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Inventor(s)	Sugioka; Masayuki et al.

Screw driving device

Abstract

According to the present invention, an axial force of a screw which is generated by screw driving is estimated. A control part applies a predetermined torque generated by a rotation axis servomotor to a screw in a rotation direction where a screw is driven, and thereafter releases the torque. The control part then estimates an axial force of the driven screw based on fluctuation of a rotation position of the rotation axis servomotor which occurs due to the release of the torque.

Inventors:	**Sugioka; Masayuki (Kyoto, JP), Tsukikawa; Masayoshi (Kyoto, JP), Miyamoto; Kota (Kyoto, JP), Tsuchikawa; Kento (Kyoto, JP), Sakamoto; Yuki (Kyoto, JP)**
Applicant:	**OMRON Corporation** (Kyoto, JP)
Family ID:	**1000008748113**
Assignee:	**OMRON Corporation (Kyoto, JP)**
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Background/Summary

CROSS-REFERENCE TO RELATED APPLICATION

(1) This application is a 371 application of the International PCT application serial no. PCT/JP2021/008424, filed on Mar. 4, 2021, which claims the priority benefits of Japan Patent Application No. 2020-107262, filed on Jun. 22, 2020. The entirety of each of the above-mentioned patent applications is hereby incorporated by reference herein and made a part of this specification.

TECHNICAL FIELD

(2) The disclosure relates to a screw driving device that estimates an axial force of a screw generated by screw driving.

RELATED ART

(3) Patent Literatures 1 and 2 as listed below disclose techniques for determining screw driving failures. Patent Literature 1 relates to a screw driving failure determination device which determines the occurrence and type of failure in screw driving; it determines the occurrence and type of failure in the screw driving operation by the driver based on two or more variables with respect to a first motor that provides rotational motion of the driver and a second motor that provides axial reciprocating motion of the driver.

(4) Patent Literature 2 relates to a screw driving determination device which is connected to a screw driving device and that determines whether there is a screw driving failure to an object; it generates a waveform showing the relationship between the accumulated rotation angle and the current value in the screw driving device during screw driving, and determines the screw driving failure based on the amount of change in the accumulated rotation angle and current value in the waveform when screw driving is completed.

CITATION LIST

Patent Literature

(5) [Patent Literature 1] Japanese Patent Application Laid-Open No. 2020-6452 [Patent Literature 2] Japanese Patent Application Laid-Open No. 2019-150922

SUMMARY

Technical Problem

(6) However, although Patent Literatures 1 and 2 described above disclose a technique for determining screw driving failures, they do not disclose a technique for determining screw driving failures by estimating the axial force of a screw.

(7) An embodiment of the disclosure realizes a screw driving device that estimates the axial force of a screw generated by screw driving.

Solution to Problem

(8) The disclosure adopts the following configurations in view of the above-described problems. A screw driving device according to an embodiment of the disclosure includes: a rotary tool for rotating a screw; a first motor that drives the rotary tool to rotate; and a control part that controls the first motor. The control part: applies a predetermined torque generated by the first motor to the screw in a rotation direction where the screw is driven, then performs a step of releasing the torque, and estimates an axial force of the driven screw based on a change of a rotation position of the first motor in the step of releasing the torque.

Effects of Invention

(9) According to an embodiment of the disclosure, it is possible to estimate the axial force of the screw generated by screw driving.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

(1) FIG. **1** is a diagram showing an overall configuration of a screw driving device according to an embodiment.

(2) FIG. **2** is a block diagram showing a schematic configuration of the screw driving device according to this embodiment.

(3) FIG. **3** is a table showing a processing procedure of a screw driving operation of the screw driving device according to this embodiment.

(4) FIG. **4** is a graph showing the rotation axis torque (R-axis torque) of the rotation axis servomotor at each step shown in FIG. **3**.

(5) FIG. **5** is a diagram schematically showing an axial force generated by screw driving.

(6) FIG. **6** is a graph showing the relationship between a change in the rotation position and the axial force of the screw in a normal condition.

(7) FIG. **7** is a graph showing the relationship between a change in the rotation position and the axial force of the screw at the time of bottom hitting.

(8) FIG. **8** is a graph showing an actually measured axial force of a screw and a predicted axial force value calculated using Equation (1).

(9) FIG. **9** is a graph plotting the predicted axial force value versus the measured value of each sample shown in FIG. **8**.

(10) FIG. **10** is a graph plotting the Z-axis position range in step 2 versus the R-axis position range in step 4 for each of the samples of Normal and Abnormal 2 to 5 shown in FIG. **8** where bottom hitting occurs.

DESCRIPTION OF THE EMBODIMENTS

(11) Hereinafter, embodiments according to one aspect of the disclosure will be described based on the drawings.

§ 1 Application Example

(12) FIG. **1** is a diagram showing an overall configuration of a screw driving device **1** according to this embodiment. The screw driving device **1** includes a rotation axis servomotor (first motor) **10**, a servo driver **12** that controls the rotation of the rotation axis servomotor **10**, an elevation axis servomotor (second motor) **20**, a servo driver **22** that controls the rotation of the elevation axis servomotor **20**, a ball screw **30**, a control part **31** for transmitting instructions such as torque commands to the servo drivers **12** and **22**, and a driver bit (rotary tool) **40**.

(13) Further, though not shown in FIG. **1**, the screw driving device **1** further includes an encoder **11** provided on the rotation axis servomotor **10** and an encoder **21** provided on the elevation axis servomotor **20**.

(14) The driver bit **40** is attached to the rotation axis of the rotation axis servomotor **10** and rotates

around the R axis as the rotation axis servomotor **10** rotates. By rotating the driver bit **40**, the screw to be screwed is driven.

(15) Further, the rotation axis servomotor **10** and the driver bit **40** are connected to the elevation axis servomotor **20** via the ball screw **30**. The rotation motion of the elevation axis servomotor **20** is converted into linear motion in the Z-axis direction by the ball screw **30**, and the rotation axis servomotor **10** and the driver bit **40** are raised and lowered.

(16) The control part **31** controls the rotation angle (rotation position), rotation speed, and torque of the rotation axes of the rotation axis servomotor **10** and the elevation axis servomotor **20**, controls the raising and lowering of the driver bit **40** by the rotation of the elevation axis servomotor **20**, and controls the screw driving by the driver bit **40** by the rotation of the rotation axis servomotor **10**.

(17) The control part **31** controls the raising and lowering of the elevation axis servomotor **20** to fit the tip of the driver bit **40** into the groove of the head of the male screw, and applies a predetermined torque generated by the rotation axis servomotor to the screw in a rotation direction where the screw is driven, and then starts the step of releasing the torque. At the start of the step of releasing the torque, the control part **31** acquires a first rotation angle (rotation position) of the rotation axis of the rotation axis servomotor **10**.

(18) After releasing the predetermined torque, the control part **31** ends the step of releasing the torque. At the end of the step of releasing the torque, the control part **31** acquires a second rotation angle (rotation position) of the rotation axis of the rotation axis servomotor **10**. Then, the control part **31** obtains the difference between the first rotation angle and the second rotation angle, and estimates the axial force of the screw based on the change in the rotation angle.

(19) Since the control part **31** estimates the axial force of the driven screw based on the change in the rotation position of the first motor, there is no need to measure the actual axial force of the screw, making it easy to determine the quality of the driving of the screw.

§ 2 Configuration Example

(20) FIG. **2** is a block diagram showing a schematic configuration of the screw driving device **1** according to this embodiment. The screw driving device **1** includes the rotation axis servomotor **10**, the encoder **11** provided in the rotation axis servomotor **10**, the servo driver **12** that controls the rotation of the rotation axis servomotor **10**, the elevation axis servomotor **20**, the encoder **21** provided in the elevation axis servomotor **20**, the servo driver **22** that controls the rotation of the elevation axis servomotor **20**, and the control part **31** that performs overall control of the screw driving device **1**.

(21) The encoders **11** and **21** obtain the rotation angles of the rotation axes of rotation axis servomotor **10** and elevation axis servomotor **20**, respectively, and generate and output an A-phase signal, a B-phase signal and a Z-phase signal as feedback signals.

(22) The rotation axis servomotor **10** is configured by a three-phase AC motor, and the rotation axis servomotor **10** is driven according to three-phase drive signals (U-phase signal, V-phase signal, and W-phase signal) output from the servo driver **12**. Similarly, the elevation axis servomotor **20** is configured by a three-phase AC motor, and the elevation axis servomotor **20** is driven according to three-phase drive signals (U-phase signal, V-phase signal, and W-phase signal) output from the servo driver **22**.

(23) The servo driver **12** includes an inverter part **121**, an encoder **122** and a communication part **123**. The servo driver **22** also includes an inverter part **221**, an encoder **222** and a communication part **223**. In addition, the inverter part **121** and the inverter part **221** have the same configuration and functions; the encoder **122** and the encoder **222** have the same configuration and functions, and the communication part **123** and the communication part **223** have the same configuration and functions. Accordingly, only the details of the servo driver **12** will be described, and the detailed description of the servo driver **22** will not be repeated.

(24) When the inverter part **121** receives commands of the rotation angle (rotation position), rotation speed, and torque from the control part **31** via the communication part **123**, the inverter

part **121** controls the rotation axis servomotor **10** according to the commands. Specifically, the inverter part **121** generates a pulse width modulation (PWM) waveform according to a command from the control part **31** and a feedback signal from the encoder **11**, and generates an alternating current of a required frequency from the direct current. At this time, a U-phase signal, a V-phase signal, and a W-phase signal, which are three drive signals having different phases, are generated and supplied to the rotation axis servomotor **10**.

(25) Further, the inverter part **121** receives a feedback signal from the encoder **11** provided in the rotation axis servomotor **10**, obtains the actual rotation angle, rotation speed and drive torque of the rotation axis servomotor **10**, and compares them with commands from the control part **31** to detect errors between them. Then, the operation of the rotation axis servomotor **10** is corrected in real time with this error information. The inverter part **121** feeds back the actual rotation speed and drive torque of the rotation axis servomotor **10** to the control part **31** via the communication part **123**.

(26) The encoder **122** obtains the actual rotation angle of the rotation axis of the rotation axis servomotor **10** based on the feedback signal from the encoder **11** and feeds it back to the control part **31** via the communication part **123**.

(27) The communication part **123** communicates with the control part **31** through, for example, a local area network (LAN). The communication part **123** receives commands of the rotation angle (rotation position), rotation speed, and torque from the control part **31** and outputs the commands to the inverter part **121**. Further, upon receiving the actual rotation angle of the rotation axis of the rotation axis servomotor **10** from the encoder **122** and the actual rotation speed and drive torque of the rotation axis servomotor **10** from the inverter part **121**, the communication part **123** transmits the information to the control part **31**.

(28) The control part **31** has a communication part **311**, and communicates with the servo drivers **12** and **22** via, for example, a LAN. The control part **31** transmits commands of the rotation angle, rotation speed and torque to the servo drivers **12** and **22** via the communication part **311**. In addition, the control part **31** receives feedback information regarding the actual rotation angle, rotation speed, and drive torque of the rotation axes of the rotation axis servomotor **10** and the elevation axis servomotor **20** from the servo drivers **12** and **22** via the communication part **311**.

§ 3 Operation Example

First Embodiment

(29) FIG. **3** is a table showing a processing procedure of a screw driving operation of the screw driving device **1** according to this embodiment. Further, FIG. **4** is a graph showing the rotation axis torque (R-axis torque) of the rotation axis servomotor **10** at each step shown in FIG. **3**. In this graph, the horizontal axis is time, and the vertical axis is R-axis torque. One index of time on the horizontal axis corresponds to 2 ms. Further, the R-axis torque on the vertical axis is expressed as a ratio with the rated torque being 100%. Hereinafter, the operation of the screw driving device **1** according to this embodiment will be described with reference to FIGS. **3** and **4** as appropriate.

(30) First, the control part **31** transmits commands of the rotation angle, rotation speed, and torque of the elevation axis servomotor **20** to the servo driver **22**. The servo driver **22** generates a drive waveform according to the commands from the control part **31** and supplies it to the elevation axis servomotor **20** (step 0 start). At this time, the driver bit **40** is at the origin position and descends along the Z axis at a predetermined moving speed (Vz) according to the drive waveform.

(31) The position (z) and moving speed (Vz) of the driver bit **40** may be calculated from the rotation angle and rotation speed of the rotation axis of the elevation axis servomotor **20**. The control part **31** moves the driver bit **40** to the target position.

(32) When the control part **31** detects that the Z-axis position (z) of the driver bit **40** has reached the target position, it instructs the servo driver **22** to stop driving the elevation axis servomotor **20** (end of step 0). As shown in FIG. **4**, during step 0, the rotation axis servomotor **10** is not driven, so the R-axis torque remains zero.

(33) Next, the control part **31** transmits a command of the rotation speed of the rotation axis servomotor **10** to the servo driver **12**. The servo driver **12** generates a drive waveform according to the command from the control part **31** and supplies it to the rotation axis servomotor **10**. At this time, the driver bit **40** rotates around the R axis at a predetermined rotation speed (Vr), and screw driving is started (start of step 1 (first step)).

(34) In addition, since the rotation of the screw causes the screw to move downward, the control part **31** rotates the elevation axis servomotor **20** in synchronization with the amount of movement of the screw, thereby moving the driver bit **40** downward along the Z axis. At this time, if the tip of the driver bit **40** does not fit into the groove of the head of the screw, it will fit into the groove of the head of the screw by rotating the driver bit **40** around the R axis and moving it downward.

(35) As shown in FIG. **4**, since the rotation axis of rotation axis servomotor **10** rotates at a predetermined rotation speed (Vr), the R-axis torque increases, but overshoot occurs only at the beginning. The control part **31** determines whether the R-axis torque has reached a threshold torque (for example, 62%) to determine whether it is in a temporarily seated state (the bearing surface of the screw is in contact with the part to be fastened). Since it is necessary to exclude the R-axis torque overshoot, it is not determined whether the vehicle is in the temporarily seated state for 1000 ms from the start of step 1.

(36) When the screw is in the temporarily seated state, the servo driver **12** tries to maintain a predetermined rotation speed (Vr), and the R-axis torque further increases. The control part **31** proceeds to step 2 when the drive torque received from the servo driver **12** reaches the threshold torque. In this way, the control part **31** rotates the rotation axis servomotor **10** around the R axis at a predetermined rotation speed and moves the driver bit **40** downward along the Z-axis direction by the rotation of the elevation axis servomotor **20** until the R-axis torque reaches the threshold torque (end of step 1).

(37) Next, the control part **31** causes the servo driver **12** to maintain a predetermined rotation speed (Vr) in order to perform full driving of the screw. In this way, the R-axis torque increases. Here, about 150% R-axis torque is set as the drive torque (start of step 2 (second step)).

(38) Further, since the screw moves downward due to full driving of the screw, the control part **31** rotates the elevation axis servomotor **20** in synchronization with the amount of movement, thereby moving the driver bit **40** downward along the Z axis. As shown in FIG. **4**, the R-axis torque (Tr) of the rotation axis servomotor **10** reaches the drive torque (end of step 2).

(39) Next, when the control part **31** detects that the R-axis torque (Tr) of the rotation axis servomotor **10** has reached the drive torque, the torque command to the servo driver **12** is maintained at the drive torque, so that the drive torque of the screw is maintained as it is, and driving is performed. As shown in FIG. **4**, the drive torque is maintained for a predetermined period of time. During this predetermined period of time, the screw will stop rotating and no further driving will occur (end of step 3).

(40) Further, since the screw moves downward due to driving of the screw, the control part **31** rotates the elevation axis servomotor **20** in synchronization with the amount of movement, thereby moving the driver bit **40** downward along the Z axis.

(41) Next, the control part **31** transmits a command to decrease the R-axis torque (Tr) to the servo driver **12** (start of step 4). Further, the control part **31** sets the rotation angle of the rotation axis of the rotation axis servomotor **10** at the start of step 4 as the first rotation angle. Then, the control part **31** transmits a command to the servo driver **12** so that the R-axis torque (Tr) of the rotation axis servomotor **10** is reduced to zero. At this time, as the R-axis torque is released, the screw is slightly rotated in the direction opposite to the driving direction. The rotation angle of the rotation axis of the rotation axis servomotor **10** at this time is set as the second rotation angle (end of step 4).

(42) Finally, the control part **31** transmits commands of the rotation angle, rotation speed, and torque of the elevation axis servomotor **20** to the servo driver **22**. The servo driver **22** generates a

drive waveform according to the commands from the control part **31** and supplies it to the elevation axis servomotor **20** (start of step 5). At this time, the driver bit **40** rises along the Z axis at a predetermined moving speed (Vz).

(43) Further, the control part **31** transmits commands of the rotation angle, rotation speed, and torque of the rotation axis servomotor **10** to the servo driver **12**. The servo driver **12** generates a drive waveform according to the commands from the control part **31** and supplies it to the rotation axis servomotor **10**. At this time, the driver bit **40** rotates around the R axis at a predetermined rotation speed (Vr). The control part **31** ends the process when the rotation angle (R-axis position (r)) of the rotation axis of the rotation axis servomotor **10** and the Z-axis position (z) of the driver bit **40** return to the origin position (end of step 5).

(44) FIG. **5** is a diagram schematically showing an axial force generated by screw driving. The male screw **41** is driven to a fastener (female screw) **44** so that an object to be fastened **43** is sandwiched between bearing surfaces **42**. At this time, the bearing surface **42** of the male screw **41** generates an axial force F having the same magnitude as the force for driving the object to be fastened **43**. That is, the axial force F increases as the driving force by the male screw **41** increases.

(45) As described with reference to FIG. **3**, with the rotation angle of the rotation axis of the rotation axis servomotor **10** when the driving of the screw is completed in step 3 being defined as the first rotation angle, and the rotation angle when the screw is released from driving in step 4 being defined as the second rotation angle, the rotation angle of the screw returns by (first rotation angle—second rotation angle). This return of the rotation angle of the screw (the rotation axis of the rotation axis servomotor **10**) is called a change in the rotation position.

(46) When the axial force F is small, the surface pressure (screw contact surface pressure) of the bearing surface **42** becomes small, and the rotational resistance becomes small. As a result, the change in the rotation position of the screw (the rotation axis of the rotation axis servomotor **10**) increases.

(47) Further, when the axial force F is large, the surface pressure (screw contact surface pressure) of the bearing surface **42** increases, and the rotational resistance increases. As a result, the change in the rotation position of the screw (the rotation axis of the rotation axis servomotor **10**) decreases. The control part **31** estimates the axial force F according to this change in the rotation position.

(48) FIG. **6** is a graph showing the relationship between a change in the rotation position and the axial force F of the screw in a normal condition. As described with reference to FIGS. **3** and **4**, the drive torque of the screw is maintained for a predetermined period of time (step 3), and when the drive torque is released (step 4), a change in the rotation position occurs. In FIG. **6**, the change in the rotation position occurs by 3.8°. At this time, the axial force F becomes approximately 100 kgf.

(49) In FIGS. **6** to **9**, since the axial force of the screw cannot be measured in a normal process, the screw is driven with a load cell sandwiched between the object to be fastened **43** and the fastener **44**, and the axial force of the screw is experimentally measured.

(50) FIG. **7** is a graph showing the relationship between a change in the rotation position and the axial force F of the screw when bottom hitting. Bottom hitting is a state in which the tip of the male screw **41** is in contact with the bottom of the female screw **44**, and normal screw driving cannot be performed. When bottom hitting occurs, the tip of the male screw **41** or the bottom of the female screw **44** is crushed during full driving, and normal screw driving cannot be performed. As a result, compared with normal screw driving, the axial force F decreases, and the amount of change in the rotation position of the screw is increased.

(51) In FIG. **7**, the amount of change in the rotation position occurs by 5.0°. At this time, the axial force F becomes approximately 10 kgf. Thus, it may be seen that there is a correlation between the amount of change in the rotation position of the screw and the axial force F.

(52) As described above, according to the screw driving device according to this embodiment, when the axial force F is small, the surface pressure of the bearing surface **42** is small, and the rotational resistance is small. As a result, the change in the rotation position of the screw increases.

Moreover, when the axial force F is large, the surface pressure of the bearing surface **42** becomes large, and the rotational resistance becomes large. As a result, the change in the rotation position of the screw decreases. The control part **31** may estimate the axial force F according to this change in the rotation position.

Second Embodiment

(53) In the first embodiment, the axial force of the screw was estimated only by the R-axis position range, but it was further examined whether there is a variable that may improve the accuracy of axial force estimation. The disclosure proposes the following equation as a model for estimating the axial force F as a result of experiments. Here, y is the estimated axial force; x_1 is the standard deviation of the Z-axis torque in step 1; x_2 is the average R-axis speed in step 2; x_3 is the amount of change in the R-axis position in step 4 (maximum value of R-axis position-minimum value of R-axis position (R-axis position range)). Further, a, b, c, and d are constants obtained by experiments.

$$y=ax_1+bx_2+cx_3+d \qquad (1)$$

(54) In step 1, if the screw is not properly seated and it spins idle, a constant torque is generated for a long time without the R-axis torque reaching the threshold torque. At this time, the standard deviation x_1 of the Z-axis torque decreases. From this, the variable x_1 may be used to determine whether the temporary seating of the screw is successful (whether an axial force is generated).

(55) In step 2, when it takes a long time for the R-axis torque to reach the target value due to improper screw driving, or when it does not reach the target value, the R-axis speed remains almost 0 for a long time, and the average R-axis speed x_2 becomes smaller. From this, the variable x_2 may be used to determine whether full driving of the screw is normally performed (whether the axial force is generated).

(56) In step 4, when the R-axis torque is released, a rotation force is generated in the direction of loosening the screw. The amount of reverse rotation of the screw changes depending on the driven state of the screw, and the more tightly it is driven, the smaller the amount of rotation. That is, the R-axis position range x_3 becomes smaller. From this, the variable x_3 may be used to determine whether it is tightly driven after full driving (whether the axial force is generated). Variables that have a high correlation with (being replaceable with) this variable x_3 include, for example, the R-axis speed range in step 4.

(57) FIG. **8** is a graph showing an actually measured axial force of a screw and a predicted axial force value calculated using Equation (1). In this graph, the horizontal axis is the sample number, and the vertical axis is the axial force (kgf). Sample numbers up to about 300 are samples in which screws were driven in a normal state, and sample numbers after that are samples in which screws were driven in a not-normal (abnormal) state. Measured axial force values are indicated by dots, and predicted axial force values are indicated by solid lines. The measured axial force values are shown in dots of different shapes for Normal and Abnormal 1 to 6, respectively.

(58) The sample of Abnormal 1 is a sample of screw defective thread. Abnormal 2 to 5 are samples in which bottom hitting occurred, and are classified into four samples according to the level of bottom hitting. Abnormal 2 is the sample with the lightest degree of bottom hitting. Abnormal 5 is the sample with the highest degree of bottom hitting. Abnormal 3 and Abnormal 4 are intermediate samples. The sample of Abnormal 6 is a sample in which a foreign matter is caught between the bearing surface **42** of the male screw **41** and the object to be fastened **43**.

(59) As shown in FIG. **8**, in Normal and Abnormal 1 to 5, the actually measured axial force of the screw and the predicted axial force value generally match. However, in Abnormal 6 (foreign matter caught), the difference between the actually measured axial force and the predicted axial force value of the screw is large, indicating that the prediction accuracy is not so good. Samples in which a foreign matter is caught are detected and removed by another method, and if the above axial force estimation is used only for the samples of Normal and Abnormal 1 to 5, the axial force may be

estimated with higher accuracy.

(60) FIG. **9** is a graph plotting the predicted axial force value versus the measured value of each sample shown in FIG. **8**. In this graph, the horizontal axis is the predicted axial force value (kgf) and the vertical axis is the measured axial force value (kgf), and each point of the sample corresponds to each point of the sample shown in FIG. **8**. In FIG. **9**, the sample of Abnormal 6 (foreign object caught) shown in FIG. **8** is excluded.

(61) As shown in FIG. **9**, it may be seen that the predicted axial force value and the measured axial force value approximately match each of the samples of Normal and Abnormal 1 to 5. In addition, it becomes possible to roughly determine which of the states of the Normal and Abnormal 1 to 5 the samples are in based on the predicted axial force value.

(62) As described above, since the control part **31** estimates the axial force of the screw using Equation (1), it is possible to estimate the axial force of the screw more accurately than estimating the axial force of the screw based only on the change in the rotation position of the screw.

Third Embodiment

(63) Variables that have a high correlation with (being replaceable with) this variable x_1 include, for example, the average Z-axis position in step 1 (correlation coefficient with variable x_1: 0.97), time in step 1 (correlation coefficient with variable x_1: 0.99), the average R-axis position in step 1 (correlation coefficient with variable x_1: 0.99), the R-axis position standard deviation (correlation coefficient with variable x_1: 0.99), the R-axis speed average (correlation coefficient with variable x_1: 0.97), the R-axis speed average (correlation coefficient with variable x_1: −0.96), and the like. It may be expected that the estimation accuracy may be further improved by using any of these variables in place of x_1 or in combination with x_1.

Fourth Embodiment

(64) Variables that have a high correlation with (being replaceable with) this variable x_2 include, for example, the time in step 2 (correlation coefficient with variable x_2: −0.77), the R-axis position standard deviation in step 2 (correlation coefficient with variable x_2: −0.75), the R-axis speed standard deviation (correlation coefficient with variable x_2: 0.94), the R-axis torque average (correlation coefficient with variable x_2: 0.84), the Z-axis position range (maximum value of Z-axis position−minimum value of Z-axis position) (correlation coefficient with variable x_2: −0.74), and the like. It may be expected that the estimation accuracy may be further improved by using any of these variables in place of x_2 or in combination with x_2.

Fifth Embodiment

(65) FIG. **10** is a graph plotting the Z-axis position range in step 2 versus the R-axis position range in step 4 for each of the samples of Normal and Abnormal 2 to 5 shown in FIG. **8** where bottom hitting occurs. FIG. **10** shows that with the ability to estimate the axial force of the screw by using the R-axis position range as described above, the determination accuracy is good when quality determination is made by two-dimensional plotting using the R-axis position range and other variables.

(66) In this graph, the horizontal axis is the Z-axis position range (mm) in step 2, and the vertical axis is the R-axis position range (°) in step 4. The points of each sample correspond to the points each sample of Normal and Abnormal 2 to 5 shown in FIG. **8** where bottom hitting occurred.

(67) A score is calculated by applying isolation forest, which is a technique of machine learning, to the Z-axis position range in step 2 and the R-axis position range in step 4 of each sample. In FIG. **10**, the contour lines indicate the scores, and it may be seen that the samples in the normal state concentrate on scores of 0.55 or less. In this way, it is possible to determine that a sample with a score less than or equal to a predetermined value indicates that driving has been performed normally.

(68) As described above, the control part **31** applies the isolation forest to the Z-axis position range in step 2 and the R-axis position range in step 4 of each sample to estimate the axial force of the

screw; therefore, it becomes possible to easily determine the quality of the driving of the screw based on the numerical value.

§ 4 Modified Example

(69) The control block (especially the control part **31**) of the screw driving device **1** may be implemented by a logic circuit (hardware) formed in an integrated circuit (IC chip) or the like, or may be implemented by software.

(70) In the latter case, the screw driving device **1** includes a computer that executes program instructions, which are software for realizing each function. This computer includes, for example, one or more processors, and a computer-readable recording medium storing the program. In the computer, the processor reads the program from the recording medium and executes it, thereby achieving embodiments of the disclosure. As the processor, for example, a central processing unit (CPU) may be used. As the recording medium, a "non-transient tangible medium" such as a read only memory (ROM), a tape, a disk, a card, a semiconductor memory, a programmable logic circuit, or the like may be used. Further, a random access memory (RAM) for developing the above program may be further provided. Further, the program may be supplied to the computer via any transmission medium (communication network, broadcast wave, and the like) capable of transmitting the program. In addition, one embodiment of the disclosure may also be implemented in the form of a data signal embedded in a carrier wave in which the program is embodied by electronic transmission.

SUMMARY

(71) The disclosure adopts the following configurations in view of the above-described problems. A screw driving device according to an embodiment of the disclosure includes: a rotary tool for rotating a screw; a first motor that drives the rotary tool to rotate; and a control part that controls the first motor. The control part: applies a predetermined torque generated by the first motor to the screw in a rotation direction where the screw is driven, then performs a step of releasing the torque, and estimates an axial force of the driven screw based on a change of a rotation position of the first motor in the step of releasing the torque.

(72) According to the above configuration, since the axial force of the driven screw is estimated based on the change in the rotation position of the first motor, there is no need to measure the actual axial force of the screw, making it easy to determine the quality of the driving of the screw.

(73) The above screw driving device according to an embodiment of the disclosure further includes a second motor controlled by the control part for moving the rotary tool in an axial direction. The control part performs: a first step of screwing the screw into a screw hole, in which the first motor is set at a predetermined rotation speed and the rotary tool is moved by the second motor until the torque generated by the first motor reaches a threshold torque; and a second step of increasing the torque generated by the first motor until the torque reaches the predetermined torque for full driving of the screw.

(74) According to the above configuration, the screw may be properly seated by the first step. In addition, the second step enables proper full driving of the screw.

(75) In the above screw driving device according to an embodiment of the disclosure, the control part estimates the axial force by reflecting variations in a torque of the second motor in the first step.

(76) According to the above configuration, it is possible to estimate the axial force in consideration of whether the screw is successfully seated. Therefore, it is possible to estimate the axial force more accurately than estimating the axial force only from the change in the rotation position of the first motor.

(77) In the above screw driving device according to an embodiment of the disclosure, the control part estimates the axial force by reflecting any one of an average position of the rotary tool by the second motor, a time of the first step, an average rotation position of the first motor, a standard deviation of a rotation position of the first motor, an average rotation speed of the first motor and a

standard deviation of a rotation speed of the first motor in the first step.

(78) According to the above configuration, the axial force of the screw may be estimated using any one of the variables. Therefore, the axial force of the screw may be estimated using a variable that may be obtained more easily than the variation in the torque of the second motor.

(79) In the above screw driving device according to an embodiment of the disclosure, the control part estimates the axial force by reflecting an average value of the rotation speed of the first motor in the second step.

(80) According to the above configuration, it is possible to estimate the axial force in consideration of whether the full driving of the screw is normally performed. Therefore, it is possible to estimate the axial force more accurately than estimating the axial force only from the change in the rotation position of the first motor.

(81) In the above screw driving device according to an embodiment of the disclosure, the control part estimates the axial force by reflecting any one of a time of the second step, a standard deviation of a rotation position of the first motor in the second step, a standard deviation of a rotation speed of the first motor, an average of the torque of the first motor, and a range of positions of the rotary tool by the second motor.

(82) According to the above configuration, the axial force of the screw may be estimated using any one of the variables. Therefore, the axial force of the screw may be estimated using a variable that may be obtained more easily than the average value of the rotation speed of the first motor.

(83) In the above screw driving device according to an embodiment of the disclosure, the control part determines a quality of driving of the screw based on a change in a position of the rotary tool caused by the second motor in the second step and the estimated axial force.

(84) According to the above configuration, it is possible to determine the quality of the driving of the screw in multiple ways.

(85) In the above screw driving device according to an embodiment of the disclosure, the control part determines the quality of the driving of the screw based on a score obtained by applying an isolation forest to the change in the position of the rotary tool caused by the second motor in the second step and the estimated axial force.

(86) According to the above configuration, since the isolation forest is applied to determine the quality of the driving of the screw, it is possible to objectively determine the quality of the driving of the screw based on numerical values.

(87) In the above screw driving device according to an embodiment of the disclosure, the control part performs a step of maintaining the predetermined torque for a predetermined period of time just prior to the step of releasing the torque.

(88) According to the above configuration, the screw may be driven by maintaining the predetermined torque for the predetermined period of time.

(89) The disclosure is not limited to the above-described embodiments, various modifications may be made possible within the scope of the claims, and embodiments obtained by appropriately combining technical methods disclosed in different embodiments are also included in the technical scope of the disclosure. In each embodiment, step 3 is not necessarily required and may be omitted.

Claims

1. A screw driving device comprising: driver bit, configured to rotate a screw; a first motor, configured to drive the driver bit to rotate; and controller, configured to control the first motor, wherein the controller is configured to: apply a predetermined torque generated by the first motor to the screw in a rotation direction where the screw is driven, then perform a step of releasing the torque, wherein at a start of the step of releasing the torque, the controller is configured to acquire a first rotation angle of a rotation axis of the first motor, and at an end of the step of releasing the torque, the controller is configured to acquire a second rotation angle of the rotation axis of the first

motor; and determine an axial force of the driven screw based on a change of a rotation position of the first motor in the step of releasing the torque, wherein the axial force is along a direction of the rotation axis.

2. The screw driving device according to claim 1, further comprising a second motor controlled by the controller for moving the driver bit in an axial direction, wherein the controller performs: a first step of screwing the screw into a screw hole, wherein the first motor is set at a predetermined rotation speed and the driver bit is moved by the second motor until the torque generated by the first motor reaches a threshold torque; and a second step of increasing the torque generated by the first motor until the torque reaches the predetermined torque for full driving of the screw.

3. The screw driving device according to claim 2, wherein the controller is configured to determine the axial force by reflecting variations in a torque of the second motor in the first step.

4. The screw driving device according to claim 3, wherein the controller is configured to determine the axial force by reflecting an average value of the rotation speed of the first motor in the second step.

5. The screw driving device according to claim 4, wherein the controller is configured to determine a state of driving of the screw is a normal state or an abnormal state based on a change in a position of the driver bit caused by the second motor in the second step and the determined axial force.

6. The screw driving device according to claim 3, wherein the controller is configured to determine the axial force by reflecting any one of a time of the second step, a standard deviation of a rotation position of the first motor in the second step, a standard deviation of a rotation speed of the first motor, an average of the torque of the first motor, and a range of positions of the driver bit by the second motor.

7. The screw driving device according to claim 6, wherein the controller is configured to determine a state of driving of the screw is a normal state or an abnormal state based on a change in a position of the driver bit caused by the second motor in the second step and the determined axial force.

8. The screw driving device according to claim 3, wherein the controller is configured to determine a state of driving of the screw is a normal state or an abnormal state based on a change in a position of the driver bit caused by the second motor in the second step and the determined axial force.

9. The screw driving device according to claim 2, wherein the controller is configured to determine the axial force by reflecting any one of an average position of the driver bit by the second motor, a time of the first step, an average rotation position of the first motor, a standard deviation of a rotation position of the first motor, an average rotation speed of the first motor and a standard deviation of a rotation speed of the first motor in the first step.

10. The screw driving device according to claim 9, wherein the controller is configured to determine the axial force by reflecting an average value of the rotation speed of the first motor in the second step.

11. The screw driving device according to claim 10, wherein the controller is configured to determine a state of driving of the screw is a normal state or an abnormal state based on a change in a position of the driver bit caused by the second motor in the second step and the determined axial force.

12. The screw driving device according to claim 9, wherein the controller is configured to determine the axial force by reflecting any one of a time of the second step, a standard deviation of a rotation position of the first motor in the second step, a standard deviation of a rotation speed of the first motor, an average of the torque of the first motor, and a range of positions of the driver bit by the second motor.

13. The screw driving device according to claim 9, wherein the controller is configured to determine a state of driving of the screw is a normal state or an abnormal state based on a change in a position of the driver bit caused by the second motor in the second step and the determined axial force.

14. The screw driving device according to claim 2, wherein the controller is configured to

determine the axial force by reflecting an average value of the rotation speed of the first motor in the second step.

15. The screw driving device according to claim 14, wherein the controller is configured to determine a state of driving of the screw is a normal state or an abnormal state based on a change in a position of the driver bit caused by the second motor in the second step and the determined axial force.

16. The screw driving device according to claim 2, wherein the controller is configured to determine the axial force by reflecting any one of a time of the second step, a standard deviation of a rotation position of the first motor in the second step, a standard deviation of a rotation speed of the first motor, an average of the torque of the first motor, and a range of positions of the driver bit by the second motor.

17. The screw driving device according to claim 16, wherein the controller is configured to determine a state of driving of the screw is a normal state or an abnormal state based on a change in a position of the driver bit caused by the second motor in the second step and the determined axial force.

18. The screw driving device according to claim 2, wherein the controller is configured to determine a state of driving of the screw is a normal state or an abnormal state based on a change in a position of the driver bit caused by the second motor in the second step and the estimated determined axial force.

19. The screw driving device according to claim 18, wherein the controller is configured to determine a state of the driving of the screw based on a score obtained by applying an isolation forest to the change in the position of the driver bit caused by the second motor in the second step and the determined axial force.

20. The screw driving device according to claim 1, wherein the controller performs a step of maintaining the predetermined torque for a predetermined period of time just prior to the step of releasing the torque.