J in response to the rotation of the first drive shaft 32B of the first electric motor 32. The output member 33C is attached to the first end 21A of the boom 21. In other words, the output member 33C inputs torque about the first rotation axis 31J to the boom 21. The boom 21 can rotate about the first rotation axis 31J when acted upon by the torque from the first drive shaft 32B and thus the torque from the output member 33C.

[0036] As shown in Figs. 3 and 4, the drive system of the excavator 10 has a first brake device 81 for the boom actuator 31. As shown in Fig. 2, the first brake device 81 is located on the opposite side of the first speed reducer 33 across the first electric motor 32. In other words, in the direction along the first rotation axis 31J, the first brake device 81 is located between the first electric motor 32 and the second swing wall 17B of the swing bracket 17. As shown in Figs. 3 and 4, the first brake device 81 is fixed to the housing 32A of the first electric motor 32. The first brake device 81 is connected to the first drive shaft 32B of the first electric motor 32. The first brake device 81 is electrically connected to the battery 19.

[0037] The first brake device 81 is switchable between a braking state in which it applies braking torque to the

first drive shaft 32B and a released state in which it releases application of the braking torque to the first drive shaft 32B. Specifically, the first brake device 81 enters the braking state in which it applies braking torque to the first drive shaft 32B upon termination of power supply from the battery 19. Thus, the first brake device 81 disables the first drive shaft 32B from rotating. While receiving power from the battery 19, on the other hand, the first brake device 81 is placed in the released state in which it releases application of the braking torque to the first drive shaft 32B. In this case, the first drive shaft 32B is enabled to rotate. In the present embodiment, the first brake device 81 can apply to the first drive shaft 32B braking torque of a fixed value. The fixed value is the maximum value of the braking torque the first brake device 81 can apply to the first drive shaft 32B. In other words, the first brake device 81 may apply the maximum braking torque.

[0038] The first brake device 81 has a housing 81A, an excitation coil 81B, a contact plate 81C, a movable plate 81D, and a relay 81E. The housing 81A is cylindrical. The central axis of the housing 81A substantially coincides with the first rotation axis 31J of the housing 32A of the first electric motor 32. One of the ends of the housing 81A in the direction along its central axis is blocked. The other end of the housing 81A is fixed to the housing 32A. A portion of the first drive shaft 32B of the first electric motor 32 is located inside the housing 81A.

[0039] The excitation coil 81B, the contact plate 81C, and the movable plate 81D are located inside the housing 81A. The contact plate 81C is located closer to the housing 32A in the direction along the central axis of the housing 81A. The contact plate 81C is shaped like a disc. The first drive shaft 32B of the first electric motor 32 penetrates the contact plate 81C at a position near the center thereof. The contact plate 81C rotates together with the first drive shaft 32B.

[0040] The excitation coil 81B is located on the opposite side of the housing 32A across the contact plate 81C. Although not shown in detail, the excitation coil 81B has a coil body and a spring. The excitation coil 81B is fixed to the housing 81A. The coil body receives power supply from the battery 19 or is cut off from the power supply.

[0041] The movable plate 81D is located between the excitation coil 81B and the contact plate 81C. The movable plate 81D is shaped like a disc. The movable plate 81D has a hole at the center. The diameter of the hole is greater than the diameter of the first drive shaft 32B of the first electric motor 32. This hole receives therein the first drive shaft 32B. The movable plate 81D is movable in the direction along the first rotation axis 31J of the first drive shaft 32B. The movable plate 81D is subject to a bias force directed toward the contact plate 81C and exerted by the spring of the excitation coil 81B.

[0042] The relay 81E is located in the middle of a power line 81F, which is connected to the coil body of the excitation coil 81B. Depending on whether the relay 81E is turned on or off, the coil body of the excitation coil 81B is energized or de-energized. The excitation coil 81B

changes the position of the movable plate 81D depending on whether the coil body is energized or de-energized. While the coil body is de-energized, or the excitation coil 81B is not excited, the spring presses the movable plate 81D against the contact plate 81C. Accordingly, braking torque is applied to the contact plate 81C and thus to the first drive shaft 32B of the first electric motor 32 to stop the rotation of the first drive shaft 32B. In other words, the movable plate 81D applies braking torque to the first drive shaft 32B. On the other hand, while the coil is energized, or the excitation coil 81B is excited, the movable plate 81D overcomes the biasing force of the spring and moves away from the contact plate 81C. In this case, braking on the contact plate 81C and the first drive shaft 32B is released. The power line 81F, where the relay 81E is provided, is connected to a power line 89, which connects the first inverter 35 and the first electric motor 32, for example. Although not shown, a converter to perform DC-AC conversion or the like is provided on the power line 81F on the first inverter 35 side with respect to the relay 81E.

[0043] As shown in Fig. 2, the arm actuator 41 is attached to the boom 21. The arm actuator 41 is located between the second end 21B of the boom 21 and the first end 23A of the arm 23. The arm actuator 41 is basically configured the same as the boom actuator 31, except for the specific details such as the dimensions, reduction ratio, and output. The configuration of the arm actuator 41 is therefore only briefly described below.

[0044] As shown in Fig. 3, the arm actuator 41 has 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. A second drive shaft 42B of the second electric motor 42 outputs torque about its own central axis, which is referred to as the second rotation axis 41J. The second drive shaft 42B can rotate bi-directionally about the second rotation axis 41J. As shown in Fig. 2, the second rotation axis 41J runs through both the second end 21B of the boom 21 and the first end 23A of the arm 23. An output member 43C of the second speed reducer 43 is attached to the first end 23A of the arm 23. As shown in Fig. 3, the output member 43C outputs torque about the second rotation axis 41J. The arm 23 can rotate about the second rotation axis 41J, which is parallel to the first rotation axis 31J, in response to the torque from the second drive shaft 42B and thus the torque from the output member 43C. 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. The second drive shaft 42B is equivalent to a second output shaft.

[0045] As shown in Fig. 3, the drive system of the excavator 10 has a second brake device 82 for the arm actuator 41. The configuration of the second brake device 82 is basically the same as that of the first brake device 81, except for dimensions and other specific details. Therefore, the configuration of the second brake

device 82 is only briefly described in the following. As shown in Fig. 2, the second brake device 82 is located on the opposite side of the second speed reducer 43 across the second electric motor 42. In other words, in the direction along the second rotation axis 41J, the second brake device 82 is located between the second electric motor 42 and the second end 21B of the boom 21. As shown in Fig. 3, the second brake device 82 is fixed to the housing 42A of the second electric motor 42. The second brake device 82 is connected to the second drive shaft 42B of the second electric motor 42. The second brake device 82 is electrically connected to the battery 19.

[0046] The second brake device 82 is switchable between a braking state in which it applies braking torque to the second drive shaft 42B and a released state in which it releases application of the braking torque to the second drive shaft 42B. Specifically, the second brake device 82 enters the braking state in which it applies braking torque to the second drive shaft 42B upon termination of power supply from the battery 19. Thus, the second brake device 82 disables the second drive shaft 42B from rotating. While receiving power from the battery 19, on the other hand, the second brake device 82 is placed in the released state in which it releases application of the braking torque to the second drive shaft 42B. In this case, the second drive shaft 42B is enabled to rotate. The second brake device 82 can apply to the second drive shaft 42B braking torque of a fixed value. The fixed value is the maximum value of the braking torque the second brake device 82 can apply to the second drive shaft 42B. In other words, the second brake device 82 may apply the maximum braking torque.

[0047] The second brake device 82 has a housing 82A and an excitation coil 82B. The housing 82A is cylindrical. The central axis of the housing 82A substantially coincides with the second rotation axis 41J of the housing 42A of the second electric motor 42. One of the ends of the housing 82A in the direction along its central axis is blocked. The other end of the housing 82A is fixed to the housing 42A. A portion of the second drive shaft 42B of the second electric motor 42 is located inside the housing 82A.

[0048] The excitation coil 82B is located inside the housing 82A. While the excitation coil 82B is not excited, braking torque is applied to the second drive shaft 42B of the second electric motor 42 to stop the rotation of the second drive shaft 42B. On the other hand, while the excitation coil 82B is excited, the braking on the second drive shaft 42B of the second electric motor 42 is released. Although not shown, the second brake device 82 includes a relay that can switch whether the excitation coil 82B is energized or de-energized, and thus switch whether the excitation coil 82B is excited or not. The power line where the relay is provided is connected to the power line connecting the second inverter 45 and the second electric motor 42.

[0049] As shown in Fig. 2, the bucket actuator 51 is located between the second end 23B of the arm 23 and

the bucket connecting wall 28 of the bucket 25. The bucket actuator 51 is basically configured the same as the boom actuator 31, except for the specific details such as the dimensions, reduction ratio, and output. The configuration of the bucket actuator 51 is therefore only briefly described below.

[0050] As shown in Fig. 3, the bucket actuator 51 has 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. A third drive shaft 52B of the third electric motor 52 outputs torque about its own central axis, which is referred to as the third rotation axis 51J. The third drive shaft 52B can rotate bi-directionally about the third rotation axis 51J. As shown in Fig. 2, the third rotation axis 51J runs through both the second end 23B of the arm 23 and the bucket connecting wall 28. An output member 53C of the third speed reducer 53 is attached to the bucket connecting wall 28. As shown in Fig. 3, the output member 53C outputs torque about the third rotation axis 51J. The bucket 25 can rotate about the third rotation axis 51J, which is parallel to the first rotation axis 31J and the second rotation axis 41J, in response to the torque from the third drive shaft 52B and thus the torque from the output member 53C. 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.

[0051] As shown in Fig. 3, the drive system of the excavator 10 has a third brake device 83 for the bucket actuator 51. The configuration of the third brake device 83 is basically the same as that of the first brake device 81, except for dimensions and other specific details. Therefore, the configuration of the third brake device 83 is only briefly described in the following. As shown in Fig. 2, the third brake device 83 is located on the opposite side of the third speed reducer 53 across the third electric motor 52. In other words, in the direction along the third rotation axis 51J, the third brake device 83 is located between the third electric motor 52 and the second end 23B of the arm 23. As shown in Fig. 3, the third brake device 83 is fixed to the housing 52A of the third electric motor 52. The third brake device 83 is connected to the third drive shaft 52B of the third electric motor 52. The third brake device 83 is electrically connected to the battery 19.

[0052] The third brake device 83 is switchable between a braking state in which it applies braking torque to the third drive shaft 52B and a released state in which it releases application of the braking torque to the third drive shaft 52B. Specifically, the third brake device 83 enters the braking state in which it applies braking torque to the third drive shaft 52B upon termination of power supply from the battery 19. Thus, the third brake device 83 disables the third drive shaft 52B from rotating. While receiving power from the battery 19, on the other hand, the third brake device 83 is placed in the released state in which it releases application of the braking torque to the third drive shaft 52B. In this case, the third drive shaft 52B is enabled to rotate. The third brake device 83 can apply

to the third drive shaft 52B braking torque of a fixed value. The fixed value is the maximum value of the braking torque the third brake device 83 can apply to the third drive shaft 52B. In other words, the third brake device 83 may apply the maximum braking torque.

[0053] The third brake device 83 has a housing 83A and an excitation coil 83B. The housing 83A is cylindrical. The central axis of the housing 83A substantially coincides with the third rotation axis 51J of the housing 52A of the third electric motor 52. One of the ends of the housing 83A in the direction along its central axis is blocked. The other end of the housing 83A is fixed to the housing 52A. A portion of the third drive shaft 52B of the third electric motor 52 is located inside the housing 83A.

[0054] The excitation coil 83B is located inside the housing 83A. While the excitation coil 83B is not excited, braking torque is applied to the third drive shaft 52B of the third electric motor 52 to stop the rotation of the third drive shaft 52B. On the other hand, while the excitation coil 83B is excited, the braking on the third drive shaft 52B of the third electric motor 52 is released. Although not shown, the third brake device 83 includes a relay that can switch whether the excitation coil 83B is energized or de-energized, and thus switch whether the excitation coil 82B is excited or not. The power line where the relay is provided is connected to the power line connecting the third inverter 55 to the third electric motor 52.

[0055] As shown in Fig. 3, the excavator 10 includes a swing actuator 61 and a fourth inverter 65. As shown in Fig. 1, the swing actuator 61 is housed in the casing front portion 14B of the upper body 14. Although not shown, the fourth inverter 65 is housed in the casing main portion 14A of the upper body 14. The swing actuator 61 is basically configured the same as the boom actuator 31, except for the specific details such as the dimensions, reduction ratio, and output. The configuration of the swing actuator 61 is therefore only briefly described below.

[0056] As shown in Fig. 3, the swing actuator 61 has a fourth electric motor 62 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 and a fourth drive shaft 62B. The fourth drive shaft 62B outputs torque about its own central axis, which is referred to as the fourth rotation axis 61J. The fourth drive shaft 62B can rotate bi-directionally about the fourth rotation axis 61J. An output member 63C of the fourth speed reducer 63 is attached to the first swing wall 17A of the swing bracket 17. The output member 63C outputs torque about the fourth rotation axis 61J. The swing bracket 17 rotates about the fourth rotation axis 61J in response to the torque from the output member 63C. 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.

[0057] As shown in Fig. 3, the excavator 10 includes a slew actuator 71 and a fifth inverter 75. The slew actuator

71 and the fifth inverter 75 are housed in the casing main portion 14A of the upper body 14. The slew actuator 71 is basically configured the same as the boom actuator 31, except for specific details such as the dimensions, reduction ratio, and output. The configuration of the slew actuator 71 is therefore only briefly described below.

[0058] 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 attached to the casing main portion 14A of the upper body 14. The fifth electric motor 72 has a fifth drive shaft 72B configured to output torque about its own central axis, which is referred to as a fifth rotation axis 71J. The fifth drive shaft 72B can rotate bi-directionally about the fifth rotation axis 71J. The fifth speed reducer 73 has an output member 73C with a plurality of teeth. The teeth engage with the teeth of the inner ring 18A of the slewing bearing 18. The output member 73C outputs torque about the fifth rotation axis 71J. This torque causes the upper body 14 to rotate with the housing 72A of the fifth electric motor 72, relative to the inner ring 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>

[0059] As shown in Fig. 3, the drive system of the excavator 10 has a first angle sensor 38, a second angle sensor 48, and a third angle sensor 58. The first angle sensor 38 detects an angular position 38S of the first drive shaft 32B of the first electric motor 32. The second angle sensor 48 detects an angular position 48S of the second drive shaft 42B of the second electric motor 42. The third angle sensor 58 detects an angular position 58S of the third drive shaft 52B of the third electric motor 52. The angular positions detected by the respective angle 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 respective angular positions represent the absolute angles of the drive shafts of the respective electric motors. The angle sensors repeatedly transmit the information detected by themselves to a control device 100, which will be described below.

[0060] In addition to the above sensors, the drive system of the excavator 10 includes various other sensors necessary for operating the excavator 10. For example, the drive system of the excavator 10 has a first current sensor 91, a second current sensor 92, and a third current sensor 93. The first current sensor 91 detects a first current value 91S, which indicates the magnitude of the current supplied to the first electric motor 32 of the boom actuator 31. The second current sensor 92 detects

a second current value 92S, which indicates the magnitude of the current supplied to the second electric motor 42 of the arm actuator 41. The third current sensor 93 detects a third current value 93S, which indicates the magnitude of the current supplied to the third electric motor 52 of the bucket actuator 51. The respective current sensors repeatedly transmit the information detected by themselves to the control device 100.

[0061] The drive system of the excavator 10 includes various operating devices 90 configured to be operated by the operator. Fig. 3 shows the various operating devices as a single unit. The various operating devices 90 are located in the cabin. The various operating devices 90 transmit various signals 90S to the control device 100, for example, in response to the operator's operations.

<Control Device>

[0062] As shown in Fig. 3, the drive system of the excavator 10 includes a control device 100. The control device 100 can control the boom actuator 31, the arm actuator 41, the bucket actuator 51, the swing actuator 61, and the slew actuator 71. The control device 100 can also control the first brake device 81, the second brake device 82, and the third brake device 83. The control device 100 is a computer with a processing circuit. The processing circuit has a CPU 101 and a memory 102. The memory 102 includes three types of memory: RAM, ROM, and electrically rewritable nonvolatile memory. In the present embodiment, these three types 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 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.

[0063] The CPU 101 can also receive the angular position 38S transmitted from the first angle sensor 38. The CPU 101 can receive the angular position 48S transmitted from the second angle sensor 48. The CPU 101 can receive the angular position 58S transmitted from the third angle sensor 58. The CPU 101 can receive the first current value 91S transmitted from the first current sensor 91. The CPU 101 can receive the second current value 92S transmitted from the second current sensor 92. The CPU 101 can receive the third current value 93S transmitted from the third current sensor 93. The CPU 101 can receive the signals 90S transmitted from the operating devices 90.

[0064] The CPU 101 converts the angular position 38S received from the first angle sensor 38, which represents the actual angle of the first electric motor 32, into a first angular position pertaining to the boom 21. The first angular position is the angular position of the boom 21 relative to a predetermined first position. The first position and the first angular position are defined based on a

particular planar view of the excavator 10 as viewed along the first rotation axis 31J. For example, the first position is an angular position where both the first and second ends 21A and 21B of the boom 21 are positioned on a virtual straight line orthogonal to both the first and fourth rotation axes 31J and 61J. When the first position is defined as in this example, the second end 21B of the boom 21 is positioned opposite the vehicle body 15 across the first rotation axis 31J. The first angular position indicates the position of the boom 21 relative to the swing bracket 17 or vehicle body 15. The first angle sensor 38, which detects the actual angle of the first electric motor 32, effectively detects the first angular position.

[0065] As in the case of the first electric motor 32 described above, the CPU 101 converts the angular position 48S received from the second angle sensor 48, which represents the actual angle of the second electric motor 42, into a second angular position pertaining to the arm 23. The second angular position is the angular position of the arm 23 relative to a predetermined second position. The second position and the second angular position are defined based on a particular planar view of the excavator 10 as viewed along the second rotation axis 41J, which is parallel to the first rotation axis 31J. For example, the second position is an angular position where both the first and second ends 23A and 23B of the arm 23 are positioned on a virtual straight line passing through both the first and second rotation axes 31J and 41J. When the second position is defined as in this example, the second end 23B of the arm 23 is positioned opposite the first rotation axis 31J across the second rotation axis 41J. The second angular position indicates the position of the arm 23 relative to the boom 21. The second angle sensor 48, which detects the actual angle of the second electric motor 42, effectively detects the second angular position.

[0066] As in the case of the electric motors 32 and 42 described above, the CPU 101 converts the angular position 58S received from the third angle sensor 58, which represents the actual angle of the third electric motor 52, into a third angular position pertaining to the bucket 25. The third angular position is the angular position of the bucket 25 relative to a predetermined third position. The third position and the third angular position are defined based on a particular planar view of the excavator 10 as viewed along the third rotation axis 51J, which is parallel to the first rotation axis 31J. For example, the third position is an angular position where the teeth 27 of the bucket 25 are positioned on a virtual straight line passing through both the second and third rotation axes 41J and 51J. When the third position is defined as in this example, the teeth 27 of the bucket 25 are positioned opposite the second rotation axis 41J across the third rotation axis 51J. The third angular position indicates the position of the bucket 25 relative to the arm 23. The third angle sensor 58, which detects the actual angle of the third electric motor 52, effectively detects the third angular position.

[0067] The CPU 101 calculates the first angular position every time it receives the angular position 38S from the first angle sensor 38. In other words, the CPU 101 repeats the calculation of the first angular position. The CPU 101 calculating the first angular position is equivalent to the CPU 101 acquiring the first angular position. As with the first angular position, the CPU 101 repeats the calculation of the second and third angular positions. As with the first angular position, the CPU 101 calculating these angular positions is equivalent to the CPU 101 acquiring these angular positions.

<Holding Control>

[0068] The CPU 101 is capable of performing drive control of the movable members of the working attachment 20, including the boom 21, the arm 23, and the bucket 25. In drive control of each movable member, the CPU 101 controls the electric motor of the corresponding actuator so that the target movable member rotates. For example, in drive control of the arm 23, the CPU 101 controls the second electric motor 42 so that the second drive shaft 42B of the second electric motor 42 outputs torque to rotate the arm 23. The CPU 101 performs drive control of each movable member according to a drive signal associated with the target movable member, which is transmitted from the operating devices 90 in response to the operator's operation. In controlling each electric motor, the CPU 101 essentially controls the inverter connected to the target electric motor.

[0069] The CPU 101 is capable of performing holding control for the boom 21. The holding control for the boom 21 is executed to hold the boom 21 at a substantially fixed angular position. Upon receiving a holding signal for the boom 21 transmitted from the operating devices 90, the CPU 101 starts holding control for the boom 21. According to the present embodiment, the holding control for the boom 21 is performed in parallel with the drive control for the arm 23. In other words, the CPU 101 performs the holding control for the boom 21 while performing the drive control for the arm 23. All torques described herein take positive values.

[0070] As shown in Fig. 5, the CPU 101 starts the holding control for the boom 21 by first performing the step S100. In the step S100, the CPU 101 performs a preparation process in which the first brake device 81 is placed in the braking state and power supply to the first electric motor 32 is suspended. Specifically, the CPU 101 turns off the relay 81E of the first brake device 81 and cuts off the power supply to the excitation coil 81B. This results in a non-excitation state in which the battery 19 does not energize the excitation coil 81B of the first brake device 81, thereby applying braking torque to the first drive shaft 32B. This braking torque is the maximum braking torque of the first brake device 81. The CPU 101 also suspends the power supply from the battery 19 to the first electric motor 32 by controlling the first inverter 35. Upon performing the preparation process, the CPU 101 proceeds

to the step S110 while maintaining the state established by the preparation process.

[0071] In the step S110, the CPU 101 calculates a pressing reaction force FA1 shown in Fig. 6. The pressing reaction force FA1 is the reaction force acting on the bucket 25 from an object when the bucket 25 is pressed against the object as a result of rotation of the arm 23. The pressing reaction force FA1 acts in the direction orthogonal to a virtual straight line A2 in a particular planar view. The virtual straight line A2 is the virtual straight line passing through the second rotation axis 41J and the tips of the teeth 27 of the bucket 25 in the particular planar view. The object is the ground surface G, for example. In Fig. 6, the force acting on the object from the bucket 25 is represented by the reference sign "F".

[0072] In calculating the pressing reaction force FA1, the CPU 101 first calculates the output torque of the arm actuator 41. The output torque of the arm actuator 41 is the torque output from the second drive shaft 42B of the second electric motor 42, amplified by the second speed reducer 43, and output from the output member 43C. The memory 102 stores in advance torque conversion information as information to be used by the CPU 101 to calculate the output torque of the arm actuator 41. The torque conversion information represents the relationship between the output torque of the arm actuator 41 and the second current value 92S of the current supplied to the second electric motor 42. The CPU 101 calculates the output torque of the arm actuator 41 by applying the second current value 92S most recently received from the second current sensor 92 to the torque conversion information.

[0073] After this, the CPU 101 calculates a second distance L2, which is the distance from the second rotation axis 41J to the teeth 27 of the bucket 25 in the particular planar view. The second distance L2 is an indicator of the positional relationship between the second rotation axis 41J and the tips of the teeth 27 of the bucket 25. The memory 102 stores second distance information in advance to be used by the CPU 101 to calculate the second distance L2. The second distance information represents the relationship between the third angular position and the second distance L2. Specifically, the second distance information indicates values of the second distance L2 associated with different values of the third angular position. The second distance information is in the form of a table, a graph, or a formula, for example. In calculating the second distance L2, the CPU 101 acquires the most recent value of the third angular position. The CPU 101 then calculates the second distance L2 by applying the acquired value of the third angular position to the second distance information. Thus, the CPU 101 calculates the second distance L2 based on the third angular position.

[0074] After calculating the output torque of the arm actuator 41 and the second distance L2, the CPU 101 calculates the pressing reaction force FA1 by dividing the output torque of the arm actuator 41 by the second

distance L2. As shown in Fig. 5, after calculating the pressing reaction force FA1, the CPU 101 proceeds to the step S120.

[0075] In the step S120, the CPU 101 calculates an orthogonal component A of the pressing reaction force FA1. As shown in Fig. 6, the orthogonal component A is the component of the pressing reaction force FA1 directed orthogonally to a virtual straight line A1 passing through the first rotation axis 31J and the tips of the teeth 27 in the particular planar view. In other words, the orthogonal component A is calculated by multiplying the pressing reaction force FA1 with $\cos\theta$. The angle θ is the minor angle formed between the direction orthogonal to the virtual straight line A1 and the direction in which the pressing reaction force FA1 acts. The memory 102 stores angle information about the angle θ in advance. The angle information represents the relationship between the first, second, and third angular positions and the angle θ . Specifically, the angle information indicates the values of the angle θ associated with various combinations of the first, second, and third angular positions. The angle information is in the form of, for example, a table, a graph, or a formula. In calculating the angle θ , the CPU 101 acquires the most recent values of the first, second and third angular positions. The CPU 101 then calculates the angle θ by applying the acquired values of the first, second, and third angular positions to the angle information. Thus, the CPU 101 calculates the angle θ based on the most recent values of the first, second and third angular positions. After calculating the angle θ , the CPU 101 calculates the product of the pressing reaction force FA1 obtained in the step S110 and $\cos\theta$ as the orthogonal component A. As shown in Fig. 5, after calculating the orthogonal component A, the CPU 101 proceeds to the step S130.

[0076] In the step S130, the CPU 101 calculates reaction torque FR1. The reaction torque FR1 is a torque of a reaction force that the pressing reaction force FA1 exerts on the first drive shaft 32B of the boom actuator 31 through the bucket 25, the arm 23, and the boom 21. The reaction torque FR1 can be alternatively defined as a torque of a reaction force acting on the first drive shaft 32B through the bucket 25, the arm 23, and the boom 21 as the second drive shaft 42B outputs torque. In calculating the reaction torque FR1, the CPU 101 first calculates a first distance L1. As shown in Fig. 6, the first distance L1 is the distance from the first rotation axis 31J to the tips of the teeth 27 in the particular planar view. The first distance L1 is an indicator of the positional relationship between the first rotation axis 31J and the tips of the teeth 27 of the bucket 25. The CPU 101 calculating the first distance L1 is equivalent to the CPU 101 estimating the above positional relationship. The memory 102 stores first distance information in advance to be used by the CPU 101 to calculate the first distance L1. The first distance information represents the relationship between the second and third angular positions and the first distance L1. Specifically, the first distance information re-

presents values of the first distance L1 for different combinations of the second and third angular positions. The first distance information is in the form of a table, a graph, or a formula, for example. In calculating the first distance L1, the CPU 101 acquires the most recent values of the second and third angular positions. The CPU 101 then calculates the first distance L1 by applying the acquired values of the second and third angle positions to the first distance information. Thus, the CPU 101 calculates the first distance L1 based on the second and third angular positions. After calculating the first distance L1, the CPU 101 calculates the product of the first distance L1 and the orthogonal component A calculated in the step S120 as a tentative value. The tentative value is the reaction torque acting on the output member 33C of the first speed reducer 33. The CPU 101 converts the tentative value into the reaction torque FR1 acting on the first drive shaft 32B, taking into account the reduction ratio of the first speed reducer 33. In the above-described manner, the CPU 101 calculates the reaction torque FR1 based on the first distance L1. The orthogonal component A used by the CPU 101 to calculate the reaction torque FR1 reflects the pressing reaction force FA1 and thus the second current value 92S detected by the second current sensor 92. In other words, the CPU 101 calculates the reaction torque FR1 based on the second current value 92S. After calculating the reaction torque FR1, the CPU 101 proceeds to the step S140. The process in the step S130 serves as both third and fourth processes.

[0077] In the step S140, the CPU 101 determines whether the reaction torque FR1 is equal to or less than a determination threshold Q1. The determination threshold Q1 is the maximum braking torque of the first brake device 81. The memory 102 stores the determination threshold Q1 in advance. If the reaction torque FR1 calculated in the step S130 is equal to or less than the determination threshold Q1 (step S140: YES), the CPU 101 proceeds to the step S150.

[0078] As a premise for describing the step S150, it is possible that power is being supplied to the first electric motor 32 at the time the process proceeds to the step S150, in view of the relationship with the step S170 described below. It should be also noted that, due to the relationship with the steps S100 and S170, the first brake device 81 is in the braking state at the time the process proceeds to the step S150. In the step S150, the CPU 101 maintains the braking state of the first brake device 81 initiated in the preparation process and interrupts the current flow to the first electric motor 32. In other words, in the step S150, the CPU 101 performs a second process in which the first brake device 81 is placed in the braking state and the power supply to the first electric motor 32 is suspended. The CPU 101 proceeds to the step S180 while maintaining the state established by the second process. The CPU 101 maintains the state established the second process until it subsequently performs the step S150 or S170 described below.

[0079] On the other hand, if the reaction torque FR1 is

greater than the determination threshold Q1 in the step S140 (step S140: NO), the CPU 101 proceeds to the step S160. In the step S160, the CPU 101 calculates required torque FN1. The required torque FN1 is the magnitude of torque required to compensate for the insufficient braking force of the first brake device 81 in holding the boom 21 at the fixed angular position. The CPU 101 calculates the required torque FN1 by subtracting the determination threshold Q1 from the reaction torque FR1 calculated in the step S130. After calculating the required torque FN1, the CPU 101 proceeds to the step S170.

[0080] In the step S170, the CPU 101 controls the first electric motor 32 such that the first drive shaft 32B outputs torque equal to the required torque FN1 in the direction opposite to the reaction torque FR1, while maintaining the braking state of the first brake device 81 initiated in the preparation process. Stated differently, in the step S170, the CPU 101 performs a first process in which the first brake device 81 is placed in the braking state and the first electric motor 32 is controlled such that the first drive shaft 32B outputs torque acting in the direction opposite to the reaction torque FR1. The CPU 101 can ascertain the direction of rotation of the reaction torque FR1 acting on the first drive shaft 32B, based on the direction of rotation of the arm 23 caused by the drive control for the arm 23 and the like. The memory 102 stores in advance information about the direction of the reaction torque FR1 acting on the first drive shaft 32B during execution of the drive control for the arm 23.

[0081] Here, the required torque FN1 is the absolute value of the difference between the determination threshold Q1 and the reaction torque FR1. Note that the determination threshold Q1 is the maximum braking torque. Therefore, when the first drive shaft 32B is controlled to output the required torque FN1, the following first relationship holds in relation to the reaction torque FR1. The first relationship states that the sum of the braking torque applied by the first brake device 81 to the first drive shaft 32B and the torque output from the first drive shaft 32B is equal in magnitude to the reaction torque FR1. In the first process, the CPU 101 controls the first brake device 81 and the boom actuator 31 such that this first relationship is satisfied. In the first process, the CPU 101 therefore sets the rotation speed of the first drive shaft 32B lower than a setting value. The setting value is predetermined as the value at which the first drive shaft 32B can be substantially regarded as not rotating. The CPU 101 proceeds to the step S180 while maintaining the state established by the first process. As in the case of the step S150, the CPU 101 maintains the state established by the first process until it subsequently performs the step S150 or S170.

[0082] In the step S180, the CPU 101 determines whether a termination condition is satisfied. The termination condition is, for example, that the CPU 101 receives from the operating devices 90 a termination signal to terminate the holding control for the boom 21. If the termination condition is not satisfied (step S180: NO),

the CPU 101 returns to the step S110. If the termination condition is satisfied (step S180: YES), on the other hand, the CPU 101 cancels the state established by the first or second process. The CPU 101 then terminates the holding control for the boom 21. After this, the CPU 101 controls the current flow to the first electric motor 32 and the first brake device 81, according to the operator's operation of the operating devices 90. Referring to the holding control described above, the CPU 101 performs each step promptly on a time scale of less than one second, for example.

<How First Embodiment Works>

[0083] It is now assumed that the arm 23 is rotated while the boom 21 is held at a substantially fixed angular position to cause the bucket 25 to excavate the ground surface G. In this case, the bucket 25 is subjected to the pressing reaction force FA1 associated with the excavation of the ground surface G. The pressing reaction force FA1 acts on the first drive shaft 32B through the bucket 25, the arm 23, and the boom 21 as the reaction torque FR1, which tends to turn the first drive shaft 32B. In the holding control for the boom 21, if the reaction torque FR1 is equal to or less than the maximum braking torque of the first brake device 81 (step S140: YES), the CPU 101 holds the boom 21 at a substantially fixed angular position only with the braking torque of the first brake device 81 (step S150). On the other hand, if the reaction torque FR1 is greater than the maximum braking torque (step S140: NO), the CPU 101 uses the first electric motor 32 in addition to the first brake device 81 to hold the boom 21 at a substantially fixed angular position (step S170). During the excavation of the ground surface G achieved through rotation of the arm 23, the pressing reaction force FA1 changes sequentially according to the change in the angular position of the arm 23 and other factors. In the holding control for the boom 21, the CPU 101 adjusts the amount of assist provided by the first electric motor 32 in holding the boom 21 at a fixed angular position, in accordance with the change in the pressing reaction force FA1. In other words, in the holding control, the CPU 101 repeats the step S150 or S170 while the determination made in the step S180 is NO. In this way, the CPU 101 sequentially changes the torque output from the first electric motor 32 and thus the amount of assist mentioned above. By doing so, the CPU 101 holds the boom 21 at a substantially fixed angular position regardless of the change in the angular position of the arm 23 and thus the change in the pressing reaction force FA1.

<Advantageous Effects of First Embodiment>

[0084] (1-1) In holding the boom 21 at a substantially fixed angular position, the CPU 101 of the present embodiment energizes the first electric motor 32 only when the reaction torque FR1 is greater than the maximum braking torque of the first brake device 81. In other words,

the CPU 101 suspends the power supply to the first electric motor 32 until the reaction torque FR1 exceeds the maximum braking torque. Therefore, the drive time of the first electric motor 32 can be shortened in the present embodiment, so that the power consumption of the first electric motor 32 can be reduced.

[0085] (1-2) If the reaction torque FR1 exceeds the maximum braking torque, the CPU 101 of the present embodiment holds the boom 21 at a substantially fixed angular position by using the first brake device 81 and the first electric motor 32 together. In this case, the CPU 101 causes the first electric motor 32 to only output the shortfall relative to the maximum braking torque of the first brake device 81 required to hold the boom 21 at a fixed angular position. Since the first electric motor 32 is only required to output the shortfall relative to the maximum braking torque, the torque output from the first electric motor 32, and thus the power consumption of the first electric motor 32, can be minimized. When the first brake device 81 and the first electric motor 32 are used together to hold the boom 21 at a fixed angular position, the first electric motor 32 can assist the first brake device 81 and compensate for the insufficient braking force. Due to the assist provided by the first electric motor 32, the angular position of the boom 21 can be held even if a brake device with relatively small maximum braking torque is used as the first brake device 81. Therefore, the present embodiment tolerates use of an electric motor with relatively small maximum braking torque, and thus an electric motor of a small physical size, as the first electric motor 32. This contributes to the miniaturization of the first electric motor 32.

[0086] (1-3) Based on the position of the arm 23 relative to the boom 21 and the position of the bucket 25 relative to the arm 23, the CPU 101 of the present embodiment calculates the first distance L1, which is the distance from the first rotation axis 31J to the tips of the teeth 27. The CPU 101 then calculates the reaction torque FR1 based on the calculated first distance L1. This enables the CPU 101 to accurately calculate real-time the reaction torque FR1 according to the orientations of the boom 21, the arm 23, and the bucket 25.

<Second Embodiment>

[0087] The following now describes a second embodiment of a drive system of a working machine, a method of controlling a working machine, and a control program of a working machine. The second embodiment is different from the first embodiment in terms of the target to which the holding control is applied. Except for this, the second embodiment is the same as the first embodiment. In the following description of the second embodiment, redundant description of the same features as in the first embodiment may be omitted or simplified to focus on the differences from the first embodiment.

[0088] The CPU 101 of the present embodiment is capable of performing holding control for the arm 23.

The holding control for the arm 23 is performed to hold the arm 23 at a substantially fixed angular position. Upon receiving a holding signal for the arm 23 from the operating devices 90, the CPU 101 starts holding control for the arm 23. According to the present embodiment, the holding control for the arm is performed in parallel with the drive control for the boom 21. In other words, the CPU 101 performs the holding control for the arm 23 while performing the drive control for the boom 21. In the drive control for the boom 21, the CPU 101 controls the first electric motor 32 such that the first drive shaft 32B of the first electric motor 32 outputs torque to rotate the boom 21.

[0089] The holding control for the arm 23 is obtained by replacing the respective processes of the holding control for the boom 21 with those for holding the position of the arm 23, and shares the same basic concept as the holding control for the boom 21. For this reason, the following describes the processes mainly in terms of the differences between the holding control for the arm 23 and the holding control for the boom 21.

[0090] As shown in Fig. 5, the CPU 101 first performs the step S100 in the holding control for the arm 23. In the step S100, the CPU 101 performs a preparation process in which the second brake device 82 is placed in the braking state and the power supply to the second electric motor 42 is suspended. The CPU 101 proceeds to the step S110 while maintaining the state established by the preparation process. To place the second brake device 82 in the braking state, the CPU 101 turns off the relay and cuts off the power supply to the excitation coil 82B. The CPU 101 also suspends power supply to the second electric motor 42 by controlling the second inverter 45.

[0091] In the step S110, the CPU 101 calculates a pressing reaction force FA2 shown in Fig. 7. The pressing reaction force FA2 is the reaction force acting on the bucket 25 from an object when the bucket 25 is pressed against the object as a result of rotation of the boom 21. The pressing reaction force FA2 acts in the direction orthogonal to the virtual straight line A1 in the particular planar view. The CPU 101 calculates the pressing reaction force FA2 by dividing the output torque of boom actuator 31 by the first distance L1. The CPU 101 calculates the first distance L1 by applying the most recent values of the second and third angular positions to the first distance information stored in the memory 102. The CPU 101 also calculates the output torque of the boom actuator 31 based on the first current value 91S detected by the first current sensor 91. The memory 102 stores information necessary for this calculation in advance.

[0092] As shown in Fig. 5, the CPU 101 calculates an orthogonal component B in the step S120 after the step S110. As shown in Fig. 7, the orthogonal component B is the component of the pressing reaction force FA2 that is directed orthogonally to the virtual straight line A2 in the particular planar view. The CPU 101 converts the pressing reaction force FA2 into the orthogonal component B based on the most recent values of the first, second and third angular positions.

[0093] After this, the CPU 101 calculates reaction torque FR2 in the step S130. The reaction torque FR2 is a torque of a reaction force that the pressing reaction force FA2 exerts on the second drive shaft 42B of the arm actuator 41 through the bucket 25 and the arm 23. The reaction torque FR2 can be alternatively defined as a torque of a reaction force acting on the second drive shaft 42B through the bucket 25 and the arm 23 as the first drive shaft 32B outputs torque. The CPU 101 converts the product of the orthogonal component B calculated in the step S120 and the second distance L2 into the reaction torque FR2, taking into account the reduction ratio of the second speed reducer 43. Thus, the CPU 101 calculates the reaction torque FR2 based on the orthogonal component B, and thus the first current value 91S from which the orthogonal component B is calculated, and the second distance L2. This process serves as a fourth process. The CPU 101 calculates the second distance L2 by applying the most recent value of the third angular position to the second distance information stored on the memory 102. In other words, the CPU 101 calculates the second distance L2 based on the third angular position. This process serves as a third process. The CPU 101 calculating the second distance L2 is equivalent to the CPU 101 estimating the positional relationship between the second rotation axis 41J and the tips of the teeth 27 of the bucket 25.

[0094] After the step S130, the CPU 101 determines in the step S140 whether the reaction torque FR2 calculated in the step S130 is equal to or less than a determination threshold Q2. The determination threshold Q2 is the maximum braking torque of the second brake device 82. If the reaction torque FR2 is equal to or less than the determination threshold Q2 (step S140: YES), the CPU 101 proceeds to the step S150. In the step S150, the CPU 101 suspends the power supply to the second electric motor 42. In relation with the preparation process, the CPU 101 performs the second process in the step S150 in which the second brake device 82 is placed in the braking state and the power supply to the second electric motor 42 is suspended. The CPU 101 proceeds to the step S180 while maintaining the state established by the second process.

[0095] On the other hand, in the step S140, if the reaction torque FR2 is greater than the determination threshold Q2 (step S140: NO), the CPU 101 proceeds to the step S160. In the step S160, the CPU 101 calculates required torque FN2 by subtracting the determination threshold Q2 from the reaction torque FR2. In the subsequent step S170, the CPU 101 controls the second electric motor 42 such that the second drive shaft 42B outputs torque equal to the required torque FN2 in the direction opposite to the reaction torque FR2. Stated differently, the CPU 101 performs the first process in which the second brake device 82 is placed in the braking state and the second electric motor 42 is controlled such that the second drive shaft 42B outputs torque acting in the direction opposite to the reaction torque FR2. The

CPU 101 proceeds to the step S180 while maintaining the state established by the first process. Then, in the step S180, the CPU 101 determines whether a termination condition is satisfied. The termination condition is, for example, that the CPU 101 receives from the operating devices 90 a termination signal to terminate the holding control for the arm 23.

[0096] In the first process of the step S170, the CPU 101 controls the second brake device 82 and the arm actuator 41 such that the sum of the braking torque applied by the second brake device 82 to the second drive shaft 42B and the torque output by the second drive shaft 42B becomes equal in magnitude to the reaction torque FR2. In the first process, the CPU 101 therefore sets the rotation speed of the second drive shaft 42B lower than a setting value.

<Operations and Advantageous Effects of Second Embodiment>

[0097] The present embodiment works in the same manner as the first embodiment and also produces the same advantageous effects as described in (1-1) to (1-3), in terms of the arm 23, the second electric motor 42, and the second brake device 82.

<Modification Examples>

[0098] The above embodiments can be modified as described below. The above embodiments and the following modification examples can be implemented in combination to the extent where they are technically consistent with each other.

[0099] With respect to the first embodiment, instead of or in addition to performing the holding control for the boom 21, holding control for the bucket 25 may be performed. In other words, the holding control for the bucket 25 may be performed while the drive control for the arm 23 is being performed. Similarly, with respect to the second embodiment, instead of or in addition to performing the holding control for the arm 23, holding control for the bucket 25 may be performed. In other words, the holding control for the bucket 25 may be performed while the drive control for the boom 21 is being performed.

[0100] The following description handles an example case where the holding control for the bucket 25 is performed while the drive control for the arm 23 is being performed. In the holding control for the bucket 25, the CPU 101 performs the following processes in the steps shown in Fig. 5. In the step S100, the CPU 101 places the third brake device 83 in the braking state and suspends the power supply to the third electric motor 52. In the step S110, the CPU 101 calculates the pressing reaction force FA1 in the same manner as in the holding control for the boom 21. In the step S120, the CPU 101 calculates an orthogonal component C shown in Fig. 8. The orthogonal component C is the component of the pressing reaction

force FA1 directed orthogonally to a virtual straight line A3 passing through the third rotation axis 51J and the tips of the teeth 27 in the particular planar view. In the step S130, the CPU 101 converts the product of the orthogonal component C and a third distance L3 into a reaction torque FR3 acting on the third drive shaft 52B, taking into account the reduction ratio of the third speed reducer 53. The third distance L3 is the distance from the third rotation axis 51J to the tips of the teeth 27 of the bucket 25 in the particular planar view. In the step S140, the CPU 101 compares the reaction torque FR3 with a determination threshold Q3. The determination threshold Q3 is the maximum braking torque of the third brake device 83. If the reaction torque FR3 is equal to or less than the determination threshold Q3, the CPU 101 suspends the power supply to the third electric motor 52 while maintaining the third brake device 83 in the braking state in the step S150. On the other hand, if the reaction torque FR3 is greater than the determination threshold Q3, the CPU 101 causes the third electric motor 52 to output required torque, which is the difference between the reaction torque FR3 and the determination threshold Q3, while maintaining the third brake device 83 in the braking state in the step S170. Here, the CPU 101 controls the third electric motor 52 such that the third drive shaft 52B outputs torque in the direction opposite to the reaction torque FR3. Then, in the step S180, the CPU 101 terminates the holding control for the bucket 25 upon reception of a termination signal to terminate the holding control. In this example of the holding control for the bucket 25, the respective members are equivalent to the following constituent elements. The arm 23 is equivalent to the first movable member. The arm actuator 41 is equivalent to the first electric actuator. The second drive shaft 42B of the arm actuator 41 is equivalent to the first output shaft. The bucket 25 is equivalent to the second movable member. The bucket actuator 51 is equivalent to the second electric actuator. The third drive shaft 52B of the bucket actuator 51 is equivalent to the second output shaft.

[0101] As described in connection with the holding control for the bucket 25, any of the members of the working attachment 20 can be treated as the first and second movable members as appropriate. The member that is treated as the first movable member may determine which actuator constitutes the first electric actuator. When a different member than in the foregoing embodiments is treated as the first movable member, the first electric actuator may be the actuator that is configured to rotate the first movable member. Similarly, the member that is treated as the second movable member may determine which actuator constitutes the second electric actuator. The second electric actuator may be any actuator that is configured to rotate the second movable member. When another movable member different from the first movable member is connected to the second movable member, this movable member constitutes the third movable member. The actuator that is configured to

rotate the third movable member constitutes the third electric actuator.

[0102] At least one of the holding control for the arm 23 or the holding control for the boom 21 may be performed while the drive control for the bucket 25 is being performed. In this case, the pressing reaction force is obtained by dividing the output torque of the bucket actuator 51 by the third distance L3. The output torque of the bucket actuator 51 can be calculated based on the third current value 93S detected by the third current sensor 93. Provided that the pressing reaction force can be calculated, the calculated pressing reaction force can be used to calculate the reaction torque acting on the first drive shaft 32B or second drive shaft 42B. For example, in the case of the first drive shaft 32B, the product of the component of the pressing reaction force that is orthogonal to the virtual straight line A1 and the first distance L1 may be converted into the reaction torque acting on the first drive shaft 32B, taking into account the reduction ratio of the first speed reducer 33.

[0103] The respective brake devices may be configured in any other manners than in the above embodiments. The brake devices may be configured in any manner as long as they can apply and release application of the braking force to the target output shafts. For example, any brake device that can adjust the braking force applied to the first drive shaft 32B may be employed as the first brake device 81. In this case, the braking force applied to the first drive shaft 32B by the first brake device 81 in the preparation process may be set to a predetermined value below the maximum braking torque, which is the braking torque the first brake device 81 can apply to the first drive shaft 32B. In addition, the determination threshold Q1 may be set to this predetermined value. From the same perspective, the determination thresholds Q2 and Q3 may depend on the configurations of the second and third brake devices 82 and 83, and thus the braking forces set in the preparation process.

[0104] As described in the above modification example, the determination thresholds are not limited to the maximum braking torques of the brake devices. The determination thresholds may only be required to be no more than the maximum braking torques of the respective brake devices. As in the modification example above, when the first brake device 81 is configured to provide an adjustable braking force, the braking forces applied by the first brake device 81 to the first drive shaft 32B may vary in magnitude among the preparation process, the first process, and the second process. The same is true for the second and third brake devices 82 and 83.

[0105] The first brake device 81 may be configured to apply braking torque to the output member 33C of the first speed reducer 33. In this case, the first brake device 81 can indirectly apply braking torque to the first drive shaft 32B, which is the first output shaft. The output member 33C may be treated as the first output shaft. Like the first brake device 81, the second and third brake devices 82

and 83 may also be configured to apply braking torques to the output members of the speed reducers. The output member 43C of the second speed reducer 43 may be treated as the second output shaft, or the output member 53C of the third speed reducer 53 as the third output shaft.

[0106] The electrical system supplying power to the first brake device 81 can be configured in any other manner than in the foregoing illustrative embodiments. For example, the relay 81E may be eliminated. In this case, whether the first electric motor 32 is energized is directly reflected in whether the excitation coil 81B is energized. When such a configuration is employed, the CPU 101 can cut off the power supply to both the first electric motor 32 and the first brake device 81 by interrupting the current flow to the first electric motor 32 in the preparation and second processes of the holding control for the boom 21. Alternatively, the relay 81E may not be eliminated, and the power line 81F may be connected directly to the battery 19 without going through the power line 89 connecting the first inverter 35 and the first electric motor 32. From the same perspective, the electrical systems of the second and third brake devices 82 and 83 may also be configured in any other manner than in the foregoing illustrative embodiments.

[0107] In connection with the above modification example of the electrical systems, in the first process of the holding control for the boom 21, the first electric motor 32 may be energized, so that power may be supplied to the first electric motor 32 and also to the first brake device 81. In this way, the boom 21 may be held at a substantially fixed position only with the torque of the first electric motor 32, while the first brake device 81 releases braking on the first drive shaft 32B. In this case, the CPU 101 may not perform the step S160 and, in the step S170, control the first electric motor 32 such that the first drive shaft 32B outputs torque equal to the reaction torque FR1 in the direction opposite to the reaction torque FR1 while energizing the first brake device 81. By doing so, the CPU 101 may set the rotation speed of the first drive shaft 32B below the setting value. The holding control for the boom 21 is used as an example here, but the same can be said for the holding control for the other movable members. In other words, in holding the movable member at a substantially fixed angular position in the first process of the holding control for each movable member, it is not mandatory to use both the brake device and the electric motor.

[0108] With respect to the first process, the setting value can be determined in any other manner than in the above illustrative embodiments. The setting value may be determined as appropriate from the viewpoint of holding the target movable member at a substantially fixed position. The reaction torque can be calculated in any other manner than in the above illustrative embodiments. For example, the excavator 10 may include a strain sensor or other sensor that can be used to calculate the reaction torque. The reaction torque may then be calculated based on the values detected by these sensors. Any calculation method is acceptable as long as the

reaction torque can be calculated appropriately.

[0109] Of the three movable members in the working attachment 20, driving control of two or more movable members may be performed while holding control of one movable member is being executed. Even in this case, it is sufficient to calculate the reaction torque acting on the output shaft associated with the movable member whose position is being held. In addition, the first process or the second process may be performed according to the magnitude of this reaction torque.

[0110] The specific portion of the bucket 25 is not limited to the tips of the teeth 27 of the bucket 25. The specific portion of the bucket 25 is preferably set at the position where a force from an object such as soil or sand acts when the bucket 25 collides with the object during operation of the excavator 10.

[0111] The overall configuration of the working attachment 20 is not limited to the examples described in the above embodiments. Appropriate movable members for required work may be employed and included in the working attachment 20. For example, other movable member than the bucket 25 may be employed as the third movable member. Depending on what movable member is employed as the third movable member, the specific portion of the third movable member can vary. The third movable member may be eliminated. The working attachment 20 is only required to include two or more movable members.

[0112] The shape of the first drive shaft 32B of the first electric motor 32 and the shape of the output member 33C of the first speed reducer 33 are not limited to a cylindrical shape. The first drive shaft 32B and output member 33C need only be shaped to transmit torque to the target member. Similarly, the shape of the second drive shaft 42B of the second electric motor 42 and the shape of the output member 43C of the second speed reducer 43 are not limited to a cylindrical shape. The same is true for the shape of the third drive shaft 52B of the third electric motor 52 and the shape of the output member 53C of the third speed reducer 53.

[0113] The boom actuator 31 may be configured in any other manner than in the above illustrative embodiments. The boom actuator 31 can be configured in any manner as long as it includes an electric motor and is capable of causing the boom 21 to rotate. For example, the boom actuator 31 may be embodied without the first speed reducer 33. Furthermore, the boom actuator 31 is not limited to an actuator configured to output torque that is coaxial with the drive shaft of the electric motor to an external device.

[0114] The boom actuator 31 may be installed on the boom 21 and the swing bracket 17 in any other manner than in the above illustrative embodiments. The boom actuator 31 can be installed in any manner as long as the boom 21 can be rotated by the boom actuator 31. For example, the orientation of the boom actuator 31 between the second swing wall 17B of the swing bracket 17 and the boom 21 may be reversed. In other words, the

first speed reducer 33 is positioned closer to the second swing wall 17B and the first electric motor 32 closer to the boom 21, so that the boom actuator 31 may be attached to the boom 21 and the swing bracket 17.

[0115] Like the above modification example regarding the boom actuator 31, the arm actuator 41 can be configured and installed in any other manner than in the above illustrative embodiments. The arm actuator 41 is only required to include an electric motor and be capable of causing the arm 23 to rotate.

[0116] Like the above modification example regarding the boom actuator 31, the bucket actuator 51 can be configured and installed in any other manner than in the above illustrative embodiments. The bucket actuator 51 is only required to include an electric motor and be capable of causing the bucket 25 to rotate.

[0117] The upper body 14 may be configured in any other manner than in the above illustrative embodiments. For example, the cabin may be eliminated from the upper body 14. The casing main portion 14A and the casing front portion 14B 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 for the required functions, 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 devices 90 may be eliminated from the upper body 14. Along with this, various signals transmitted to the control device 100 to instruct the excavator 10 how to operate may be transmitted via wireless communication from a device external to the vehicle body 15.

[0119] The constituent elements included in the drive system of the excavator 10 are not limited to those described in the above illustrative embodiments. For example, the working attachment 20 may be treated as a constituent element excluded from the drive system. For example, the various sensors and various operation devices may be treated as constituent elements excluded from the drive system.

[0120] 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 is only required to be configured as a whole to realize required work, for example, excavation.

[0121] The working machine is not limited to the excavator 10. The working machine may be any construction machine other than the excavator 10. Furthermore, the working machine is not limited to a construction machine. Other than a construction machine, examples of the working machine include machines used in forestry, crushed-stone production, industrial waste treatment, and agriculture.

[0122] The processing circuit of the control device 100

is acceptable as long as it is configured in any one of the following manners (a) to (c).

- (a) The processing circuit has one or more processors that execute various processes according to computer programs. The processors include the CPU 101 and the 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.
- (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.
- (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.

[0123] The foregoing embodiments describe 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.

[0124] 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.

[0125] The following describes the technical ideas that can be ascertained from the above embodiments and their modifications.

(A) In the drive system of a working machine according to Claim 1 or 2, the second movable member is configured to rotate about a second axis parallel to a first axis about which the first output shaft is configured to rotate, the working machine includes: a third movable member connected to the second movable member such that the third movable member is rotatable about a third axis parallel to the first axis; a current sensor configured to detect a current value indicating a current supplied to the second electric actuator; a second angle sensor configured to detect a second angular position indicating an angular position of the second movable member; and a third angle sensor configured to detect a third angular position indicating an angular position of the third movable member, when a particular planar view is

defined as a view of the working machine as seen along a direction parallel to the first axis, the control device stores in advance distance information indicating relationship between (i) the second and third angular positions and (ii) a first distance indicating a distance from the first axis to a specific portion of the third movable member in the particular planar view, and, while performing the drive control, the control device performs (I) a third process where the first distance is calculated by obtaining the current value, the second angular position and the third angular position and applying the obtained second and third angular positions to the distance information, and (II) a fourth process where the reaction torque is calculated based on the calculated first distance and the current value.

(B) In the drive system of a working machine according to Claim 4 or 5, the working machine includes: a third movable member coupled to the second movable member such that the third movable member is rotatable about a third axis parallel to a first axis about which the first output shaft is rotatable; a current sensor configured to detect a current value of a current supplied to the first electric actuator; and an angle sensor configured to detect an angular position of the third movable member, when a particular planar view is defined as a view of the working machine as seen along a direction parallel to the first axis, the control device stores in advance distance information indicating relationship between (i) the angular position and (ii) a second distance indicating a distance from the second axis to a specific portion of the third movable member in the particular planar view, and while performing the drive control, the control device performs (I) a third process where the second distance is calculated by obtaining the current value and the angular position and applying the obtained angular position to the distance information, and (II) a fourth process where the reaction torque is calculated based on the calculated second distance and the current value.

[0126] The configuration described in (A) or (B) above enables accurate and real-time calculation of the reaction torque considering the orientations.

Claims

1. A drive system of a working machine, wherein the drive system is applied to a working machine including a first movable member and a second movable member, the second movable member being rotatably connected to the first movable member, wherein the drive system comprises:

a first electric actuator having a first output shaft

configured to output torque to the first movable member;

a second electric actuator attached to the first movable member, the second electric actuator having a second output shaft configured to output torque to the second movable member;

a brake device configured to be switched between a braking state in which the brake device applies braking torque to the first output shaft and a released state in which the brake device releases application of the braking torque to the first output shaft; and

a control device configured to control the first electric actuator, the second electric actuator, and the brake device, and

wherein, when reaction torque is defined as torque of a reaction force acting on the first output shaft as the second output shaft outputs the torque, the control device performs:

a first process if drive control for controlling the second electric actuator is being performed such that the second output shaft outputs the torque and if the reaction torque is greater than a predetermined threshold, the predetermined threshold being a value equal to or less than a maximum value of the braking torque the brake device is capable of applying to the first output shaft, the first process including controlling a rotation speed of the first output shaft to be equal to or less than a predetermined setting value by controlling the first electric actuator such that the first output shaft outputs the torque in a direction opposite to the reaction torque; and

a second process if the drive control is being performed and if the reaction torque is equal to or less than the threshold, the second process including placing the brake device in the braking state and suspending power supply to the first electric actuator.

2. The drive system of claim 1, wherein, in the first process, the control device controls the brake device and the first electric actuator such that a sum of the braking torque applied by the brake device and the torque output by the first output shaft becomes equal in magnitude to the reaction torque.

3. The drive system of claim 1 or 2,

wherein the working machine includes a third movable member rotatably connected to the second movable member, and

wherein the control device performs:

a third process in which positional relation-

ship between the first output shaft and the third movable member is estimated based on a position of the second movable member relative to the first movable member and a position of the third movable member relative to the second movable member; and

a fourth process in which the reaction torque is calculated based on the positional relationship estimated in the third process.

4. A drive system of a working machine,

wherein the drive system is applied to a working machine including a first movable member and a second movable member, the second movable member being rotatably connected to the first movable member,

wherein the drive system comprises:

a first electric actuator having a first output shaft configured to output torque to the first movable member;

a second electric actuator attached to the first movable member, the second electric actuator having a second output shaft configured to output torque to the second movable member;

a brake device configured to be switched between a braking state in which the brake device applies braking torque to the second output shaft and a released state in which the brake device releases application of the braking torque to the second output shaft; and

a control device configured to control the first electric actuator, the second electric actuator, and the brake device, and wherein, when reaction torque is defined as torque of a reaction force acting on the second output shaft as the first output shaft outputs the torque, the control device performs:

a first process if drive control for controlling the first electric actuator is being performed such that the first output shaft outputs the torque and if the reaction torque is greater than a predetermined threshold, the predetermined threshold being a value equal to or less than a maximum value of the braking torque the brake device is capable of applying to the second output shaft, the first process including controlling a rotation speed of the second output shaft to be equal to or less than a predetermined setting value by controlling the

second electric actuator such that the second output shaft outputs the torque in a direction opposite to the reaction torque; and

a second process if the drive control is being performed and if the reaction torque is equal to or less than the threshold, the second process including placing the brake device in the braking state and suspending power supply to the second electric actuator.

5. The drive system of claim 4, wherein, in the first process, the control device controls the brake device and the second electric actuator such that a sum of the braking torque applied by the brake device and the torque output by the second output shaft becomes equal in magnitude to the reaction torque.

6. The drive system of claim 4 or 5,

wherein the working machine includes a third movable member rotatably connected to the second movable member, and
wherein the control device performs:

a third process in which positional relationship between the second output shaft and the third movable member is estimated based on a position of the third movable member relative to the second movable member; and
a fourth process in which the reaction torque is calculated based on the positional relationship estimated in the third process.

7. A method of controlling a working machine, wherein the method is applied to a working machine including:

a first electric actuator having a first output shaft configured to output torque; a first movable member configured to rotate in response to the torque from the first output shaft;
a second electric actuator attached to the first movable member, the second electric actuator having a second output shaft configured to output torque;
a second movable member configured to rotate in response to the torque from the second output shaft;
a brake device configured to be switched between a braking state in which the brake device applies braking torque to the first output shaft and a released state in which the brake device releases application of the braking torque to the first output shaft; and a control device configured to control the first electric actuator, the second

electric actuator, and the brake device, and wherein, when reaction torque is defined as torque of a reaction force acting on the first output shaft as the second output shaft outputs the torque, the control device performs:

a first process if drive control for controlling the second electric actuator is being performed such that the second output shaft outputs the torque and if the reaction torque is greater than a predetermined threshold, the predetermined threshold being a value equal to or less than a maximum value of the braking torque the brake device is capable of applying to the first output shaft, the first process including controlling a rotation speed of the first output shaft to be equal to or less than a predetermined setting value by controlling the first electric actuator such that the first output shaft outputs the torque in a direction opposite to the reaction torque; and
a second process if the drive control is being performed and if the reaction torque is equal to or less than the threshold, the second process including placing the brake device in the braking state and suspending power supply to the first electric actuator.

8. A method of controlling a working machine, wherein the method is applied to a working machine including:

a first electric actuator having a first output shaft configured to output torque;
a first movable member configured to rotate in response to the torque from the first output shaft;
a second electric actuator attached to the first movable member, the second electric actuator having a second output shaft configured to output torque;
a second movable member configured to rotate in response to the torque from the second output shaft;
a brake device configured to be switched between a braking state in which the brake device applies braking torque to the second output shaft and a released state in which the brake device releases application of the braking torque to the second output shaft; and
a control device configured to control the first electric actuator, the second electric actuator, and the brake device, and wherein, when reaction torque is defined as torque of a reaction force acting on the second output shaft as the first output shaft outputs the torque, the control device performs:

- a first process if drive control for controlling the first electric actuator is being performed such that the first output shaft outputs the torque and if the reaction torque is greater than a predetermined threshold, the predetermined threshold being a value equal to or less than a maximum value of the braking torque the brake device is capable of applying to the second output shaft, the first process including controlling a rotation speed of the second output shaft to be equal to or less than a predetermined setting value by controlling the second electric actuator such that the second output shaft outputs the torque in a direction opposite to the reaction torque; and
- a second process if the drive control is being performed and if the reaction torque is equal to or less than the threshold, the second process including placing the brake device in the braking state and suspending power supply to the second electric actuator.
9. A control program for controlling a working machine, wherein the control program is applied to a working machine including:
- a first electric actuator having a first output shaft configured to output torque;
- a first movable member configured to rotate in response to the torque from the first output shaft;
- a second electric actuator attached to the first movable member, the second electric actuator having a second output shaft configured to output torque;
- a second movable member configured to rotate in response to the torque from the second output shaft;
- a brake device configured to be switched between a braking state in which the brake device applies braking torque to the first output shaft and a released state in which the brake device releases application of the braking torque to the first output shaft; and
- a control device configured to control the first electric actuator, the second electric actuator, and the brake device, and
- wherein, when reaction torque is defined as torque of a reaction force acting on the first output shaft as the second output shaft outputs the torque, the control program causes the control device to perform:
- a first process if drive control for controlling the second electric actuator is being performed such that the second output shaft outputs the torque and if the reaction torque is greater than a predetermined threshold,

the predetermined threshold being a value equal to or less than a maximum value of the braking torque the brake device is capable of applying to the first output shaft, the first process including controlling a rotation speed of the first output shaft to be equal to or less than a predetermined setting value by controlling the first electric actuator such that the first output shaft outputs the torque in a direction opposite to the reaction torque; and

a second process if the drive control is being performed and if the reaction torque is equal to or less than the threshold, the second process including placing the brake device in the braking state and suspending power supply to the first electric actuator.

10. A control program for controlling a working machine, wherein the control program is applied to a working machine including:
- a first electric actuator having a first output shaft configured to output torque;
- a first movable member configured to rotate in response to the torque from the first output shaft;

a second electric actuator attached to the first movable member, the second electric actuator having a second output shaft configured to output torque;

a second movable member configured to rotate in response to the torque from the second output shaft;

a brake device configured to be switched between a braking state in which the brake device applies braking torque to the second output shaft and a released state in which the brake device releases application of the braking torque to the second output shaft; and

a control device configured to control the first electric actuator, the second electric actuator, and the brake device, and

wherein, when reaction torque is defined as torque of a reaction force acting on the second output shaft as the first output shaft outputs the torque, the control program causes the control device to perform:

a first process if drive control for controlling the first electric actuator is being performed such that the first output shaft outputs the torque and if the reaction torque is greater than a predetermined threshold, the predetermined threshold being a value equal to or less than a maximum value of the braking

torque the brake device is capable of
applying to the second output shaft, the
first process including controlling a ro-
tation speed of the second output shaft
to be equal to or less than a predeter- 5
mined setting value by controlling the
second electric actuator such that the
second output shaft outputs the torque
in a direction opposite to the reaction
torque; and 10
a second process if the drive control is
being performed and if the reaction tor-
que is equal to or less than the thresh-
old, the second process including pla- 15
cing the brake device in the braking
state and suspending power supply to
the second electric actuator.

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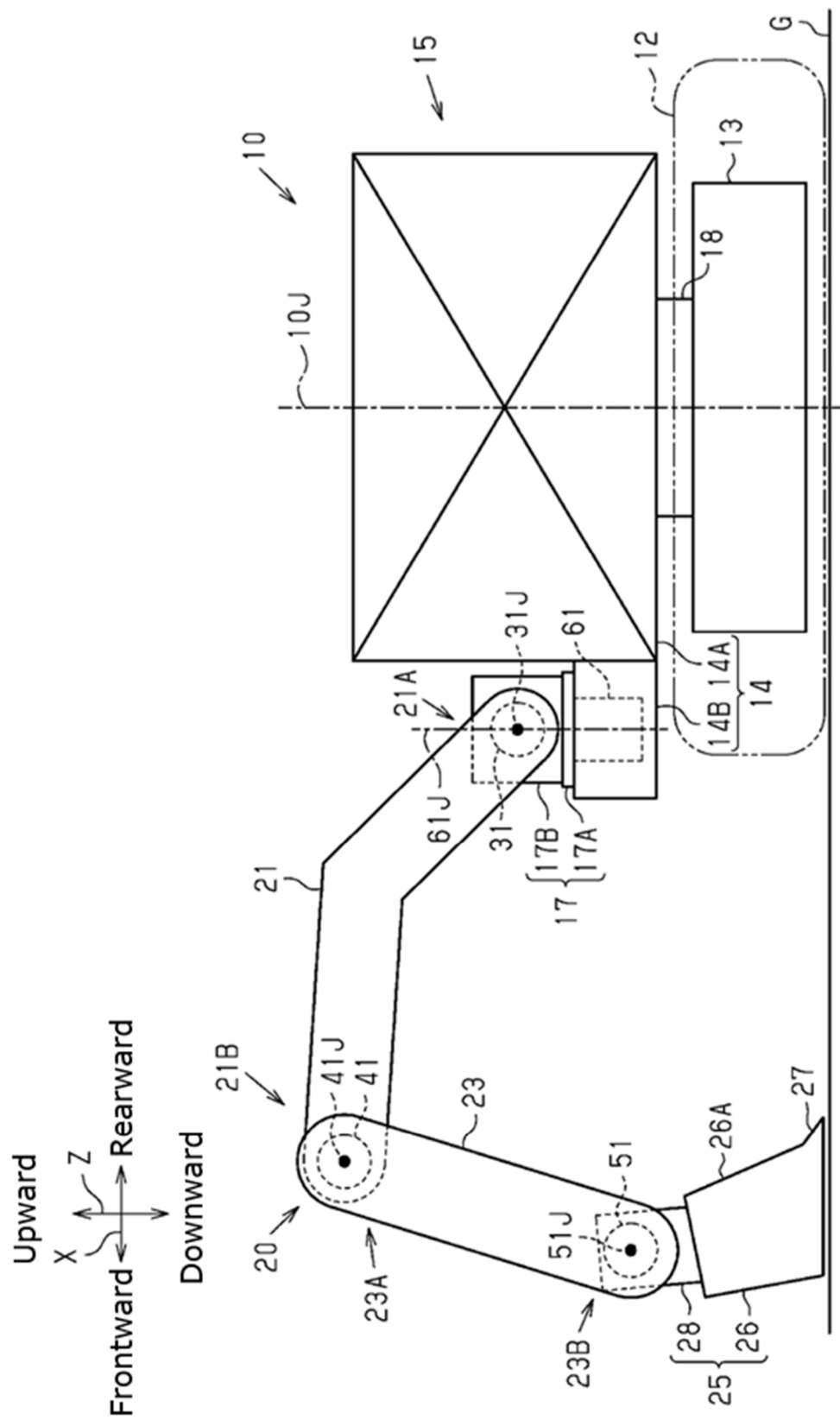


Fig. 1

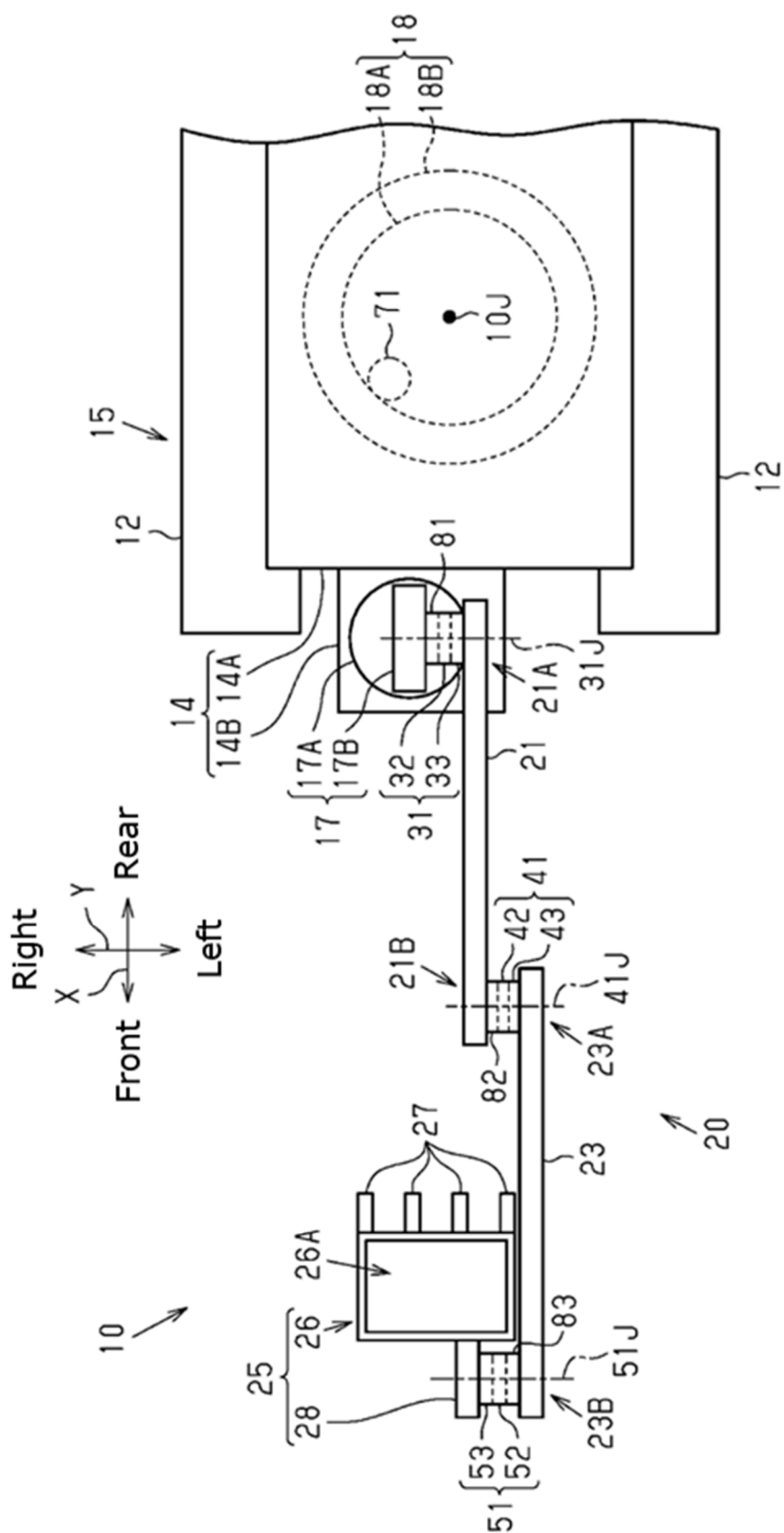


Fig. 2

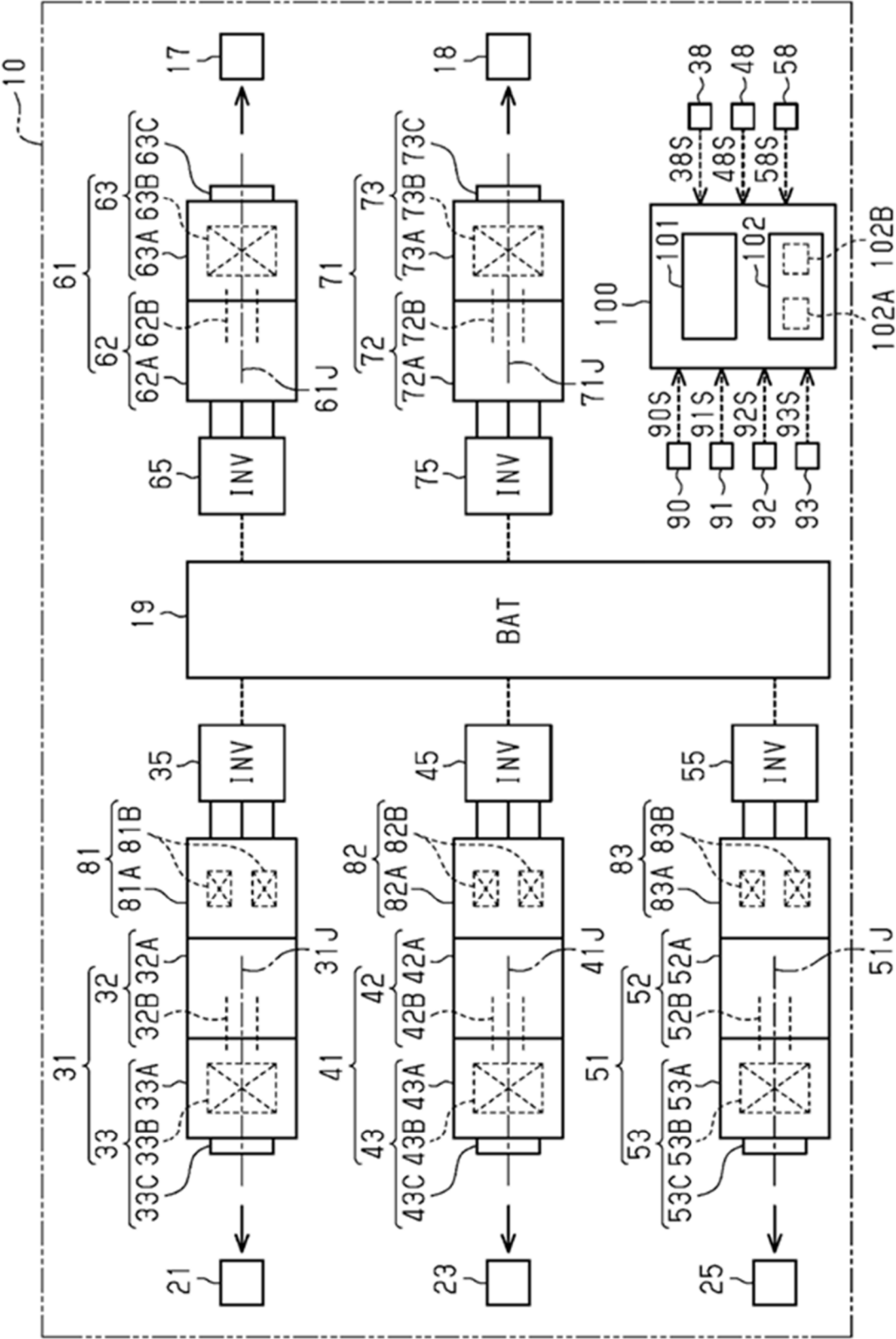


Fig. 3

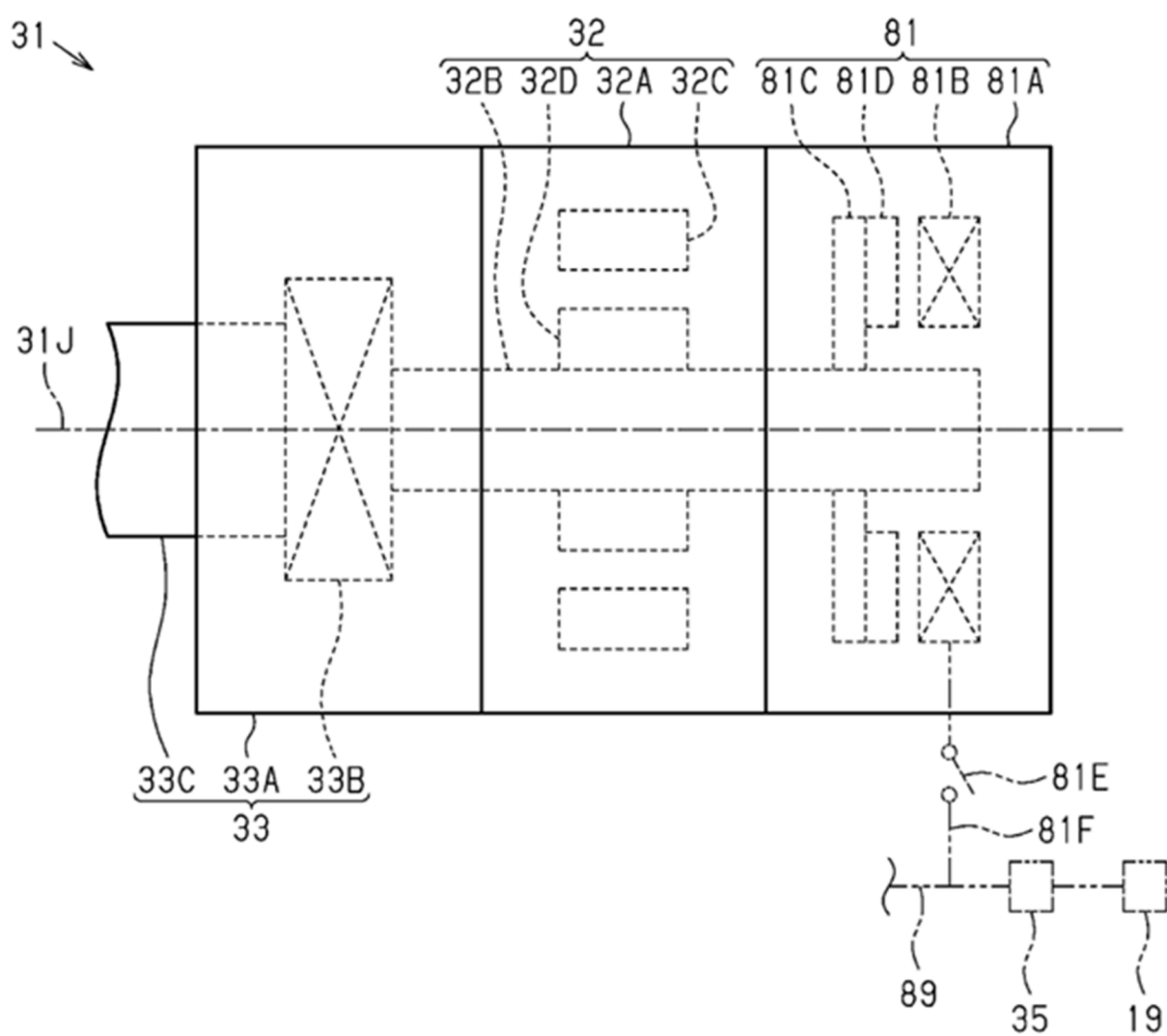


Fig. 4

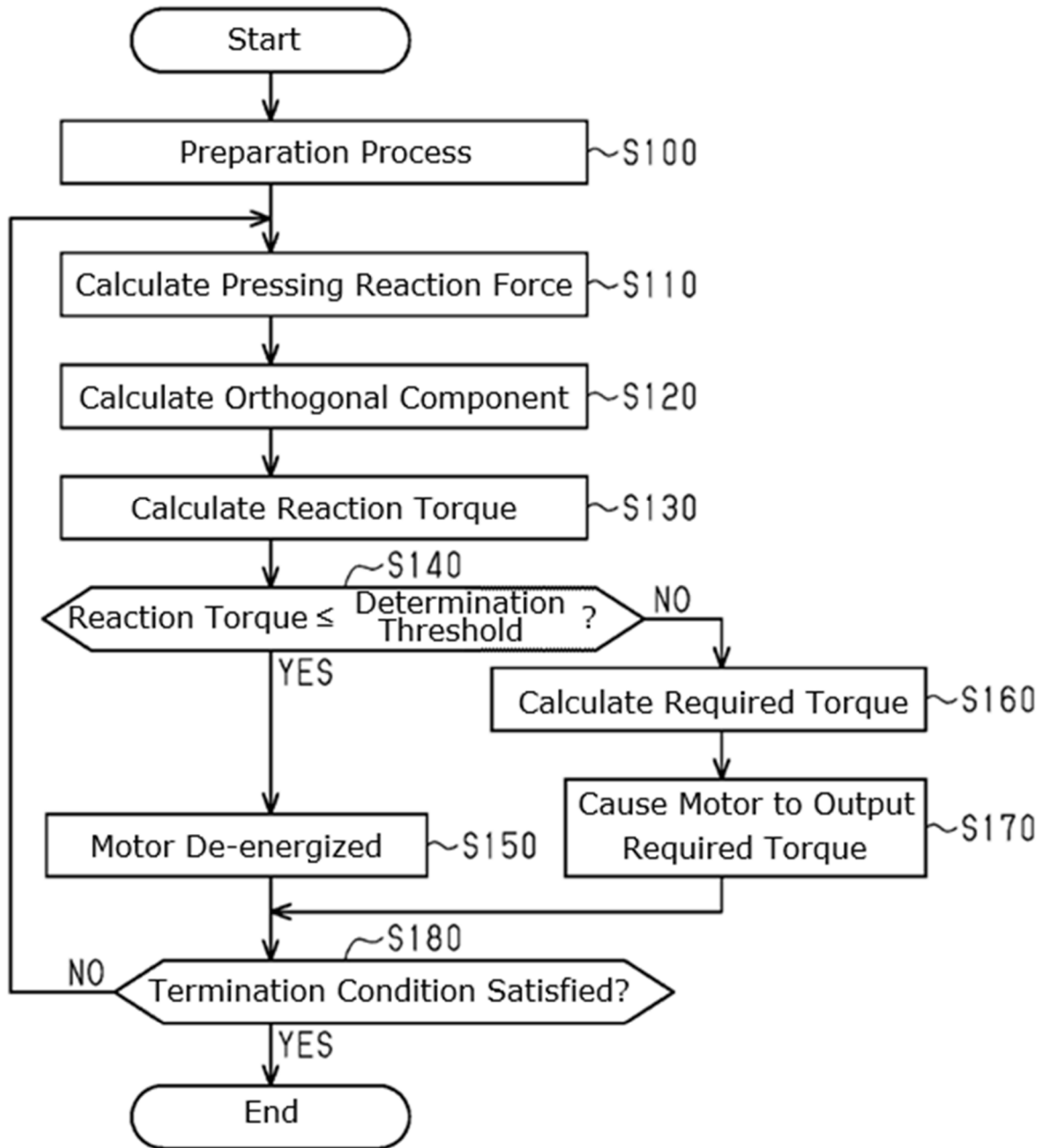


Fig. 5

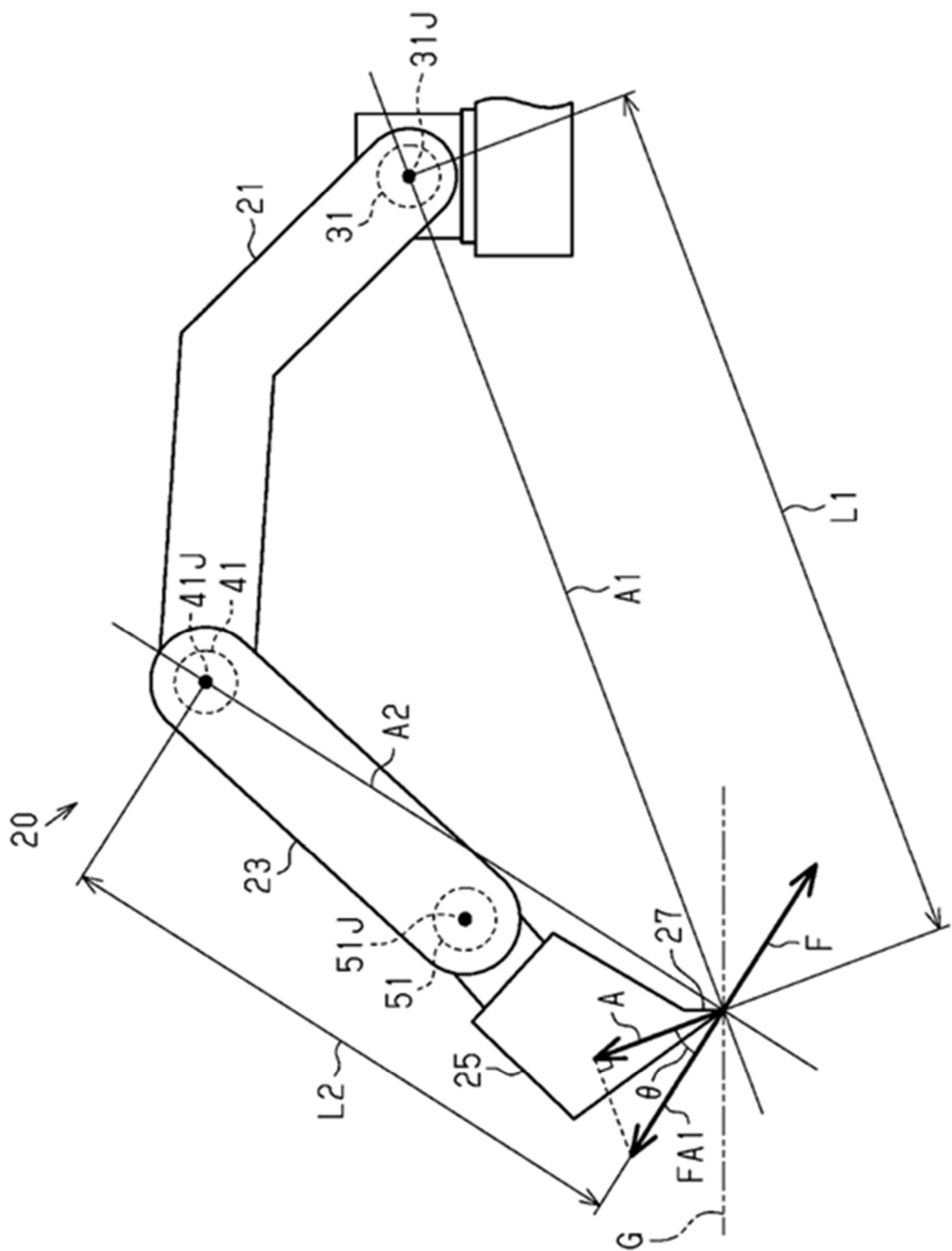


Fig. 6

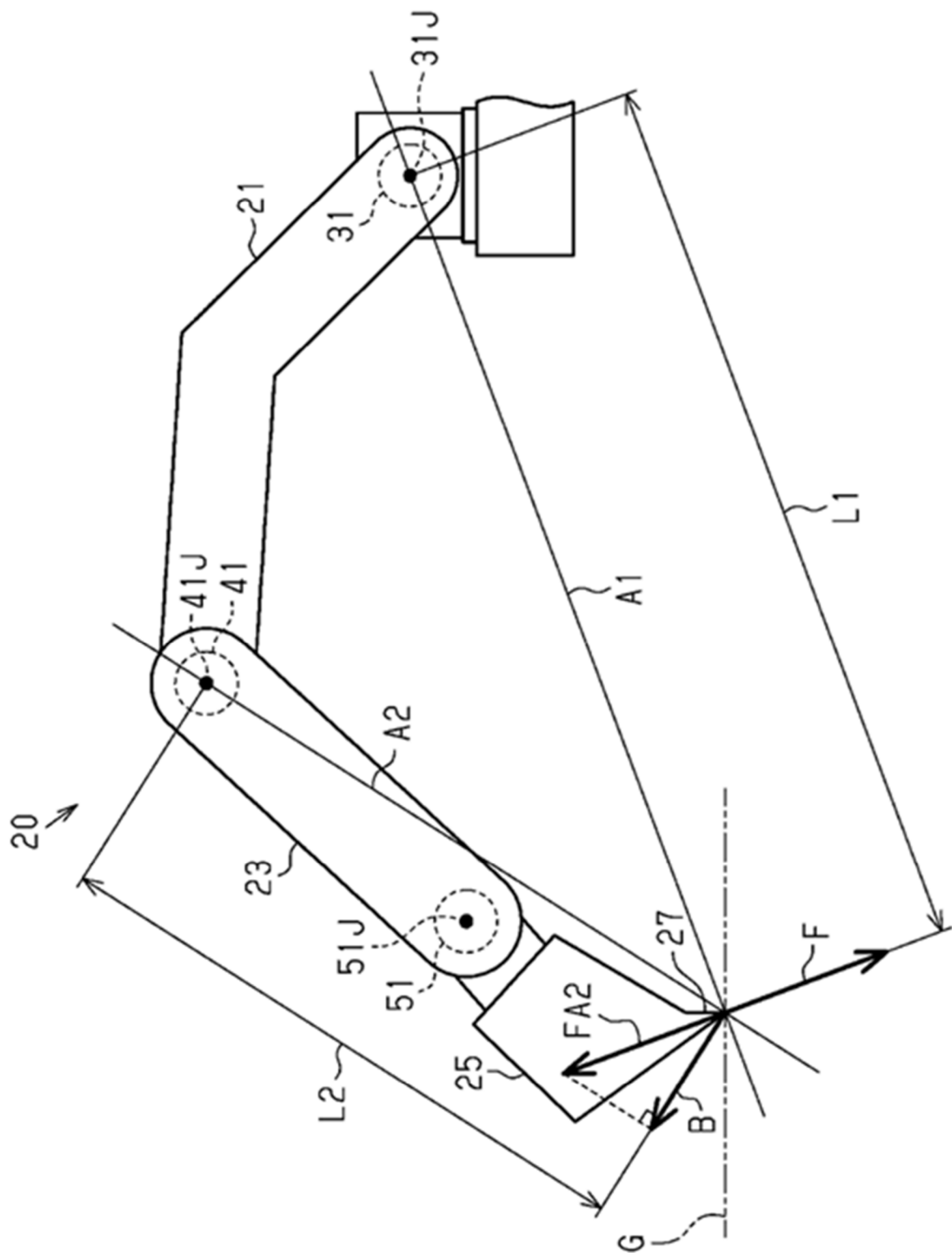


Fig. 7

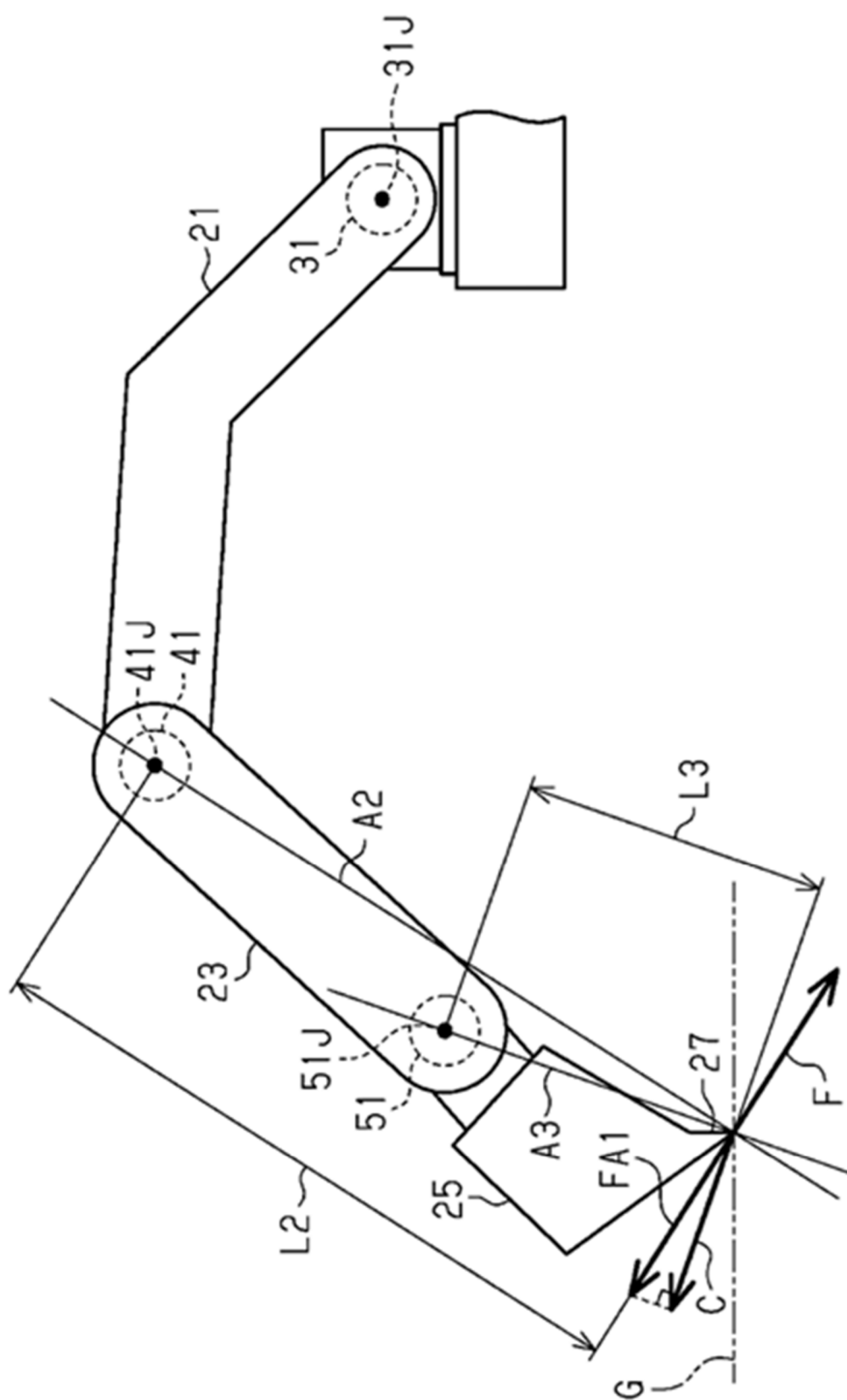


Fig. 8



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Application Number
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			E02F
The present search report has been drawn up for all claims			
Place of search Munich		Date of completion of the search 4 August 2026	Examiner Rocabruna Vilardell
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