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

(57) One object is to restrict a circumferential speed of a distal end of an attachment. An excavator includes: an attachment having a first movable member and a second movable member; and a drive unit having a first electric actuator having a first output shaft for rotating the first movable member and a second electric actuator having a second output shaft for rotating the second movable member. A control device performs: a first process to calculate an upper-limit rotational frequency of the first output shaft; and a second process to control the first electric actuator such that the rotational frequency of the first output shaft is lower than or equal to the upper-limit rotational frequency, and the first process is performed such that the upper-limit rotational frequency is lower as a distance from the first output shaft to a distal end of the attachment is longer.

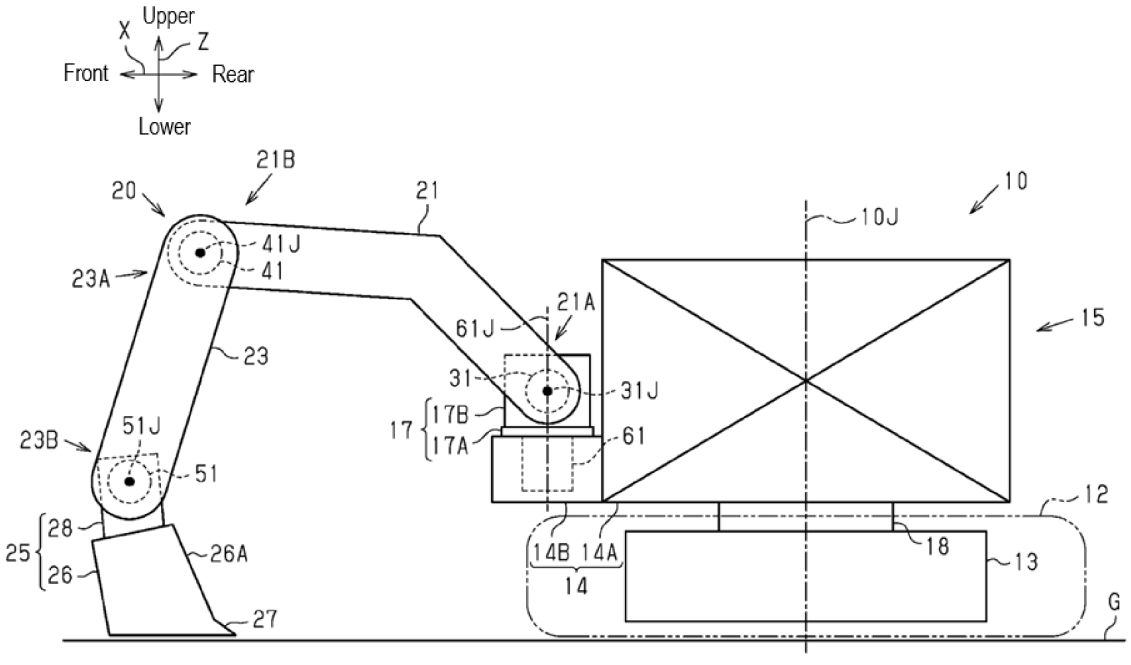


Fig. 1

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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. 2025-061851 (filed on April 3, 2025), the contents of which are hereby incorporated by reference in their entirety.

TECHNICAL FIELD

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

BACKGROUND

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

[0004] In technologies such as the one disclosed in the '395 Publication, electric actuators that output torque may be located at joints, for example, at the coupling point between the vehicle body and the boom. These electric actuators may rotate movable members such as the boom, arm, and bucket. When this type of structure is used, the movable range of each movable member is wider. Along with this, the distance from the output shaft of the electric actuator that rotates the boom to the distal end of the bucket may be considerably longer. When the boom is rotated in this condition, the long distance described above can result in a considerably high circumferential speed at the distal end of the bucket. In this case, when the distal end of the bucket collides with an excavation object or an obstacle, the impact on the attachment is large.

SUMMARY

[0005] The above drawback can be overcome with a drive system for a work machine, the work machine including an attachment having a first movable member and a second movable member, the second movable member being rotatably coupled to the first movable member, the drive system comprising: a drive unit having a first electric actuator and a second electric actuator, the first electric actuator having a first output shaft for rotating the first movable member, the second electric actuator having a second output shaft for rotating the second movable member; and a control device for controlling the drive unit, wherein the control device performs: a first process to calculate a limit value for a rotational speed of the first output shaft based on a relative position of the second movable member relative to the first movable member; and a second process to control the first electric actuator such that the rotational speed of the first output shaft is lower than or equal to the limit value, and wherein the first process is performed such that the limit value is lower when a distance is a first value than when the distance is a second value smaller than the first value, the distance being from the first output shaft to a distal end of the attachment opposite to a coupling point with the first output shaft.

[0006] According to the above configuration, when the distance between the first output shaft and the distal end of the attachment is long, the limit value for the rotational speed of the first output shaft is low. This makes it possible to restrict the circumferential speed of the distal end of the attachment even when the above distance is long.

[0007] In the drive system for a work machine, supposing that an upper-limit circumferential speed is defined as an upper limit of a circumferential speed for the distal end of the attachment, the control device may perform the first process such that the limit value is calculated at a value corresponding to a divided value, the divided value being obtained by dividing, by the distance, the upper-limit circumferential speed predetermined.

[0008] In the drive system for a work machine, the attachment may have a third movable member rotatably coupled to the second movable member, the drive unit may have a third electric actuator having a third output shaft for rotating the third movable member, the distal end of the attachment may be a distal end of the third movable member opposite to a coupling point with the third output shaft, and the control device may perform the first process such that the limit value is calculated based on the relative position of the second movable member relative to the first movable member and a relative position of the third movable member relative to the second movable member.

[0009] In the drive system for a work machine, supposing that the limit value is a first limit value, the control device may perform: the first process to calculate the first limit value, a second limit value as a limit value for a rotational speed of the second output shaft, and a third limit value as a limit value for a rotational speed of the third output shaft, based on the relative position of the second movable member relative to the first movable member and the relative position of the third movable member relative to the second movable member; and the second process to control the first electric actuator such that the rotational speed of the first output shaft is lower than or equal to the first limit value, control the second electric actuator such that the rotational speed of the second output shaft is lower than or equal to the second limit value, and control the third electric actuator such that the rotational speed of the third output shaft is lower than or

equal to the third limit value, and the first process may be performed such that the first limit value, the second limit value, and the third limit value are lower when the distance is the first value than when the distance is the second value, the distance being from the first output shaft to the distal end of the attachment.

[0010] In the drive system for a work machine, the work machine may be a construction machine, the first movable member may be a boom, the second movable member may be an arm, and the third movable member may be a bucket.

[0011] The above drawback can be overcome with a control device for a work machine, the work machine including: an attachment having a first movable member and a second movable member, the second movable member being rotatably coupled to the first movable member; and a drive unit having a first electric actuator and a second electric actuator, the first electric actuator having a first output shaft for rotating the first movable member, the second electric actuator having a second output shaft for rotating the second movable member, wherein the control device performs: a first process to calculate a limit value for a rotational speed of the first output shaft based on a relative position of the second movable member relative to the first movable member; and a second process to control the first electric actuator such that the rotational speed of the first output shaft is lower than or equal to the limit value, and wherein the first process is performed such that the limit value is lower when a distance is a first value than when the distance is a second value smaller than the first value, the distance being from the first output shaft to a distal end of the attachment opposite to a coupling point with the first output shaft.

[0012] According to the above configuration, when the distance between the first output shaft and the distal end of the attachment is long, the limit value for the rotational speed of the first output shaft is low. This makes it possible to restrict the circumferential speed of the distal end of the attachment even when the above distance is long.

[0013] The above drawback can be overcome with a control method for a work machine, the work machine including: an attachment having a first movable member and a second movable member, the second movable member being rotatably coupled to the first movable member; and a drive unit having a first electric actuator and a second electric actuator, the first electric actuator having a first output shaft for rotating the first movable member, the second electric actuator having a second output shaft for rotating the second movable member, wherein a control device applied to the work machine performs: a first process to calculate a limit value for a rotational speed of the first output shaft based on a relative position of the second movable member relative to the first movable member; and a second process to control the first electric actuator such that the rotational speed of the first output shaft is lower than or equal to the limit value, and wherein the first process is performed such that the limit value is lower when a distance is a first value than when the distance is a second value smaller than the first value, the distance being from the first output shaft to a distal end of the attachment opposite to a coupling point with the first output shaft.

[0014] According to the above method, when the distance between the first output shaft and the distal end of the attachment is long, the limit value for the rotational speed of the first output shaft is low. This makes it possible to restrict the circumferential speed of the distal end of the attachment even when the above distance is long.

[0015] The above drawback can be overcome with a control program for a work machine, the work machine including: an attachment having a first movable member and a second movable member, the second movable member being rotatably coupled to the first movable member; and a drive unit having a first electric actuator and a second electric actuator, the first electric actuator having a first output shaft for rotating the first movable member, the second electric actuator having a second output shaft for rotating the second movable member, wherein the control program causes a control device applied to the work machine to perform: a first process to calculate a limit value for a rotational speed of the first output shaft based on a relative position of the second movable member relative to the first movable member; and a second process to control the first electric actuator such that the rotational speed of the first output shaft is lower than or equal to the limit value, and wherein the first process is performed such that the limit value is lower when a distance is a first value than when the distance is a second value smaller than the first value, the distance being from the first output shaft to a distal end of the attachment opposite to a coupling point with the first output shaft.

[0016] According to the above program, when the distance between the first output shaft and the distal end of the attachment is long, the control device is caused to make the limit value for the rotational speed of the first output shaft low. This makes it possible to restrict the circumferential speed of the distal end of the attachment even when the above distance is long.

ADVANTAGEOUS EFFECTS

[0017] In the technical idea described above, the circumferential speed of a distal end of an attachment can be restricted.

BRIEF DESCRIPTION OF DRAWINGS

[0018]

Fig. 1 is a side view schematically showing an excavator relating to a first embodiment.

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

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

Fig. 4 is a flowchart showing the steps of driving control relating to the first embodiment.

Fig. 5 is a flowchart showing the steps of driving control relating to a second embodiment.

Fig. 6 is a side view for explaining a circumferential speed of the distal end of a bucket.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

<First Embodiment>

[0019] A construction machine is hereinafter used as an example for describing a first embodiment of a drive system for a work machine, a control device for a work machine, a control method for a work machine, and a control program for a work machine. For simplicity and clarity of explanation, the components shown in the drawings are not necessarily drawn to a fixed scale.

<Overall Configuration>

[0020] As shown in Figs. 1 and 2, an excavator 10, serving as a work machine and a construction machine, includes a lower body 13 and an upper body 14. The upper body 14 is located on the opposite side to the ground surface G with respect to the lower body 13. In this embodiment, when viewed from the lower body 13, the upper body 14 is located in the upper direction, and the opposite direction is the lower direction. A specific one of the directions orthogonal to the upper direction is the front direction, and the opposite direction is the rear direction. Furthermore, the direction that is orthogonal to both of the upper and front directions faces the left and right directions, which are opposite to each other. The front and rear directions may be collectively referred to as X direction. The left and right directions may be collectively referred to as Y direction. The upper and lower directions may be collectively referred to as Z direction.

[0021] As shown in Fig. 1, the lower body 13 and the upper body 14 constitute a vehicle body 15. The lower body 13 is shaped like a rectangular parallelepiped, for example. The upper body 14 includes a case main portion 14A and a case front portion 14B. The case main portion 14A is shaped like a rectangular parallelepiped, for example. The interior of the case main portion 14A constitutes a hollow housing space. The housing space houses various devices for operating the excavator 10. The case front portion 14B is positioned frontward of the case main portion 14A. The case front portion 14B is positioned substantially in the middle of the case main portion 14A in the Y direction. The case front portion 14B is fixed to the front surface of the case main portion 14A. The case front portion 14B is shaped like a rectangular parallelepiped, for example, smaller than the case main portion 14A. The interior of the case front portion 14B is hollow. Although not shown in the drawings, the upper body 14 includes a cabin for the operator. The upper body 14 may be herein referred to as a slewable upper structure.

[0022] As shown in Figs. 1 and 2, the excavator 10 includes a slewing bearing 18. The slewing bearing 18 is interposed between the lower body 13 and the upper body 14. In Fig. 1, the width of the slewing bearing 18 in the top-to-bottom direction is shown in an exaggerated manner in the Z direction. As shown in Fig. 2, the slewing bearing 18 has an annular inner race 18A, an annular outer race 18B, and a plurality of rolling elements. Fig. 2 does not show the rolling elements. The outer diameter of the inner race 18A is smaller than the inner diameter of the outer race 18B. A slewing axis 10J, which is the central axis of the inner race 18A, substantially coincides with the central axis of the outer race 18B. The slewing axis 10J extends in the upper and lower directions, or the Z direction, of the vehicle body 15. As shown in Fig. 1, the slewing axis 10J extends in the top-to-bottom direction through both the upper body 14 and the lower body 13. The rolling elements are interposed between the inner race 18A and the outer race 18B. The rolling elements support the inner race 18A and the outer race 18B such that they can rotate relative to each other. The outer race 18B is thus rotatable about the slewing axis 10J relative to the inner race 18A. The inner race 18A is fixed to the lower body 13. The outer race 18B is fixed to the case main portion 14A of the upper body 14. Accordingly, the upper body 14 is rotatable about the slewing axis 10J relative to the lower body 13.

[0023] As shown in Fig. 2, the excavator 10 includes a slewing actuator 71. The slewing actuator 71 includes an electric motor and a speed reducer. The speed reducer multiplies the torque of the electric motor and outputs the resulting torque. The slewing actuator 71 is housed in the case main portion 14A of the upper body 14. The slewing actuator 71 outputs torque to rotate the upper body 14 relative to the lower body 13.

[0024] As shown in Figs. 1 and 2, the excavator 10 includes a pair of traveling units 12. The pair of traveling units 12 are provided at the left and right sides of the lower body 13. The pair of traveling units 12 are connected to the lower body 13. The pair of traveling units 12 each include a traveling crawler and an operating mechanism that circles the crawler. 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. As the crawler circles, the excavator 10 travels. The traveling units 12 and the lower body 13 may be collectively referred to as an undercarriage.

[0025] As shown in Figs. 1 and 2, the excavator 10

includes a swing bracket 17. The swing bracket 17 is positioned frontward of the case main portion 14A of the upper body 14. The swing bracket 17 includes a first swing wall 17A and a second swing wall 17B. The first swing wall 17A is located on the upper surface the case front portion 14B in the upper body 14. The first swing wall 17A is shaped like a circular plate, for example. The second swing wall 17B protrudes upward from the upper surface of the first swing wall 17A. The second swing wall 17B is shaped like a rectangular plate, for example.

[0026] As shown in Fig. 1, the excavator 10 includes a swing actuator 61. The swing actuator 61 is housed in the case front portion 14B of the upper body 14. The swing actuator 61 includes an electric motor and a speed reducer. The speed reducer multiplies the torque of the electric motor and outputs the resulting torque. The swing actuator 61 outputs torque about a fourth axis 61J that extends in the top-to-bottom direction of the vehicle body 15. The fourth axis 61J is substantially parallel to the slewing axis 10J. The output shaft of the swing actuator 61 is connected to the first swing wall 17A. The swing actuator 61 rotates the swing bracket 17 relative to the case front portion 14B.

<Attachment>

[0027] As shown in Figs. 1 and 2, the drive system of the excavator 10 includes an attachment 20. The attachment 20 includes a boom 21, an arm 23, and a bucket 25.

[0028] As shown in Figs. 1 and 2, the boom 21 is positioned frontward of the case main portion 14A of the upper body 14. The boom 21 is shaped like an elongated plate or column. For example, the boom 21 is bent at a midpoint in its longitudinal direction. As shown in Fig. 2, the first end portion 21A of the boom 21 in its longitudinal direction is aligned with the second swing wall 17B of the swing bracket 17 in the direction along a first axis 31J. The first axis 31J is an imaginary axis that is substantially orthogonal to the fourth axis 61J. The first end portion 21A of the boom 21 is rotatably coupled to the second swing wall 17B. The boom 21 corresponds to a first movable member.

[0029] As shown in Figs. 1 and 2, the arm 23 extends from a second end portion 21B of the boom 21 opposite to the first end portion 21A. The arm 23 is shaped like an elongated plate or column. As shown in Fig. 2, a first end portion 23A of the arm 23 in its longitudinal direction is aligned with the second end portion 21B of the boom 21 in the direction along a second axis 41J. The second axis 41J is an imaginary axis that is substantially parallel to the first axis 31J. The first end portion 23A of the arm 23 is rotatably coupled to the second end portion 21B of the boom 21. The arm 23 corresponds to a second movable member.

[0030] As shown in Figs. 1 and 2, the bucket 25 is positioned near a second end portion 23B of the arm 23 opposite to the first end portion 23A. The bucket 25 includes a bucket body 26. a plurality of teeth 27, and a bucket coupling wall 28. The bucket body 26 is shaped like a box. As shown in Fig. 2, the bucket body 26 has an opening 26A. The teeth 27 protrude from one of the rectangular opening edges of the bucket body 26. The bucket coupling wall 28 protrudes from a portion of the outer wall of the bucket body 26, located opposite the teeth 27 across the opening 26A. As shown in Fig. 2, the bucket coupling wall 28 is aligned with the second end portion 23B of the arm 23 in the direction along a third axis 51J. The third axis 51J is an imaginary axis that is substantially parallel to both the first axis 31J and the second axis 41J. The bucket coupling wall 28 is rotatably coupled to the second end portion 23B of the arm 23. The bucket 25 corresponds to a third movable member.

<Drive Unit>

[0031] As shown in Fig. 3, the drive system of the excavator 10 includes a drive unit 30. The drive unit 30 has a boom actuator 31, an arm actuator 41, and a bucket actuator 51. The excavator 10 also includes a first inverter 35, a second inverter 45, a third inverter 55, and a battery 19. Although not shown in the drawings, the first inverter 35, the second inverter 45, the third inverter 55, and the battery 19 are housed in the case main portion 14A of the upper body 14. The boom actuator 31 corresponds to a first electric actuator. The arm actuator 41 corresponds to a second electric actuator. The bucket actuator 51 corresponds to a third electric actuator.

[0032] 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 portion 21A of the boom 21. As shown in Fig. 3, the boom actuator 31 includes a first electric motor 32 and a first speed reducer 33. The first electric motor 32 is a three-phase AC motor. The first electric motor 32 is electrically connected to the battery 19 via the first inverter 35. The first electric motor 32 includes a housing 32A and a first drive shaft 32B. The housing 32A is mounted to the second swing wall 17B of the swing bracket 17. The first drive shaft 32B protrudes from the inside to the outside of the housing 32A. The first drive shaft 32B is shaped like a circular column. The first drive shaft 32B can rotate about its own central axis, the first axis 31J, relative to the housing 32A. In other words, the first drive shaft 32B outputs torque centered on the first axis 31J. The first drive shaft 32B is rotatable in both forward and reverse directions about the first axis 31J. As shown in Fig. 2, the first axis 31J extends through both the second swing wall 17B of the swing bracket 17 and the first end portion 21A of the boom 21.

[0033] As shown in Fig. 3, the first speed reducer 33 includes a housing 33A, a reduction mechanism 33B, and an output member 33C. The housing 33A is mounted to the housing 32A of the first electric motor 32. The reduction mechanism 33B is located inside the housing 33A. The reduction mechanism 33B receives the torque from the first drive shaft 32B of the first electric motor 32. The reduction mechanism 33B multiplies the torque out-

put from the first drive shaft 32B with a predetermined ratio and outputs the resulting torque to the output member 33C. The reduction mechanism 33B may be of, for example, an eccentric oscillation gear type or planetary gear type. The output member 33C is shaped like a circular column. The central axis of the output member 33C substantially coincides with the first axis 31J. The output member 33C is rotatable relative to the housing 33A. The output member 33C rotates about the first axis 31J in accordance with the rotation of the first drive shaft 32B. The output member 33C is mounted to the first end portion 21A of the boom 21. Thus, the output member 33C inputs torque centered on the first axis 31J into the boom 21. When acted upon by this torque, the boom 21 rotates around the first axis 31J. Through this series of torque transmission, the first drive shaft 32B rotates the boom 21 via the reduction mechanism 33B and the output member 33C. The first drive shaft 32B corresponds to a first output shaft.

[0034] As shown in Fig. 2, the arm actuator 41 is located between the second end portion 21B of the boom 21 and the first end portion 23A of the arm 23. The configuration of the arm actuator 41 is basically the same as that of the boom actuator 31, except for details such as dimensions, reduction ratio, and output. Therefore, the configuration of the arm actuator 41 is briefly described below.

[0035] As shown in Fig. 3, the arm actuator 41 includes a second electric motor 42 and a second speed reducer 43. The second electric motor 42 is electrically connected to the battery 19 via the second inverter 45. The housing 42A of the second electric motor 42 is mounted to the second end portion 21B of the boom 21. The second drive shaft 42B of the second electric motor 42 outputs torque centered on its own central axis, the second axis 41J. As shown in Fig. 2, the second axis 41J extends through both the second end portion 21B of the boom 21 and the first end portion 23A of the arm 23. The output member 43C of the second speed reducer 43 is mounted to the first end portion 23A of the arm 23. As shown in Fig. 3, the torque output by the second drive shaft 42B is input to the arm 23 via the reduction mechanism 43B and the output member 43C of the second speed reducer 43. The arm 23 rotates about the second axis 41J together with the output member 43C. Thus, the second drive shaft 42B rotates the arm 23 via the reduction mechanism 43B and the output member 43C. The second drive shaft 42B corresponds to a second output shaft. The housing 43A of the second speed reducer 43 is mounted to the housing 42A of the second electric motor 42.

[0036] As shown in Fig. 2, the bucket actuator 51 is located between the second end portion 23B of the arm 23 and the bucket coupling wall 28 of the bucket 25. The configuration of the bucket actuator 51 is basically the same as that of the boom actuator 31, except for details such as dimensions, reduction ratio, and output. Therefore, the configuration of the bucket actuator 51 is briefly described below.

[0037] As shown in Fig. 3, the bucket actuator 51 includes a third electric motor 52 and a third speed reducer 53. The third electric motor 52 is electrically connected to the battery 19 via the third inverter 55. The housing 52A of the third electric motor 52 is mounted to the second end portion 23B of the arm 23. The third drive shaft 52B of the third electric motor 52 outputs torque centered on its own central axis, the third axis 51J. As shown in Fig. 2, the third axis 51J extends through both the second end portion 23B of the arm 23 and the bucket coupling wall 28. The output member 53C of the third speed reducer 53 is mounted to the bucket coupling wall 28. As shown in Fig. 3, the torque output by the third drive shaft 52B is input to the bucket coupling wall 28 via the reduction mechanism 53B and the output member 53C of the third speed reducer 53. The bucket coupling wall 28 rotates about the third axis 51J together with the output member 53C. Thus, the third drive shaft 52B rotates the bucket 25 via the reduction mechanism 53B and the output member 53C. The third drive shaft 52B corresponds to a third output shaft. The housing 53A of the third speed reducer 53 is mounted to the housing 52A of the third electric motor 52.

<Sensors>

[0038] As shown in Fig. 3, the drive system of the excavator 10 includes a first angle sensor 38, a second angle sensor 48, and a third angle sensor 58. The first angle sensor 38 senses the angular position 38S of the first drive shaft 32B of the first electric motor 32. The second angle sensor 48 senses the angular position 48S of the second drive shaft 42B of the second electric motor 42. The third angle sensor 58 senses the angular position 58S of the third drive shaft 52B of the third electric motor 52. The angular position sensed by each of the angle sensors 38, 48, 58 is indicated in the range of "0 to 360 degrees" relative to the predetermined reference position at "0 degrees". In other words, each angular position represents the absolute angle of the respective drive shafts of the electric motors 32, 42, 52. Each of the angle sensors 38, 48, 58 transmits a signal to a control device 100 described below according to the information it has sensed.

[0039] Although not shown in the drawings, the drive system of the excavator 10 includes various other sensors necessary for operating the excavator 10 in addition to the above sensors. For example, the drive system of the excavator 10 includes sensors for sensing the electric current flowing in the electric motors 32, 42, 52 and the temperature of the battery 19. In addition, the drive system of the excavator 10 includes various operating devices 90 operated by the operator. In the drawings, the various operating devices 90 are represented as a single unit. The various operating devices 90 are located in the cabin. The various operating devices 90 transmit signals 90S in accordance with the operator's operations to the control device 100 described below.

<Control Device>

[0040] As shown in Fig. 3, the drive system of the excavator 10 includes the control device 100. The control device 100 is a computer with a processing circuit. The processing circuit includes a CPU 101 and a memory 102. The memory 102 includes three types of storage media: RAM, ROM, and electrically rewritable nonvolatile memory. In this embodiment, these three types of storage media are collectively referred to as the memory 102. The memory 102 stores in advance various control programs 102A that describe the processes to be executed by the CPU 101. The memory 102 stores in advance various 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.

[0041] The CPU 101 can 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 signals 90S transmitted from the operating devices 90.

[0042] The CPU 101 converts the angular position 38S received from the first angle sensor 38 from the actual angle of the first electric motor 32 to a first angular position 21S relating to the boom 21. The first angular position 21S is the angular position of the boom 21 relative to a first position predetermined. The first position and the first angular position 21S are defined in a particular plan view of the excavator 10 in the direction along the first axis 31J. An example of the first position is an angular position at which both the first end portion 21A and the second end portion 21B of the boom 21 are positioned in an imaginary straight line orthogonal to both the first axis 31J and the fourth axis 61J. In this example of the first position, the second end portion 21B of the boom 21 is positioned opposite the vehicle body 15 across the first axis 31J. The first angular position 21S indicates the position of the boom 21 relative to the swing bracket 17 or the vehicle body 15. The first angle sensor 38, which senses the actual angle of the first electric motor 32, effectively senses the first angle position 21S.

[0043] The CPU 101 converts the angular position 48S received from the second angle sensor 48 from the actual angle of the second electric motor 42 to a second angular position 23S relating to the arm 23. The second angular position 23S is the angular position of the arm 23 relative to a second position predetermined. The second position and the second angular position 23S are defined in the particular plan view mentioned above. An example of the second position is an angular position at which both the first end portion 23A and the second end portion 23B of the arm 23 are positioned in an imaginary straight line passing through the first axis 31J and the second axis 41J. In this example of the second position, the second end portion 23B of the arm 23 is positioned opposite the first axis 31J across the second axis 41J. The second angular position 23S indicates the position of the arm 23 relative to the boom 21. The second angle sensor 48, which senses the actual angle of the second electric motor 42, effectively senses the second angle position 23S.

[0044] The CPU 101 converts the angular position 58S received from the third angle sensor 58 from the actual angle of the third electric motor 52 to a third angular position 25S relating to the bucket 25. The third angular position 25S is the angular position of the bucket 25 relative to a third position predetermined. The third position and the third angular position 25S are defined in the particular plan view mentioned above. An example of the third position is an angular position at which the distal end of the teeth 27 of the bucket 25 is positioned in an imaginary straight line passing through the second axis 41J and the third axis 51J. In this example of the third position, the teeth 27 of the bucket 25 are positioned opposite the second axis 41J across the third axis 51J. The third angular position 25S indicates the position of the bucket 25 relative to the arm 23. The third angle sensor 58, which senses the actual angle of the third electric motor 52, effectively senses the third angle position 25S.

[0045] The CPU 101 calculates the first angular position 21S each time it receives the angular position 38S from the first angle sensor 38. The CPU 101 thus repeats the calculation of the first angular position 21S. The calculation of the first angular position 21S by the CPU 101 corresponds to obtaining the first angular position 21S by the CPU 101. As with the first angular position 21S, the CPU 101 repeats the calculation of the second angular position 23S and the third angular position 25S. As with the first angular position 21S, the calculation of these angular positions 23S, 25S by the CPU 101 corresponds to obtaining these angular positions 23S, 25S by the CPU 101.

<Limitation>

[0046] The CPU 101 controls the drive unit 30. Specifically, the CPU 101 controls the first electric motor 32 of the boom actuator 31, the second electric motor 42 of the arm actuator 41, and the third electric motor 52 of the bucket actuator 51. In controlling the electric motors 32, 42, 52, the CPU 101 in effect controls the inverters 35, 45, 55 connected to the electric motors 32, 42, 52, respectively.

[0047] When controlling the electric motors 32, 42, 52, the CPU 101 determines the target values of rotational speeds of the respective drive shafts 32B, 42B, 52B. The electric motors 32, 42, 52 are then controlled so that the target values are matched by the actual rotational speeds. The rotational speeds of the drive shafts 32B, 42B, and 52B of the electric motors 32, 42, and 52 will be herein explained in terms of the rotational frequency. For example, the rotational speed of the first drive shaft 32B

of the first electric motor 32 will be explained in terms of the rotational frequency of the first drive shaft 32B. The rotational frequency refers to the number of rotations of a drive shaft per unit time.

[0048] The CPU 101 can perform driving control. The driving control in this embodiment is for the first electric motor 32. In the driving control, the CPU 101 drives the first electric motor 32 to rotate the boom 21. In this embodiment, the driving control is performed under the condition that the angular positions of the arm 23 and the bucket 25 are fixed. The following describes a series of steps performed by the CPU 101 in the driving control.

[0049] For example, when receiving a signal 90S with an instruction for rotating the boom 21 from an operating device 90, the CPU 101 starts the driving control. As shown in Fig. 4, when the CPU 101 starts the driving control, it first performs the process in step S10.

[0050] In step S10, the CPU 101 obtains the latest first base rotational frequency W1. The first base rotational frequency W1 is a command value that indicates the rotational frequency of the first electric motor 32. The first base rotational frequency W1 is calculated in a base value calculation process, which is separate from the driving control. For example, when the operator operates a lever, which is the operating device 90, the CPU 101 calculates the first base rotational frequency W1 according to the amount of lever operation in the base value calculation process. At this time, the CPU 101 calculates the first base rotational frequency W1 to be lower than a limiting rotational frequency. The limiting rotational frequency is the physical limit of the rotational frequency of the first drive shaft 32B, determined from the specifications of the first electric motor 32. After step S10, the CPU 101 proceeds to step S20.

[0051] In step S20, the CPU 101 obtains the latest second angular position 23S and the latest third angular position 25S. The CPU 101 then proceeds to step S30. In step S30, the CPU 101 calculates an object distance L. As shown in Fig. 6, the object distance L is the distance from the first axis 31J to the distal end of the teeth 27 of the bucket 25 in the particular plan view. The distal end of the teeth 27 of the bucket 25 is the end of the bucket 25 opposite to the coupling point with the third drive shaft 52B. The distal end of the teeth 27 of the bucket 25 can be regarded as a particular point of the bucket 25. Furthermore, the distal end of the teeth 27 of the bucket 25 is the end of the attachment 20 opposite to the first end portion 21A of the boom 21. The first end portion 21A of the boom 21 is the coupling point with the first drive shaft 32B in the attachment 20. Thus, the object distance L corresponds to the distance from the first drive shaft 32B to the distal end of the attachment 20 opposite to the coupling point with the first drive shaft 32B in the particular plan view. The object distance L is an indicator of the positional relationship between the first drive shaft 32B, and thus the first axis 31J, and the distal end of the teeth 27 of the bucket 25. In step S30, the CPU 101 calculates the object distance L and thus also estimates the positional relationship mentioned above. The following describes the method of calculating the object distance L.

[0052] The memory 102 stores distance information in advance for the CPU 101 to calculate the object distance L. The distance information represents the relationship between the second and third angular positions 23S and 25S, and the object distance L. Specifically, the distance information represents the object distance L for each of various combinations of the second and third angular positions 23S and 25S. The distance information includes, for example, a table, graph, or formula. In calculating the object distance L, the CPU 101 applies the latest second angular position 23S and the latest third angular position 25S obtained in step S20 to the distance information. Thus, in step S30, the CPU 101 calculates the object distance L based on the second angular position 23S and the third angular position 25S. As shown in Fig. 4, the CPU 101 proceeds to step S40 after calculating the object distance L.

[0053] In step S40, the CPU 101 calculates an upper-limit rotational frequency W1U. The upper-limit rotational frequency W1U is the limit value for the rotational frequency of the first drive shaft 32B. Specifically, the upper-limit rotational frequency W1U is the limit value that defines the upper limit of the rotational frequency allowed for the first drive shaft 32B. The upper-limit rotational frequency W1U is the first limit value. In step S40, the CPU 101 converts an upper-limit circumferential speed Vmax stored on the memory 102 into a rotational frequency, taking into account the object distance L calculated in step S30. Specifically, the CPU 101 first calculates a divided value by dividing the upper-limit circumferential speed Vmax by the object distance L. The CPU 101 then calculates the upper-limit rotational frequency W1U by dividing the divided value by a predetermined coefficient. The predetermined coefficient is a constant that takes into account unit conversions and pi. Suppose that the units are standardized by using "1 minute" as the unit of time and "m" as the unit of length, as in circumferential speed [m/min], object distance L [m], and rotational frequency [/min], for example. In this case, the predetermined coefficient is twice the pi. Not limited to this example, the predetermined coefficient may incorporate values for compensation to adjust the upper-limit rotational frequency W1U to a higher or lower value. Thus, the upper-limit rotational frequency W1U is a value corresponding to the divided value obtained by dividing the upper-limit circumferential speed Vmax by the object distance L.

[0054] The upper-limit circumferential speed Vmax is the upper limit of the circumferential speed V, predetermined for the distal end of the teeth 27 of the bucket 25. Fig. 6 shows an imaginary circle in the particular plan view, centered on the first axis 31J and having a radius equal to the object distance L. This imaginary circle is referred to as the particular imaginary circle Q. The circumferential speed V of the distal end of the teeth 27 of the bucket 25 is the speed in the direction along

a tangent line on the particular imaginary circle Q. The upper-limit circumferential speed Vmax is the maximum value of the circumferential speed V at which the attachment 20 can be protected when the distal end of the teeth 27 of the bucket 25 collides with an excavation object or an obstacle. The upper-limit circumferential speed Vmax is a value predetermined by experiment or simulation.

[0055] As described above, in step S40, the CPU 101 calculates the upper-limit rotational frequency W1U based on the upper-limit circumferential speed Vmax and the object distance L calculated in step S30. The upper-limit rotational frequency W1U is the reciprocal of the object distance L. Therefore, for the same upper-limit circumferential speed Vmax, the CPU 101 calculates the upper-limit rotational frequency W1U at a lower value as the object distance L is longer. The object distance L is a value calculated based on the second and third angular positions 23S and 25S. Thus, the CPU 101 calculates the upper-limit rotational frequency W1U based on the second angular position 23S and the third angular position 25S through steps S30 and S40. The processes in steps S30 and S40 constitute a first process. As shown in Fig. 4, the CPU 101 proceeds to step S50 after performing step S40.

[0056] In step S50, the CPU 101 determines whether or not the first base rotational frequency W1 obtained in step S10 is lower than or equal to the upper-limit rotational frequency W1U calculated in step S40. If the first base rotational frequency W1 is lower than or equal to the upper-limit rotational frequency W1U (step S50: YES), the CPU 101 proceeds to step S60. In step S60, the CPU 101 sets the first base rotational frequency W1 as a target rotational frequency W1F of the first drive shaft 32B.

[0057] On the other hand, in step S50, if the first base rotational frequency W1 is larger than the upper-limit rotational frequency W1U (step S50: NO), the CPU 101 proceeds to step S70. In step S70, the CPU 101 sets the upper-limit rotational frequency W1U as the target rotational frequency W1F of the first drive shaft 32B. The CPU 101 proceeds to step S80 after calculating the target rotational frequency W1F. Thus, the CPU 101 sets the lower of the first base rotational frequency W1 and the upper-limit rotational frequency W1U as the target rotational frequency W1F of the first drive shaft 32B through steps S50, S60, and S70.

[0058] In step S80, the CPU 101 controls the first electric motor 32 based on the target rotational frequency W1F calculated in step S60 or step S70. Specifically, the CPU 101 controls the first electric motor 32 so that the target rotational frequency W1F is matched by the actual rotational frequency of the first drive shaft 32B. The target rotational frequency W1F is lower than or equal to the upper-limit rotational frequency W1U as a result of the processes in steps S50, S60, and S70. Therefore, in step S80, the CPU 101 controls the first electric motor 32 so that the rotational frequency of the first drive shaft 32B is lower than or equal to the upper-limit rotational frequency W1U. The CPU 101 continues the process in step S80 until the ending condition is satisfied. An example of the ending condition is that a predetermined first control period has elapsed after the start of step S80. The first control period is, for example, a few seconds. The first control period should be a period suitable for continuing the rotation of the boom 21 in various operations such as excavation. Another example of the ending condition is that a signal 90S with an instruction for stopping the rotation of the boom 21 is received from the operating device 90. The CPU 101 ends the driving control when the ending condition is satisfied. The process in step S80 constitutes a second process.

<Operation of First Embodiment>

[0059] As shown in Fig. 6, the object distance L is the radius of rotation of the arm 23 and the bucket 25 together with the boom 21 around the first drive shaft 32B. When the object distance L is longer, the circumferential speed V of the distal end of the teeth 27 increases for the same rotation frequency of the first drive shaft 32B. This increases the kinetic energy near the distal end of the teeth 27. In this case, when the distal end of the teeth 27 collides with an excavation object or an obstacle, a large amount of energy is exerted, resulting in a large impact on the attachment 20.

[0060] Therefore, in the driving control, the CPU 101 reduces the upper-limit rotational frequency W1U as the object distance L, which is the radius of rotation, is longer (step S40). Then, the CPU 101 controls the first electric motor 32 so that the rotational frequency of the first drive shaft 32B is lower than or equal to the upper-limit rotational frequency W1U (steps S50 to S80). In this way, the rotational frequency of the first drive shaft 32B is restricted in accordance with the object distance L, such that the CPU 101 can keep the circumferential speed V of the distal end of the teeth 27 of the bucket 25 lower than or equal to the upper-limit circumferential speed Vmax regardless of the length of the object distance L.

<Advantageous Effects of First Embodiment>

[0061] (1-1) As described in the section of Operation of First Embodiment, the CPU 101 in this embodiment can restrict the circumferential speed V of the distal end of the teeth 27 of the bucket 25 regardless of the length of the object distance L. This allows the CPU 101 to mitigate the impact applied to the attachment 20 when the bucket 25 collides with an excavation object or an obstacle.

[0062] (1-2) In the first process in step S40, the CPU 101 converts the upper-limit circumferential speed Vmax to the rotational frequency by dividing the upper-limit circumferential speed Vmax by the object distance L. By limiting the rotational frequency of the first drive shaft 32B to be lower than or equal to the upper-limit rotational frequency W1U, which is a converted value, the CPU 101 can ensure that the circumferential speed V of the distal end of the teeth 27 is kept lower than or equal to the

upper-limit circumferential speed Vmax.

[0063] (1-3) The object distance L, which is the radius of rotation of the bucket 25, depends on the attitude of the attachment 20. In the first process in step S30, the CPU 101 of this embodiment calculates the object distance L based on the angular position of each movable member that reflects the attitude of the attachment 20. This allows CPU 101 to accurately calculate the object distance L and thus the upper-limit rotational frequency W1U in accordance with the attitude of the attachment 20.

[0064] (1-4) The excavator 10 often performs works in which the attachment 20 collides with target objects such as earth and sand. Therefore, applying the driving control of this embodiment to the excavator 10 is particularly effective in that there are more opportunities to utilize the technique of this embodiment to mitigate the impact applied to the attachment 20.

<Second Embodiment>

[0065] The following describes a second embodiment of a drive system for a work machine, a control device for a work machine, a control method for a work machine, and a control program for a work machine. In this embodiment, the contents of driving control differ from those in the first embodiment. Except for this point, the contents of the second embodiment are basically the same as those of 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.

[0066] The driving control in this embodiment is for the first electric motor 32, the second electric motor 42, and the third electric motor 52. In the driving control, the CPU 101 performs in parallel the rotational drive of the boom 21 by the first electric motor 32, the rotational drive of the arm 23 by the second electric motor 42, and the rotational drive of the bucket 25 by the third electric motor 52. The driving control of this embodiment is an extension of the driving control of the first embodiment for three electric motors, and the basic concept is the same as in the driving control of the first embodiment. Therefore, the following description of the driving control will be simplified.

[0067] For example, when receiving a signal 90S with an instruction for rotating the boom 21, the arm 23, and the bucket 25 from an operating device 90, the CPU 101 starts the driving control. As shown in Fig. 5, when the CPU 101 starts the driving control, it first performs the process in step S110.

[0068] In step S110, the CPU 101 obtains the latest first base rotational frequency W1, the latest second base rotational frequency W2, and the latest third base rotational frequency W3. Each of the base rotational frequency W1, W2, W3 is calculated in the base value calculation process in accordance with the operation of the operating device 90 by the operator. As with the first base rotational frequency W1, the second and third base rotational frequencies W2 and W3 are lower than the physical limits of the rotational frequencies of the respective drive shafts 42B and 52B. The CPU 101 proceeds to step S120 after obtaining the base rotational frequencies W1, W2, W3.

[0069] In step S120, the CPU 101 obtains the latest first angular position 21S, the latest second angular position 23S, and the latest third angular position 25S. The CPU 101 then proceeds to step S130.

[0070] In step S130, the CPU 101 calculates the object distance L in the same manner as in step S30 of the first embodiment. After step S130, the CPU 101 proceeds to step S140.

[0071] In step S140, the CPU 101 calculates the first upper-limit rotational frequency W1U, the second upper-limit rotational frequency W2U, and the third upper-limit rotational frequency W3U. The first upper-limit rotational frequency W1U is the limit value that defines the upper limit of the rotational frequency allowed for the first drive shaft 32B. The second upper-limit rotational frequency W2U is the limit value that defines the upper limit of the rotational frequency allowed for the second drive shaft 42B. The third upper-limit rotational frequency W3U is the limit value that defines the upper limit of the rotational frequency allowed for the third drive shaft 52B. The first upper-limit rotational frequency W1U is the first limit value. The second upper-limit rotational frequency W2U is the second limit value. The third upper-limit rotational frequency W3U is the third limit value. In step S140, as the object distance L is longer, the CPU 101 decreases the first upper-limit rotational frequency W1U, the second upper-limit rotational frequency W2U, and the third upper-limit rotational frequency W3U. The CPU 101 sets the first upper-limit rotational frequency W1U, the second upper-limit rotational frequency W2U, and the third upper-limit rotational frequency W3U as appropriate, using formulas determined based on experiments or simulations. At this time, the CPU 101 ensures that the circumferential speed V of the distal end of the teeth 27 of the bucket 25 is lower than or equal to the upper-limit circumferential speed Vmax when controlling the electric motors 32, 42, 52 later in step S160. For example, the CPU 101 may calculate the first upper-limit rotational frequency W1U using the same method as in step S40 of the first embodiment. When calculating the upper-limit rotational frequencies W1U, W2U, and W3U, the CPU 101 may adjust the upper-limit rotational frequencies W1U, W2U, and W3U based on the angular positions 21S, 23S, and 25S obtained in step S110. The CPU 101 proceeds to step S150 after calculating the upper-limit rotational frequencies W1U, W2U, W3U. Note that in steps S130 and S140, the CPU 101 calculates the upper-limit rotational frequencies W1U, W2U, W3U based on the object distance L calculated from the second angular position 23S and the third angular position 25S. The processes in steps S130 and S140 constitute a first process.

[0072] In step S150, the CPU 101 calculates the first target rotational frequency W1F, the second target rotational frequency W2F, and the third target rotational frequency W3F. The first target rotational frequency W1F is the target rotational frequency of the first drive shaft 32B. The second target rotational frequency W2F is the target rotational frequency of the second drive shaft 42B. The third target rotational frequency W3F is the target rotational frequency of the third drive shaft 52B. The CPU 101 calculates the target rotational frequencies W1F, W2F, and W3F in the same manner as in steps S50 to S70 of the first embodiment. Specifically, the CPU 101 sets the lower of the first base rotational frequency W1 and the first upper-limit rotational frequency W1U as the first target rotational frequency W1F. The CPU 101 sets the lower of the second base rotational frequency W2 and the second upper-limit rotational frequency W2U as the second target rotational frequency W2F. The CPU 101 sets the lower of the third base rotational frequency W3 and the third upper-limit rotational frequency W3U as the third target rotational frequency W3F. If the base rotational frequency and the upper-limit rotational frequency are the same, the CPU 101 can use the base rotational frequency as the target rotational frequency. As a result of setting the target rotational frequencies W1F, W2F, and W3F in this way, each of the target rotational frequencies W1F, W2F, and W3F is lower than or equal to corresponding one of the upper-limit rotational frequencies W1U, W2U, and W3U. The CPU 101 proceeds to step S160 after calculating the target rotational frequencies W1F, W2F, W3F.

[0073] In step S160, the CPU 101 controls the electric motors 32, 42, 52 based on the respective target rotational frequencies W1F, W2F, W3F. For the second electric motor 42 for example, the CPU 101 controls the second electric motor 42 so that the rotational frequency of the second drive shaft 42B matches the second target rotational frequency W2F. The same is true for the other two electric motors 32, 52. Using the target rotational frequencies W1F, W2F, W3F calculated in step S150, the CPU 101 controls the electric motors 32, 42, 52 as follows. The CPU 101 controls the first electric motor 32 so that the rotational frequency of the first drive shaft 32B is lower than or equal to the first upper-limit rotational frequency W1U. The CPU 101 controls the second electric motor 42 so that the rotational frequency of the second drive shaft 42B is lower than or equal to the second upper-limit rotational frequency W2U. The CPU 101 controls the third electric motor 52 so that the rotational frequency of the third drive shaft 52B is lower than or equal to the third upper-limit rotational frequency W3U. The CPU 101 continues the process in step S160 for a predetermined second control period. The second control period is, for example, a few seconds. When the second control period has elapsed after the process in step S160 is started, the CPU 101 ends the process in step S160. The process in step S160 constitutes a second process.

[0074] After ending the process in step S160, the CPU 101 returns to step S110. The CPU 101 then performs the processes in and after step S110 again. In this way, the CPU 101 repeats the processes in step S110 to step S160. The CPU 101 ends the driving control when the ending condition is satisfied while the processes are repeated. One example of the ending condition is that a signal 90S with an instruction for stopping the rotation of the boom 21, the arm 23, and the bucket 25 is received from the operating device 90.

<Operation and Effects of Second Embodiment>

[0075] This embodiment can produce the same advantageous effects as described in sections (1-1) to (1-4). In addition, the second embodiment produces the following advantageous effects.

[0076] (2-1) The CPU 101 of this embodiment drives the three drive shafts 32B, 42B, and 52B to operate the boom 21, the arm 23, and the bucket 25 in parallel. In this operation, the object distance L changes sequentially as the respective positions of the boom 21, arm 23, and bucket 25 change. Under these circumstances, as the object distance L is longer, the CPU 101 decreases the first upper-limit rotational frequency W1U of the first drive shaft 32B, the second upper-limit rotational frequency W2U of the second drive shaft 42B, and the third upper-limit rotational frequency W3U of the third drive shaft 52B. By setting the upper-limit rotational frequencies W1U, W2U, and W3U in accordance with the changes in the object distance L, the circumferential speed V of the distal end of the teeth 27 can be restricted even when the trajectory of the distal end of the teeth 27 changes freely.

<Modification Examples>

[0077] 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 to each other.

[0078] The upper-limit circumferential speed Vmax is not limited to the example in the above embodiments. Depending on the type of work of the excavator 10, it is possible that the circumferential speed V of the distal end of the teeth 27 needs to be limited for purposes other than protection of the attachment 20. In these and other cases, an appropriate value may be set for the upper-limit circumferential speed Vmax as needed. Furthermore, the upper-limit circumferential speed Vmax is not limited to one, but may have multiple values predetermined. Specifically, the memory 102 may store, for example, multiple upper-limit circumferential speeds Vmax for various types of work performed by the excavator 10. In this case, the CPU 101 may select one of these multiple upper-limit circumferential speeds Vmax for calculating the upper-limit rotational frequency W1U in step S40 of the first embodiment.

[0079] The method of calculating the first limit value is not limited to the example in the above embodiments. The first limit value should be lower when the object distance L is a first value than when the object distance L is a second value. The second value is smaller than the first value. It is not required that the first limit value is lower as the object distance L is longer. For example, the first limit value may vary stepwise with respect to the object distance L. In calculating the first limit value, it is not required to use the upper-limit circumferential speed Vmax of the distal end of the teeth 27 of the bucket 25. An appropriate calculation method may be employed so that the circumferential speed V of the distal end of the teeth 27 can be restricted regardless of the length of the object distance L. In such case, the first limit value should be calculated based at least on the information of the second angular position 23S.

[0080] For the second embodiment, the method of calculating the first limit value and the second limit value is not limited to the above example. As with the first limit value, it is not required to calculate the second and third limit values so that these values are lower as the object distance L is longer. Furthermore, at least one of the second and third limit values may be eliminated. For example, the first limit value may be set strictly, so as to restrict the circumferential speed V of the distal end of the teeth 27 even when the second and third limit values are eliminated.

[0081] The electric motors to be driven in the driving control are not limited to those in the above example. For example, in the driving control, it is possible to drive two of the three electric motors 32, 42, 52, i.e., the first electric motor 32 and the second electric motor 42. This may allow the boom 21 and the arm 23 to rotate. In this case, setting both the first and second limit values is suitable for restricting the circumferential speed V of the distal end of the teeth 27. As in the second embodiment, it is conceivable to calculate both the first and second limit values so that these values are lower as the object distance L is longer.

[0082] In the driving control, it is possible to drive two of the three electric motors 32, 42, 52, i.e., the second electric motor 42 and the third electric motor 52. This may allow the arm 23 and the bucket 25 to rotate. In this case, the arm 23 constitutes the first movable member, and the arm actuator 41 constitutes the first electric actuator. The bucket 25 constitutes the second movable member, and the bucket actuator 51 constitutes the second electric actuator. In such configuration, for example, the object distance should be the distance from the second axis 41J to the distal end of the teeth 27 of the bucket 25 in the particular plan view. In addition, this object distance should be calculated based on the third angular position 25S, and the limit value for the second drive shaft 42B should be calculated in accordance with the object distance L.

[0083] As described in the above modification examples, it is possible to change as necessary the member of the attachment 20 that is treated as the first movable member and the member that is treated as the second movable member. Depending on which member is treated as the first movable member, the actuator that constitutes the first electric actuator can be changed. When the first movable member is changed from the example in the above embodiment, the first electric actuator should be an actuator that rotates the first movable member. Similarly, depending on which member is treated as the second movable member, the actuator that constitutes the second electric actuator can be changed. The second electric actuator should be an actuator that rotates the second movable member. If another movable member different from the first movable member is coupled to the second movable member, the other movable member should be treated as the third movable member. The actuator that rotates the third movable member should be treated as the third electric actuator.

[0084] For the rotational speed of the drive shafts 32B, 42B, and 52B, the rotational frequency may be replaced with the angular speed, which is the amount of change in the angular position of a drive shaft per unit time. In this case, each limit value can be expressed using an angular speed.

[0085] The overall configuration of the attachment 20 is not limited to the example in the above embodiments. The attachment 20 may be configured with appropriate movable members in accordance with the type of the work. For example, a member other than the bucket 25 may be used as the third movable member. Depending on the third movable member used, the distal end of the third movable member opposite to the coupling point with the third output shaft may be changed. Simultaneously, the distal end of the attachment 20 opposite to the coupling point with the first output shaft can be changed. The third movable member may be eliminated. The attachment 20 should include at least two movable members. If the third movable member is eliminated, the distal end of the attachment 20 opposite to the coupling point with the first output shaft is a portion of the second movable member.

[0086] Instead of the first drive shaft 32B of the first electric motor 32, the first output member 33C of the first speed reducer 33 may be treated as the first output shaft. In this case, the values of the parameters such as the base rotational frequency, upper-limit rotational frequency, and target rotational frequency, which were determined for the first drive shaft 32B, should be converted to values for the first output member 33C by taking account of the reduction ratio of the first speed reducer 33. Similarly, instead of the second drive shaft 42B of the second electric motor 42, the output member 43C of the second speed reducer 43 may be treated as the second output shaft. Instead of the third drive shaft 52B of the third electric motor 52, the output member 53C of the third speed reducer 53 may be treated as the third output shaft.

[0087] 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 the output member 33C may have any shape that allows torque to be transmitted to a mating 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.

[0088] The boom actuator 31 can be configured in any other manners than described in the above embodiments. The boom actuator 31 should include an electric motor and should be able to drive the rotation of the boom 21. For example, the first speed reducer 33 may be eliminated from the boom actuator 31. Furthermore, the boom actuator 31 does not necessarily output torque to the outside coaxially with the drive shaft of the electric motor.

[0089] The boom actuator 31 may be mounted to the boom 21 and the swing bracket 17 in any other manners than described in the above embodiments. Any mounting method is acceptable as long as the boom 21 can be rotated by the boom actuator 31. For example, the boom actuator 31 may be oriented reversely between the second swing wall 17B of the swing bracket 17 and the boom 21. Specifically, the boom actuator 31 may be mounted to the boom 21 and the swing bracket 17 so that the first speed reducer 33 is located closer to the second swing wall 17B and the first electric motor 32 is located closer to the boom 21.

[0090] As in the above modification example regarding the boom actuator 31, the arm actuator 41 may be configured and mounted in any other manners than described in the above embodiments. The arm actuator 41 should include an electric motor and should be able to drive the rotation of the arm 23.

[0091] As in the above modification example regarding the boom actuator 31, the bucket actuator 51 may be configured and mounted in any other manners than described in the above embodiments. The bucket actuator 51 should include an electric motor and should be able to drive the rotation of the bucket 25.

[0092] The configuration of the upper body 14 is not limited to the example in the above embodiment. For example, the cabin may be eliminated from the upper body 14. The shape of the case main portion 14A and the case front portion 14B may be other than a rectangular parallelepiped. The upper body 14 should be configured to achieve the required function, for example, housing of various devices.

[0093] In addition to the cabin eliminated from the upper body 14 as in the above modification example, the operating device 90 may be eliminated from the upper body 14. Simultaneously, various signals to the control device 100 with an instruction for operation of the excavator 10 may be transmitted via wireless communication from a device outside the vehicle body 15.

[0094] The components included in the drive system of the excavator 10 are not limited to the example in the above embodiments. For example, the attachment 20 may be treated as a component not included in the drive system. The drive system should include the drive unit 30 and the control device 100.

[0095] The overall configuration of the vehicle body 15 and thus the excavator 10 is not limited to the example in the above embodiments. For example, the entire shape of the vehicle body 15 may be changed from the example in the above embodiments, as a result of the change in the shape of the upper body 14 as described in the above modification example. The excavator 10 as a whole should be configured to achieve the required work, for example, excavation.

[0096] The work machine is not limited to the excavator 10. The work machine may be a construction machine other than the excavator 10. Furthermore, the work machine is not limited to a construction machine. Examples of work machines other than construction machines include machines used in forestry, quarrying, industrial waste disposal, and agriculture.

[0097] The processing circuit of the control device 100 should have any one of the following configurations (a) to (c). (a) The processing circuit has one or more processors that perform various processes according to a computer program. The processors include a CPU 101 and a memory 102 such as a RAM or a ROM. The memory 102 stores program codes or instructions configured to cause the CPU 101 to perform processes. The memory 102, or a computer-readable medium, encompasses any kind of available media accessible by a general-purpose or dedicated computer.

[0098] (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.

[0099] (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.

[0100] The foregoing embodiment describes a plurality of physically separate constituent parts. They may be combined into a single part, and any one of them may be divided into a plurality of physically separate constituent parts. Irrespective of whether or not the constituent parts are integrated, they are acceptable as long as they are configured to solve the problems.

[0101] According to the foregoing embodiments, a plurality of functions are distributively provided. Some or all of the functions may be integrated. Any one of the functions may be partly or entirely segmented into a plurality of functions, which are distributively provided. Irrespective of whether the functions are integrated or distributed, they are acceptable as long as they are configured to attain the object of the invention.

Claims

1. A drive system for a work machine, the work machine including an attachment having a first movable member and a second movable member, the second movable member being rotatably coupled to the first movable member, the drive system comprising:
a drive unit having a first electric actuator and a second electric actuator, the first electric actuator having a first output shaft for rotating the first movable member, the second electric actuator having a second output shaft for rotating the second movable member; and
a control device for controlling the drive unit,
wherein the control device performs:

a first process to calculate a limit value for a rotational speed of the first output shaft based on a relative position of the second movable member relative to the first movable member; and
a second process to control the first electric actuator such that the rotational speed of the first output shaft is lower than or equal to the limit value, and
wherein the first process is performed such that the limit value is lower when a distance is a first value than when the distance is a second value smaller than the first value, the distance being from the first output shaft to a distal end of the attachment opposite to a coupling point with the first output shaft.

2. The drive system for a work machine according to claim 1, wherein supposing that an upper-limit circumferential speed is defined as an upper limit of a circumferential speed for the distal end of the attachment, the control device performs the first process such that the limit value is calculated at a value corresponding to a divided value, the divided value being obtained by dividing, by the distance, the upper-limit circumferential speed predetermined.

3. The drive system for a work machine according to claim 1,

wherein the attachment has a third movable member rotatably coupled to the second movable member,
wherein the drive unit has a third electric actuator having a third output shaft for rotating the third movable member,
wherein the distal end of the attachment is a distal end of the third movable member opposite to a coupling point with the third output shaft, and
wherein the control device performs the first process such that the limit value is calculated based on the relative position of the second movable member relative to the first movable member and a relative position of the third movable member relative to the second movable member.

4. The drive system for a work machine according to claim 3,
wherein supposing that the limit value is a first limit value, the control device performs:

the first process to calculate the first limit value, a second limit value as a limit value for a rotational speed of the second output shaft, and a third limit value as a limit value for a rotational speed of the third output shaft, based on the relative position of the second movable member relative to the first movable member and the relative position of the third movable member relative to the second movable member; and
the second process to control the first electric actuator such that the rotational speed of the first output shaft is lower than or equal to the first limit value, control the second electric actuator such that the rotational speed of the second output shaft is lower than or equal to the second limit value, and control the third electric actuator such that the rotational speed of the third output shaft is lower than or equal to the third limit value, and
wherein the first process is performed such that the first limit value, the second limit value, and the third limit value are lower when the distance is the first value than when the distance is the second value, the distance being from the first output shaft to the distal end of the attachment.

5. The drive system for a work machine according to claim 3,

wherein the work machine is a construction machine,
wherein the first movable member is a boom,
wherein the second movable member is an arm, and
wherein the third movable member is a bucket.

6. A control device for a work machine, the work machine including:

an attachment having a first movable member and a second movable member, the second movable member being rotatably coupled to the first movable member; and
a drive unit having a first electric actuator and a second electric actuator, the first electric actuator having a first output shaft for rotating the first movable member, the second electric actuator having a second output shaft for rotating the second movable member,
wherein the control device performs:

a first process to calculate a limit value for a rotational speed of the first output shaft based on a relative position of the second movable member relative to the first movable member; and
a second process to control the first electric actuator such that the rotational speed of the first output shaft is lower than or equal to the limit value, and
wherein the first process is performed such that the limit value is lower when a distance is a first value than when the distance is a second value smaller than the first value, the distance being from the first output shaft to a distal end of the attachment opposite to a coupling point with the first output shaft.

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

an attachment having a first movable member and a second movable member, the second movable member being rotatably coupled to the first movable member; and
a drive unit having a first electric actuator and a second electric actuator, the first electric actuator having a first output shaft for rotating the first movable member, the second electric actuator having a second output shaft for rotating the second movable member,
wherein a control device applied to the work machine performs:

a first process to calculate a limit value for a rotational speed of the first output shaft based on a relative position of the second movable member relative to the first movable member; and
a second process to control the first electric actuator such that the rotational speed of the first output shaft is lower than or equal to the limit value, and
wherein the first process is performed such that the limit value is lower when a distance is a first value than when the distance is a second value smaller than the first value, the distance being from the first output shaft to a distal end of the attachment opposite to a coupling point with the first output shaft.

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

an attachment having a first movable member and a second movable member, the second movable member being rotatably coupled to the first movable member; and
a drive unit having a first electric actuator and a second electric actuator, the first electric actuator having a first output shaft for rotating the first movable member, the second electric actuator having a second output shaft for rotating the second movable member,
wherein the control program causes a control device applied to the work machine to perform:

a first process to calculate a limit value for a rotational speed of the first output shaft based on a relative position of the second movable member relative to the first movable member; and
a second process to control the first electric actuator such that the rotational speed of the first output shaft is lower than or equal to the limit value, and
wherein the first process is performed such that the limit value is lower when a distance is a first value than when the distance is a second value smaller than the first value, the distance being from the first output shaft to a distal end of the attachment opposite to a coupling point with the first output shaft.

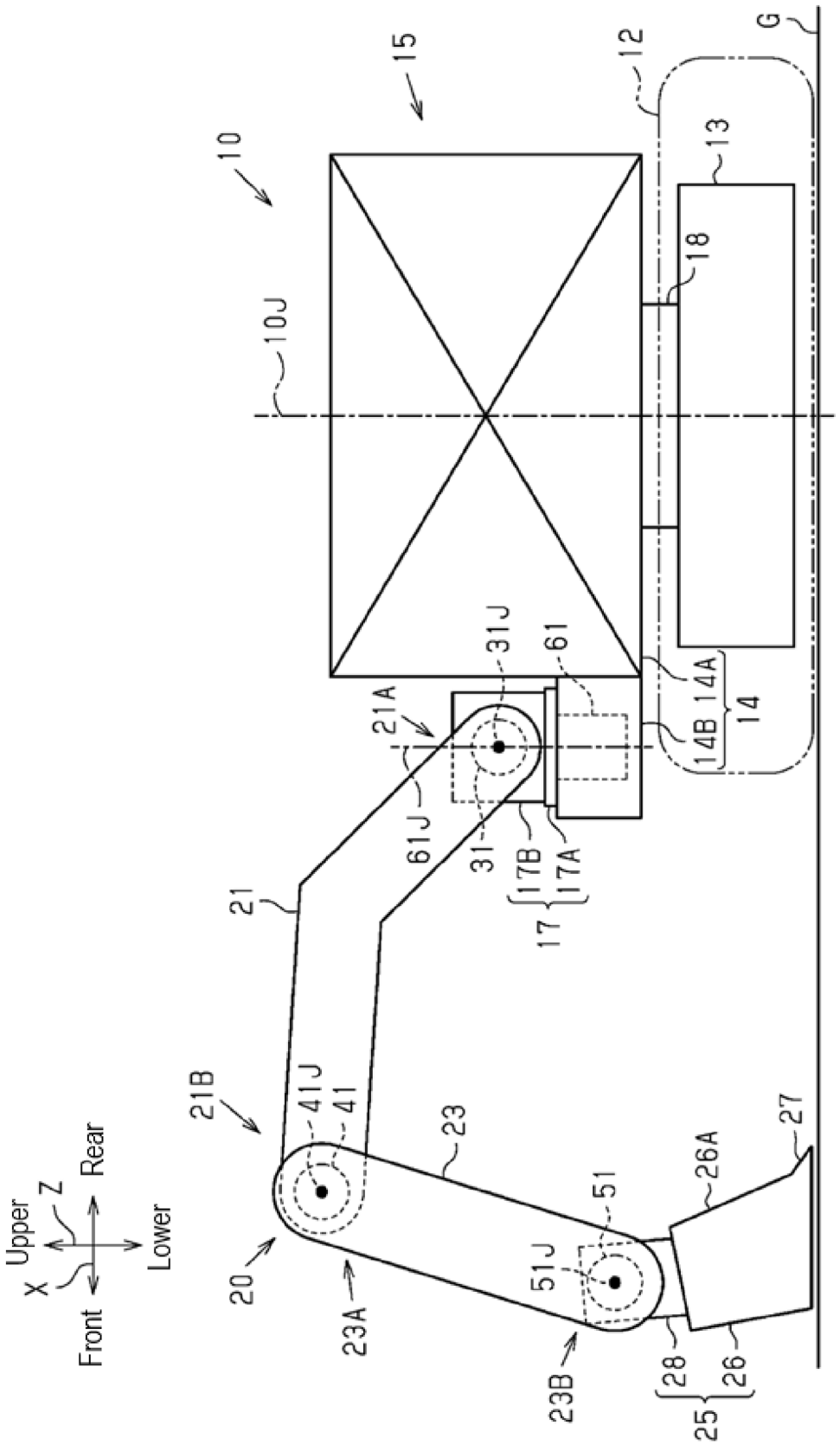

Upper
Z
Rear
X
Front
Lower
10
15
12
G
13
18
10J
31J
61
21A
14A
14
14B
61J
31
17B
17A
17
21
21B
41J
41
23
51
26A
27
20
23A
51J
23B
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26
25

Fig. 1

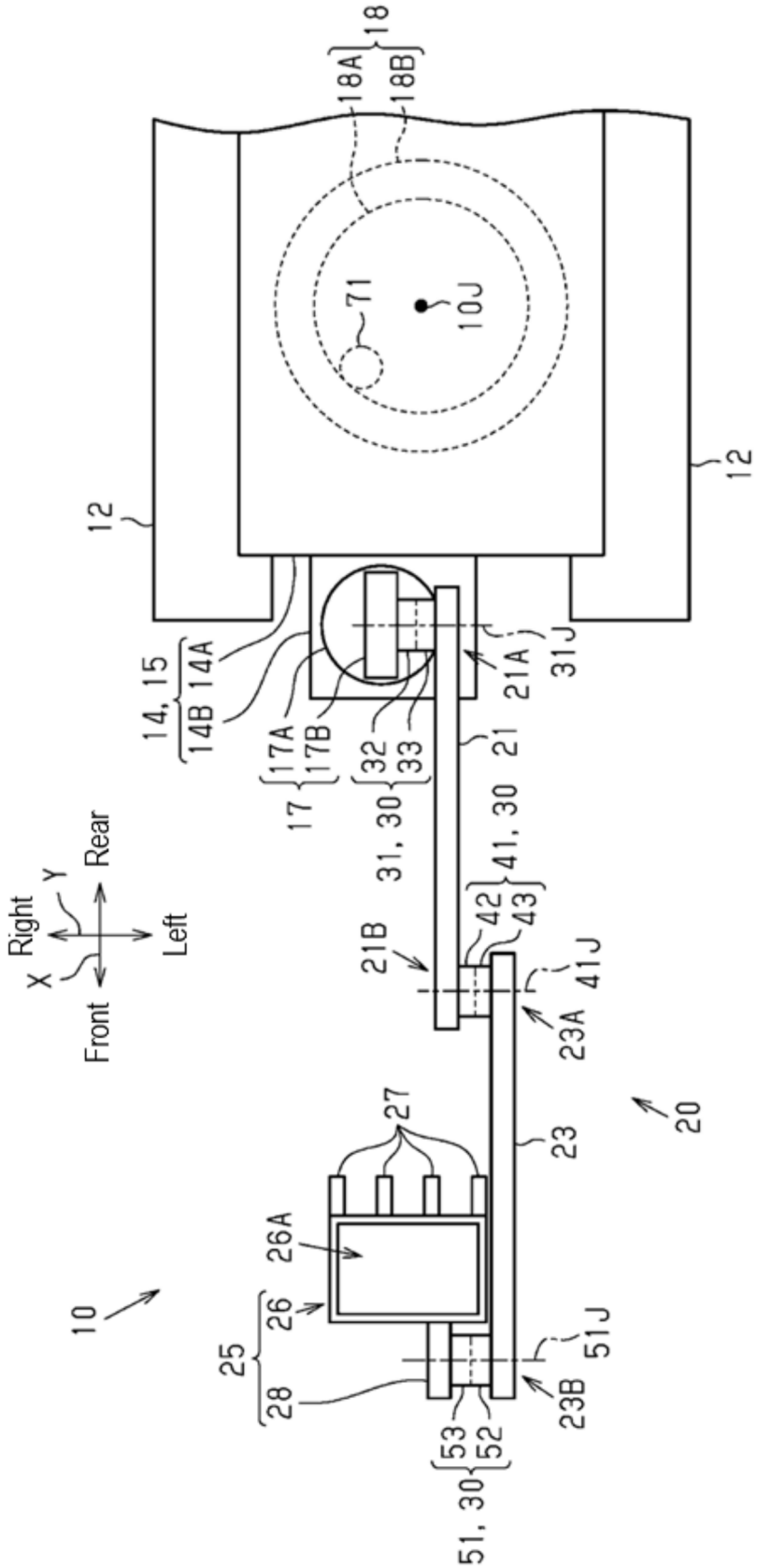

18
18A
18B
71
10J
12
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14, 15
14A
14B
17A
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31, 30
21
21A
31J
41, 30
42
43
21B
41J
23A
23
20
27
26A
26
25
28
10
51J
23B
53
52
51, 30
Y
Rear
Right
Left
X
Front

Fig. 2

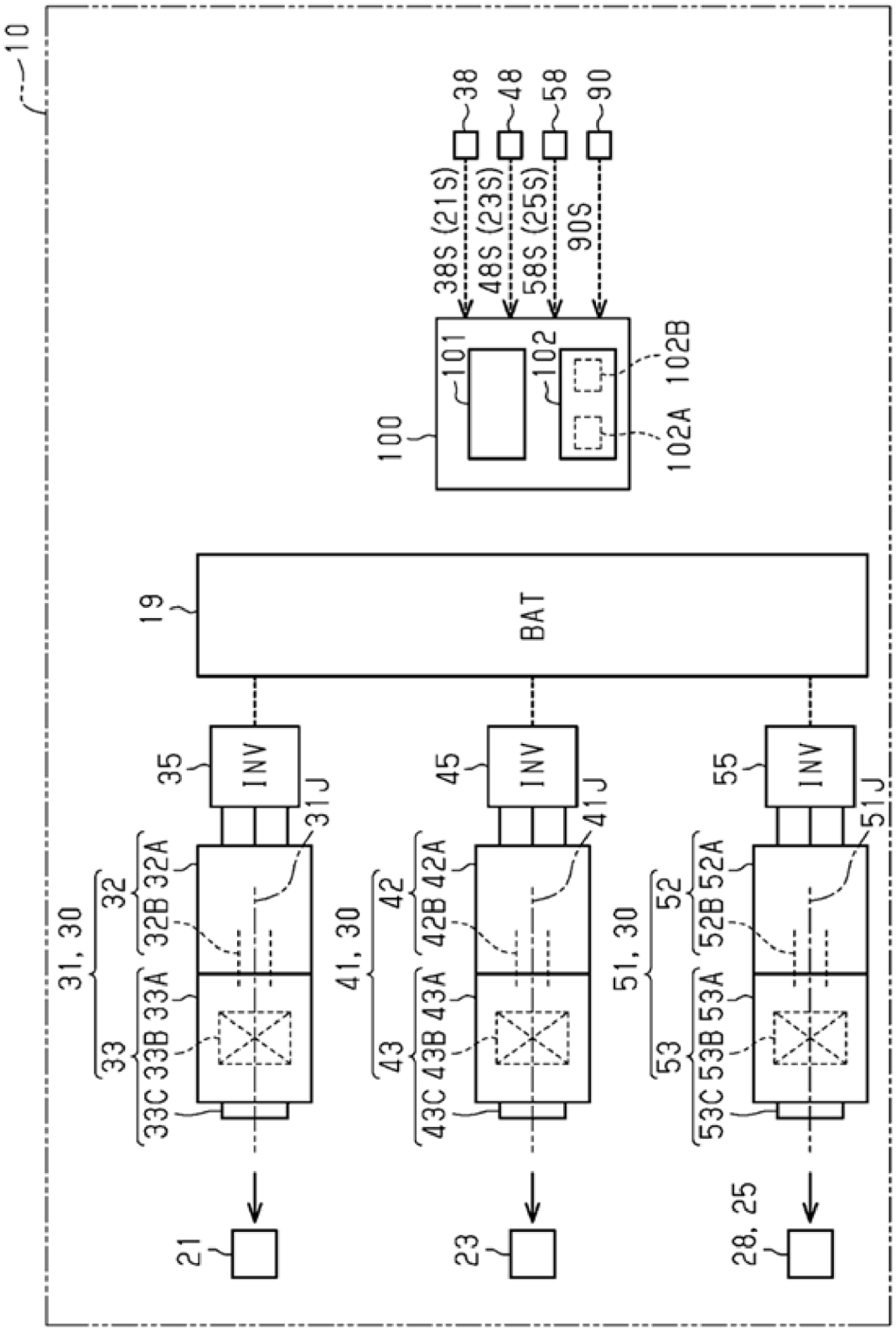

10
38
48
58
90
38S (21S)
48S (23S)
58S (25S)
90S
100
101
102
102A
102B
19
BAT
35
45
55
INV
31J
41J
51J
31, 30
32
32A
32B
33
33A
33B
33C
41, 30
42
42A
42B
43
43A
43B
43C
51, 30
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52A
52B
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53A
53B
53C
21
23
28, 25

Fig. 3

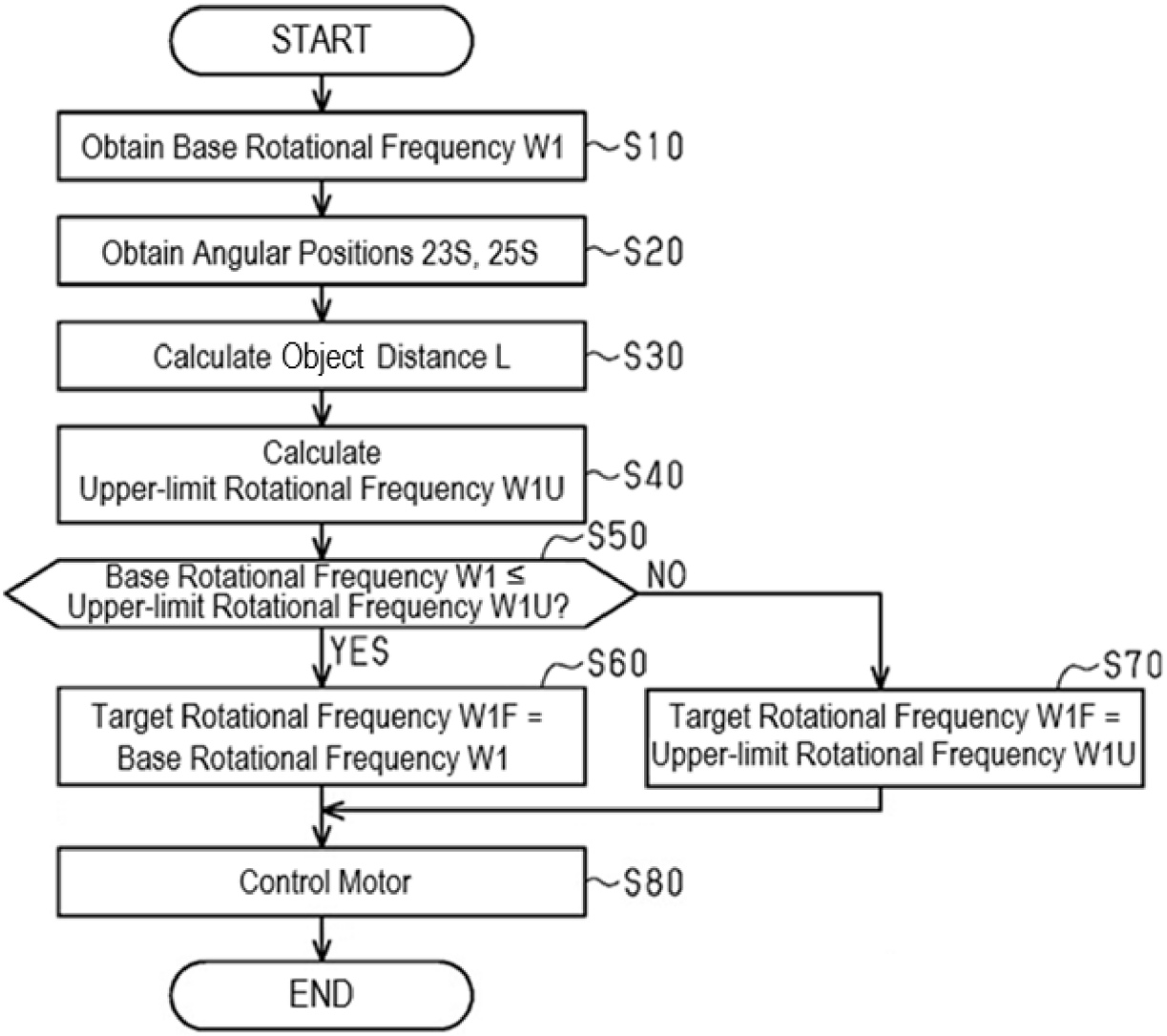

START
Obtain Base Rotational Frequency W1
S10
Obtain Angular Positions 23S, 25S
S20
Calculate Object Distance L
S30
Calculate
Upper-limit Rotational Frequency W1U
S40
S50
Base Rotational Frequency W1 ≤
Upper-limit Rotational Frequency W1U?
NO
YES
S60
Target Rotational Frequency W1F =
Base Rotational Frequency W1
S70
Target Rotational Frequency W1F =
Upper-limit Rotational Frequency W1U
Control Motor
S80
END

Fig. 4

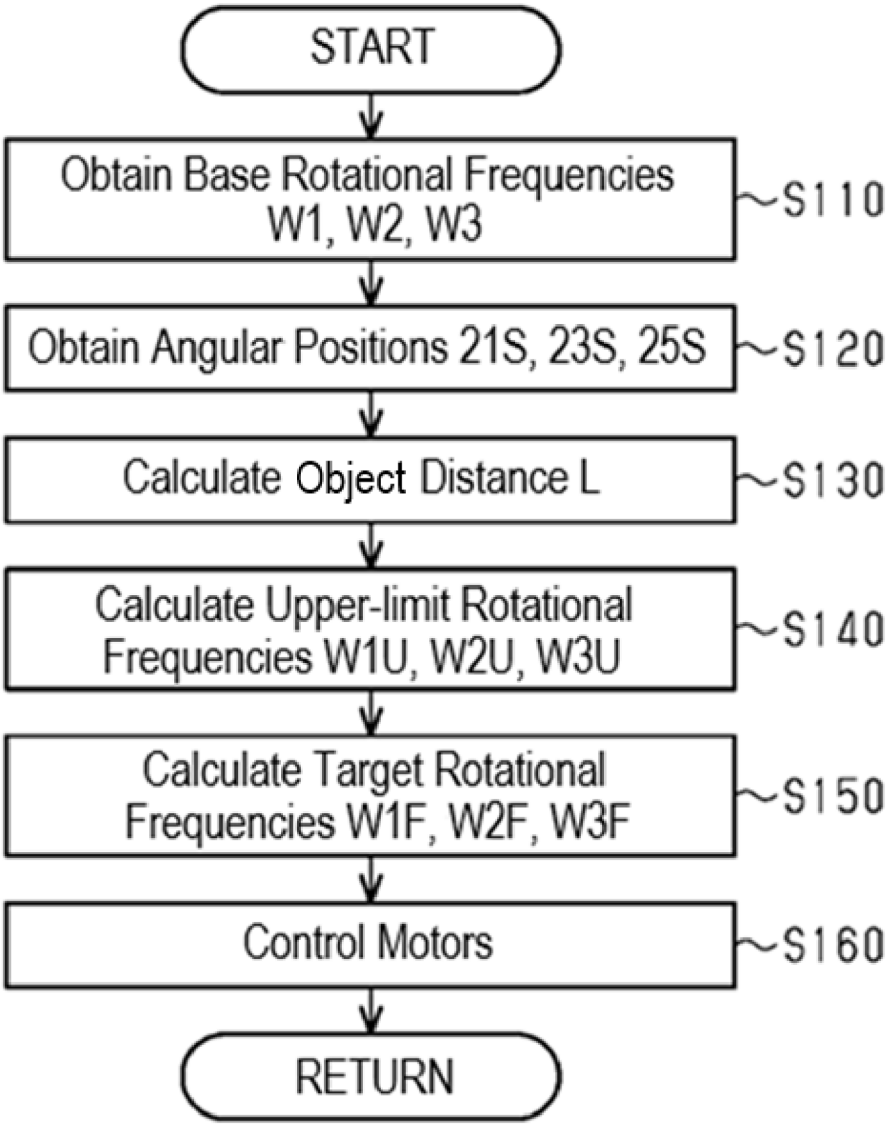

START
Obtain Base Rotational Frequencies W1, W2, W3
S110
Obtain Angular Positions 21S, 23S, 25S
S120
Calculate Object Distance L
S130
Calculate Upper-limit Rotational Frequencies W1U, W2U, W3U
S140
Calculate Target Rotational Frequencies W1F, W2F, W3F
S150
Control Motors
S160
RETURN

Fig. 5

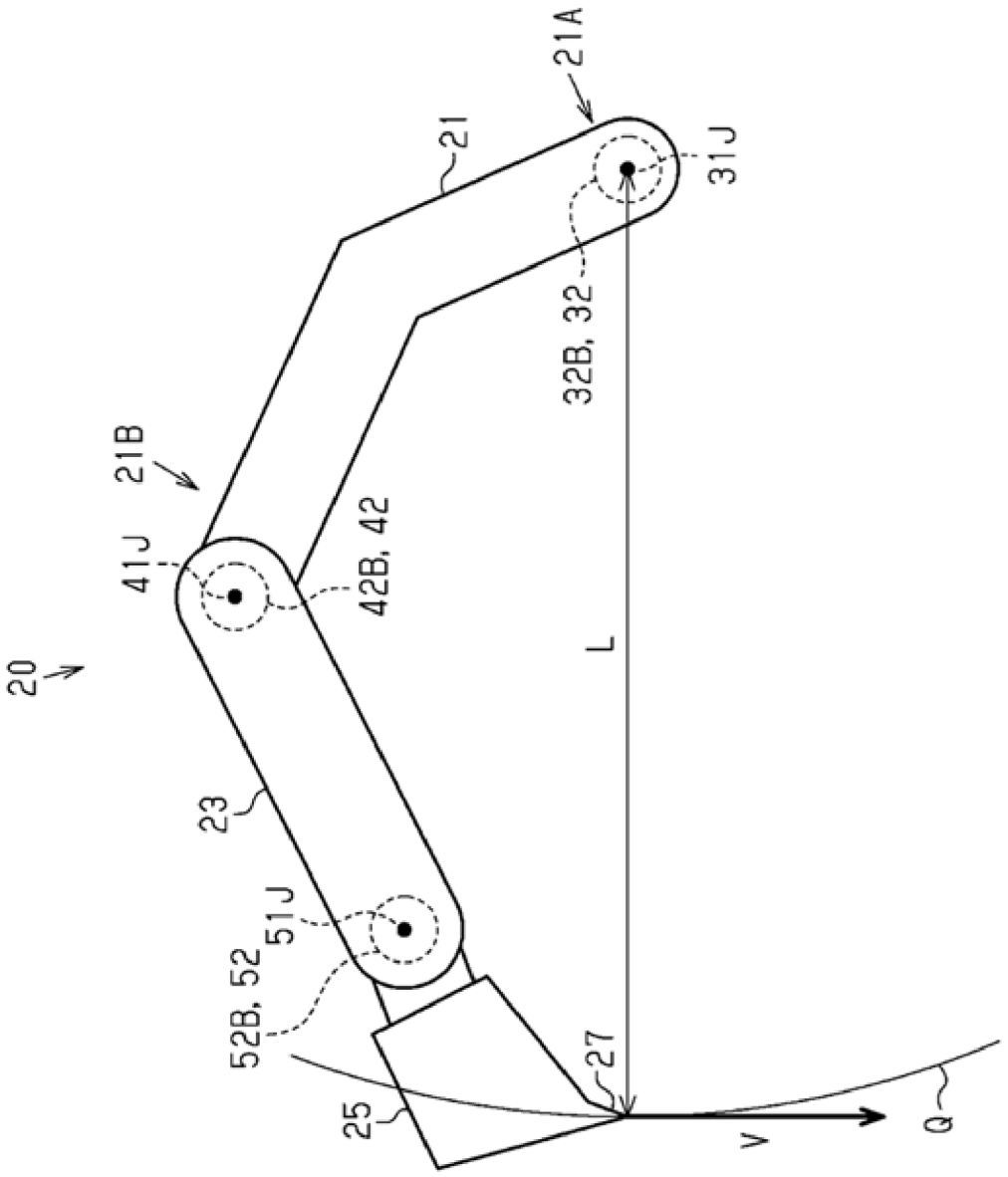


Fig. 6

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EUROPEAN SEARCH REPORT

Application Number
EP 26 16 1599

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Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
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E02F

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
Munich	20 August 2026	Clarke, Alister

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20-08-2026

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