

SEGMENT ASSEMBLY ASSISTING DEVICE AND SEGMENT ASSEMBLY ASSISTING METHOD

BACKGROUND OF THE INVENTION

5 FIELD OF THE INVENTION

[0001]

The present invention relates to segment assembly assisting devices for use in shield tunneling, and to a segment assembly assisting method for use in shield tunneling.

10 DESCRIPTION OF RELATED ART

[0002]

Shield tunnels used as pipelines for water supply and drainage, underground utility tunnels, roads, railways, etc., have been constructed using the shield tunneling method. In the shield tunneling method, a shield machine is used. Such a shield machine includes, for example, a tubular skin plate serving as an outer shell of a body of the shield machine, a cutter head for excavating the ground provided at a front end portion (tunnel face side end) of the skin plate, and propelling jacks provided inside the skin plate.

[0003]

In the shield tunneling method, for example, a launch shaft and a retrieval shaft are constructed in the ground, and then, the shield machine excavates the ground from the launch shaft to the retrieval shaft. Simultaneously, inside the rear portion (tail portion) of the skin plate, an erector device assembles segments (segment pieces) one after another in the tunnel circumferential direction to build segment rings, and adjacent segment rings are joined in the tunnel axial direction to form a tubular lining body. In this tunneling method, the shield machine pushes the built segment rings rearward with the propelling jacks, and uses the

reaction force generated thereby, as propelling power, to advance and excavate the ground.

[0004]

In this regard, a method for monitoring, for example, the roundness of a segment ring built by the shield tunneling method is disclosed in JP 2015-030994 A.

5 [0005]

However, the technique disclosed in JP 2015-030994 A monitors the shape of the built segment ring *ex post facto*. Thus, the assembly precision of the segments can be confirmed only after the segment ring is built.

[0006]

10 In view of such circumstances, an object of the present invention is to enable confirmation of assembly precision of segments even during building of a segment ring.

SUMMARY OF THE INVENTION

[0007]

15 Therefore, a device for assisting assembly of a segment (referred to as “segment assembly assisting device”) according to the present invention is for use in shield tunneling. The segment assembly assisting device according to the present invention includes a ring shape prediction unit configured to predict a shape of a new segment ring including a segment that is held by a holding unit of an erector device of a shield machine, based on a state of the
20 segment.

[0008]

A segment assembly assisting method according to the present invention is a method for assisting assembly of a segment during shield tunneling. The segment assembly assisting method according to the present invention includes the step of predicting a shape of a new
25 segment ring including a segment that is held by a holding unit of an erector device of a shield

machine, based on a state of the segment.

[0009]

According to the present invention, the shape of the new segment ring including the segment that is held by the holding unit of the erector device of the shield machine is
5 predicted based on the state of the segment. Therefore, even during building of the new segment ring, it is possible to confirm the assembly precision of a segment.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010]

10 FIG. 1 is a schematic configuration view of a shield machine according to an embodiment of the present invention.

FIG. 2 is a cross-sectional view taken along line A-A of FIG. 1.

FIG. 3 is a cross-sectional view taken along line B-B of FIG. 2.

FIG. 4 is a diagram showing sensing target areas of first distance sensors and
15 imaging target areas of imaging devices.

FIG. 5 is a diagram showing a schematic configuration of a second distance sensor.

FIG. 6 is a diagram showing a schematic configuration of a segment assembly assisting device.

FIG. 7 is a table showing an example of measurement results of the opening amount
20 and the misalignment amount.

FIG. 8 is a view showing an existing segment ring.

FIG. 9 is a view relating to FIG. 8 and showing a shape of the existing segment ring displayed on a screen.

FIG. 10 is a view showing the completed assembly of a third segment of a new
25 segment ring.

FIG. 11 is a view relating to FIG. 10 and showing a shape of the existing segment ring and a first predicted shape of the new segment ring, displayed on the screen.

FIG. 12 is a view showing an assembling state of a fourth segment of the new segment ring.

5 FIG. 13 is a view relating to FIG. 12 and showing the shape of the existing segment ring, the first predicted shape of the new segment ring, and a second predicted shape of the new segment ring, displayed on the screen.

FIG. 14 is a view showing the completed assembly of the fourth segment of the new segment ring.

10 FIG. 15 is a view relating to FIG. 14 and showing the shape of the existing segment ring, the first predicted shape of the new segment ring, and the second predicted shape of the new segment ring, displayed on the screen.

FIG. 16 is a view for explaining an example of a creating process of the first predicted shape of the new segment ring.

15 FIG. 17 is a view for explaining an example of a creating process of the second predicted shape of the new segment ring.

FIG. 18 is a view showing a modified example of a screen display.

DESCRIPTION OF PREFERRED EMBODIMENT

20 [0011]

Hereinbelow, an embodiment of the present invention will be described with reference to the accompanying drawings.

[0012]

FIG. 1 shows a schematic configuration of a shield machine according to an
25 embodiment of the present invention. FIG. 2 is a cross-sectional view taken along line A-A

of FIG. 1. FIG. 3 is a cross-sectional view taken along line B-B of FIG. 2. Here, a rotary ring 4 shown in FIGS. 1 and 3 is not shown in FIG. 2. A frame 10 and second distance sensors 16a and 16b, shown in FIGS. 1 and 2, are also not shown in FIG. 3. In this embodiment, front, rear, left, and right are defined with respect to the tunnel excavation direction, which is defined as the advancing direction, for convenience of description.

[0013]

In the present embodiment, the configuration of a shield machine will be described by taking a so-called earth pressure balanced shield machine, as an example. However, the shield machine is not limited to this type, and for example, a slurry shield machine may be used.

[0014]

A shield machine 1 for use in tunnel construction includes a tubular (for example, cylindrical) skin plate 2 that functions as its body. The shield machine 1 advances while excavating the ground with a cutter head (not shown) provided on a front surface of the skin plate 2, and then, takes in excavated materials, such as soil and sand, and transports them to the rear.

[0015]

Inside the skin plate 2 of the shield machine 1, multiple propelling jacks (not shown) are arranged along the inner surface of the skin plate 2 at intervals in the circumferential direction. Each propelling jack is a hydraulic jack composed of a cylinder (not shown) and a rod (not shown). The cylinder has one end secured to the skin plate 2, and the other end configured so that the rod moves in and out the cylinder. By making the propelling jacks extend while having the tip of the rod of every propelling jack contact a segment (segment piece) SP which had already been installed (hereinafter, referred to as “existing segment”), the shield machine 1 obtains propelling power. In this way, the propelling jacks use the reaction

force generated on the existing segments SP to propel the shield machine 1.

[0016]

The shield machine 1 includes an erector device 3 in a rear portion (tail portion) 2a of the skin plate 2. The erector device 3 includes a rotary ring 4, a pair of elevating jacks 5, 5, a U-shaped arm 6, a pair of axial jacks 7, 7, and a holding unit 8.

[0017]

The rotary ring 4 is rotatably supported in the rear portion 2a of the skin plate 2, and is configured to be driven by a rotation driving motor (not shown) to rotate around an axis (central axis) MC of the shield machine 1. To the rotary ring 4, the elevating jacks 5, 5 are attached on both sides across the axis MC. For example, the elevating jacks 5, 5 may be hydraulic jacks.

[0018]

To an end of each of the pair of elevating jacks 5, 5 (i.e., lower end in the state shown in FIGS. 1 to 3), a corresponding end portion of the U-shaped arm 6 (upper end in the state shown in FIGS. 1 to 3) is connected. To an intermediate portion (fold-back portion) 6a of the U-shaped arm 6, a front end portion of each of the pair of axial jacks 7, 7 is attached. To rear end portions of the pair of axial jacks 7, 7, the holding unit 8 is attached. For example, the axial jacks 7, 7 may be hydraulic jacks. The holding unit 8 is configured to be able to pick up and hold a segment SP having a curved cross section (for example, an arc-shaped cross section).

[0019]

Thus, the erector device 3 is configured so that, by rotating the rotary ring 4 while having the segment SP held by the holding unit 8, it is possible to move the segment SP in the tunnel circumferential direction while having the segment SP held by the holding unit 8.

[0020]

The erector device 3 is also configured so that, by extending and contracting the pair of elevating jacks 5, 5 while having the segment SP held by the holding unit 8, it is possible to move the segment SP in the inner and outer direction of the tunnel (e.g., tunnel radial direction) with respect to the rotary ring 4 while having the segment SP held by the holding unit 8.

[0021]

The erector device 3 is also configured so that, by extending and contracting the pair of axial jacks 7, 7 while having the segment SP held by the holding unit 8, it is possible to move the segment SP in the tunnel axial direction (axial direction of the shielding machine 1) with respect to the arm 6, while having the segment SP held by the holding unit 8.

[0022]

Therefore, it is possible for the erector device 3 to appropriately move the segment SP in the axial direction, the inner and outer direction, and the circumferential direction of the tunnel, while having the segment SP held by the holding unit 8. The erector device 3 assembles segments SP in the circumferential direction inside the rear portion 2a of the skin plate 2, to build a tubular (e.g., cylindrical) segment ring SR. To assemble segments SP, first, a segment SP is roughly moved toward an assembly target position by being moved in the axial direction and the circumferential direction of the tunnel, and then, in the inner and outer direction of the tunnel (first stage of the assembling process). Then, the segment SP brought into the position this time and an existing segment SP which had already been installed are joined (including fine adjustment of the relative position) (second stage of the assembling process). Here, for example, when a coupling for joining adjacent two segments SP together is composed of a metal male fastener and a metal female fastener, which are fitted together to join the segments SP, the abovementioned movement in the first stage of the assembling process is performed until the metal male fastener of one segment SP comes into a

position adjacent to the metal female fastener of the other segment SP.

[0023]

The holding unit 8 is provided with a frame body 9 arranged so as to project from the holding unit 8 to the rear in the tunnel axial direction, and in the tunnel circumferential

direction. To the frame body 9, multiple (seven in this embodiment) first distance sensors P1 to P7, and multiple (five in this embodiment) imaging devices Q1 to Q5 are attached. That is, the multiple first distance sensors P1 to P7 and the multiple imaging devices Q1 to Q5 are disposed on the holding unit 8 of the erector device 3 via the frame body 9. Although seven first distance sensors P1 to P7 and five imaging devices Q1 to Q5 are attached to the frame body 9 in this embodiment as an example, the number of the first distance sensors and the imaging devices attached to the frame body 9 is not limited thereto.

[0024]

In the present embodiment, the first distance sensor P1 and the imaging device Q1 are integrally formed, the first distance sensor P3 and the imaging device Q2 are integrally formed, the first distance sensor P4 and the imaging device Q3 are integrally formed, the first distance sensor P5 and the imaging device Q4 are integrally formed, and the first distance sensor P7 and the imaging device Q5 are integrally formed. For the first distance sensors P1 to P7 and the imaging devices Q1 to Q5, the high-speed 2D/3D laser profiler (LJ-V7000 series), manufactured by KEYENCE Corporation, may be used, for example.

[0025]

FIG. 4 shows linear or band-shaped sensing target areas LP1 to LP7 of the first distance sensors P1 to P7, and rectangular imaging target areas IQ1 to IQ5 of the imaging devices Q1 to Q5. Here, a segment SPE shown in FIG. 4 indicates a segment SP that is held by the holding unit 8 of the erector device 3 among the abovementioned segments SP.

[0026]

Each of the first distance sensors P1 to P7 faces the edge (periphery of the inner surface) of the segment SPE at a distance. Furthermore, the first distance sensors P1 to P7 are disposed at intervals along the edge (periphery of the inner surface) of the segment SPE.
[0027]

5 Each of the first distance sensors P1 to P7 is provided with an irradiation unit and a light receiving unit (not shown). Each of the first distance sensors P1 to P7 emits a line laser beam from the irradiation unit toward the corresponding sensing target area LP1 to LP7. The light receiving unit of each of first distance sensors P1 to P7 receives reflected light of the line laser beam. When the abovementioned profiler is employed as each of the first
10 distance sensors P1 to P7, cross-sectional shapes in the sensing target areas LP1 to LP7 are obtained instantaneously from reflected light received by the light receiving units of the first distance sensors P1 to P7. The resultant data of the cross-sectional shapes is used to measure dimensions, such as an opening amount and a misalignment amount between adjacent segments SP in the sensing target areas LP1 to LP7. Here, the line laser beam is a
15 laser beam that is emitted in a line shape having a constant line width and forms a fan-shaped two-dimensional plane optical path.
[0028]

As used herein, the “opening amount” refers to a gap (distance) between adjacent segments SP in the tunnel axial direction or the circumferential direction. In the present
20 embodiment, the first distance sensors P1 to P7 are configured to measure the opening amount between the segment SPE and the existing segment SP adjacent to the segment SPE.
[0029]

As used herein, the “misalignment amount” refers to unevenness (amount of deviation of location in the tunnel inner and outer direction, in other words, in the thickness
25 direction of segment SP) between adjacent segments SP in the tunnel axial direction or the

circumferential direction. In the present embodiment, the first distance sensors P1 to P7 are configured to measure the misalignment amount between the segment SPE and the existing segment SP adjacent to the segment SPE.

[0030]

5 Here, each of the sensing target areas LP1 to LP7 is set to straddle both an edge (periphery of the inner surface) of the segment SPE and an edge (periphery of the inner surface) of the existing segment SP adjacent to the segment SPE. Thus, each of the sensing target areas LP1 to LP7 includes an edge of the segment SPE and an edge of the existing segment SP adjacent to the segment SPE. In the present embodiment, the extent of the
10 sensing target areas LP1 to LP7 are set in advance in a manner such that each of the sensing target areas LP1 to LP7 straddles both an edge (periphery of the inner surface) of the segment SPE and an edge (periphery of the inner surface) of the existing segment SP adjacent to the segment SPE from, for example, the final phase of the first stage to the second stage of the assembling process.

15 [0031]

In the present embodiment, each of the sensing target areas LP1, LP2 covers a part of an edge $\alpha 1$ on one side of the segment SPE in the tunnel circumferential direction. Each of the sensing target areas LP3 to LP5 covers a part of an edge $\alpha 2$ on the rear side (tunnel portal side) of the segment SPE in the tunnel axial direction. Each of the sensing target areas LP6,
20 LP7 covers a part of an edge $\alpha 3$ on the other side of the segment SPE in the tunnel circumferential direction.

[0032]

Here, each of the first distance sensors P1 to P7 is configured to calculate a distance from the first distance sensor P1 to P7 to a sensing target based on time required for the
25 emitted laser beam to travel to the sensing target and back, and the light velocity. That is, in

the present embodiment, the first distance sensors P1 to P7 emit laser beams toward the sensing target to measure distances to the sensing target.

[0033]

Each of the imaging devices Q1 to Q5 faces the edge (periphery of the inner surface) of the segment SPE at a distance. Furthermore, the imaging devices Q1 to Q5 are disposed at intervals along the edge (periphery of the inner surface) of the segment SPE. For example, the imaging devices Q1 to Q5 may be CCD cameras or CMOS cameras.

[0034]

The imaging target area IQ1, which is an area to be imaged by the imaging device Q1, includes the sensing target area LP1 of the first distance sensor P1. The imaging target area IQ2, which is an area to be imaged by the imaging device Q2, includes the sensing target areas LP2, LP3 of the first distance sensors P2, P3. The imaging target area IQ3, which is an area to be imaged by the imaging device Q3, includes the sensing target area LP4 of the first distance sensor P4. The imaging target area IQ4, which is an area to be imaged by the imaging device Q4, includes the sensing target areas LP5, LP6 of the first distance sensors P5, P6. The imaging target area IQ5, which is an area to be imaged by the imaging device Q5, includes the sensing target area LP7 of the first distance sensor P7.

[0035]

Here, each of the imaging target areas IQ1 to IQ5 is set to straddle both an edge (periphery of the inner surface) of the segment SPE and an edge (periphery of the inner surface) of the existing segment SP adjacent to the segment SPE. Thus, each of the imaging target areas IQ1 to IQ5 includes an edge of the segment SPE and an edge of the existing segment SP adjacent to the segment SPE. In the present embodiment, the extent of the imaging target areas IQ1 to IQ5 are set in advance in a manner such that each of the imaging target areas IQ1 to IQ5 straddles both an edge (periphery of the inner surface) of the segment

SPE and an edge (periphery of the inner surface) of the existing segment SP adjacent to the segment SPE from, for example, the final phase of the first stage to the second stage of the assembling process.

[0036]

5 In the present embodiment, the imaging target area IQ1 covers a part of the edge $\alpha 1$ on one side of the segment SPE in the tunnel circumferential direction and a part of an edge $\alpha 4$ on the front side (tunnel face side) of the segment SPE in the tunnel axial direction. The imaging target area IQ2 covers a part of the edge $\alpha 1$ on one side of the segment SPE in the tunnel circumferential direction and a part of the edge $\alpha 2$ on the rear side (tunnel portal side) of the segment SPE in the tunnel axial direction. The imaging target area IQ3 covers a part of the edge $\alpha 2$ on the rear side (tunnel portal side) of the segment SPE in the tunnel axial direction. The imaging target area IQ4 covers a part of the edge $\alpha 3$ on the other side of the segment SPE in the tunnel circumferential direction and a part of the edge $\alpha 2$ on the rear side (tunnel portal side) of the segment SPE in the tunnel axial direction. The imaging target area IQ5 covers a part of the edge $\alpha 3$ on the other side of the segment SPE in the tunnel circumferential direction and a part of the edge $\alpha 4$ on the front side (tunnel face side) of the segment SPE in the tunnel axial direction.

[0037]

As shown in FIGS. 1 and 2, the shield machine 1 has a frame 10 at the center thereof.

20 The frame 10 extends rearward along the axis MC from a shield partition wall (not shown) of the shield machine 1. The frame 10 is disposed at a position that does not interfere with, for example, the rotational motion of the erector device 3. The frame 10 includes: an upper frame 11 and a lower frame 12, each having a substantially rectangular shape in a plan view; multiple pillar members 13 that are erect on both left and right sides of the lower frame 12

25 and have their upper ends secured to the upper frame 11; multiple beam members 14, each

having both ends connected to left and right sides of the upper frame 11; and multiple beam members 15, each having both ends connected to left and right sides of the lower frame 12.

[0038]

A second distance sensor 16a is arranged at the center of an upper surface of the frame 10 (e.g., the center in the right and left direction of a beam member 14). A second distance sensor 16b is arranged at the center of a lower surface of the frame 10 (e.g., the center in the right and left direction of a beam member 15).

[0039]

FIG. 5 shows a schematic configuration of the second distance sensor 16a. The second distance sensor 16a includes a body 17 thereof, a reflector 18, and a rotation mechanism 19. The body 17 of the second distance sensor 16a emits a laser beam along the axial direction. The reflector 18 reflects the laser beam from the body 17 by 90°, and directs the reflected light radially outward in the rear portion 2a of the skin plate 2. The body 17 of the second distance sensor 16a is configured to calculate a distance from the second distance sensor 16a to a sensing target based on time required for the reflected light from the reflector 18 to travel to the sensing target and back, and the light velocity.

[0040]

Here, when the reflector 18 is rotated around a laser reflection point 18a by the rotation mechanism 19, the position of the target (sensing target) to be irradiated with the reflected light moves along the circumferential direction of the skin plate 2. That is, the second distance sensor 16a is configured to have a variable irradiation direction of the laser beam. Here, since the second distance sensor 16b has the same configuration as the second distance sensor 16a, description thereof will be omitted.

[0041]

FIG. 2 shows a distance measurable range M1 of the second distance sensor 16a and

a distance measurable range M2 of the second distance sensor 16b. Therefore, by combining the distance measurable ranges M1 and M2 of the two second distance sensors 16a and 16b, it is possible to cover most of the entire circumference of the rear portion 2a of the skin plate 2 as a distance measurable range.

5 [0042]

If the holding unit 8 of the erector device 3 intercepts a laser beam from the reflectors 18 of the second distance sensors 16a, 16b, the holding unit 8 may be moved along the circumferential direction of the skin plate 2 to allow laser beam irradiation to the sensing target.

10 [0043]

FIG. 6 is a diagram showing a schematic configuration of a segment assembly assisting device 20, and is a block diagram showing the relationship between the first distance sensors P1 to P7, the imaging devices Q1 to Q5, the second distance sensors 16a, 16b, a control unit 22, and an output device 23.

15 [0044]

The segment assembly assisting device 20 is for use in shield tunneling. The segment assembly assisting device 20 has a function as a device that senses a state of the segment SPE held by the holding unit 8 of the erector device 3 (e.g., a state of the segment SPE with respect to the existing segment SP).

20 [0045]

The segment assembly assisting device 20 includes the first distance sensors P1 to P7, the imaging devices Q1 to Q5, the second distance sensors 16a, 16b, the control unit 22, and the output device 23. Here, the first distance sensors P1 to P7 achieves functions of a “segment state sensing device” of the present invention. This segment state sensing device
25 is a device that senses a state of the segment SPE. According to the present embodiment, for

example, the segment state sensing device may perform sensing from the first stage to the second stage of the abovementioned assembling process. Here, in the first stage of the abovementioned assembling process, the segment SPE held by the holding unit 8 of the erector device 3 is brought closer to the existing segment SP. Furthermore, according to the present embodiment, the segment state sensing device may perform sensing while the segment SPE held by the holding unit 8 of the erector device 3 is approaching the existing segment SP (that is, during moving).

[0046]

The first distance sensors P1 to P7 are connected to the control unit 22 via a signal line 24. The imaging devices Q1 to Q5 are connected to the control unit 22 via a signal line 25. Although the signal lines 24, 25 are separated from each other in the present embodiment, the signal lines 24 and 25 may be integrated. The second distance sensors 16a, 16b are connected to the control unit 22 via a signal line 26.

[0047]

The control unit 22 and the output device 23 are configured to wirelessly communicate with each other. For example, the output device 23 may be a mobile terminal, such as a tablet terminal. It is preferable that the output device 23 be a device that is easy for an operator to carry. The output device 23 includes a display unit (display screen) 23a that displays various information processed by the control unit 22.

[0048]

Signals corresponding to the abovementioned opening amount and misalignment amount, and a signal corresponding to the distance to the sensing target, sensed by each of the first distance sensors P1 to P7, are transmitted to the control unit 22 via the signal line 24. A signal corresponding to an image taken by each of the imaging devices Q1 to Q5 is transmitted to the control unit 22 via the signal line 25. A signal corresponding to the

distance to the sensing target sensed by each of the second distance sensors 16a, 16b is transmitted to the control unit 22 via the signal line 26, together with a signal corresponding to the rotational angle of each rotation mechanism 19 of the second distance sensors 16a, 16b at the time of the measurement.

5 [0049]

The control unit 22 includes a storage unit 22a, an opening amount and misalignment amount determining unit 22b, an image processing unit 22c, an existing ring shape determining unit 22d, a first new ring shape prediction unit 22e, and a second new ring shape prediction unit 22f. The storage unit 22a stores various information transmitted to the control unit 22 and various information including processing results of the control unit 22.

[0050]

The abovementioned signals corresponding to the opening amount, the misalignment amount, and the image transmitted from the first distance sensors P1 to P7 and the imaging devices Q1 to Q5 to the control unit 22, are appropriately processed by the opening amount and misalignment amount determining unit 22b and the image processing unit 22c, and then, the obtained processing results are transmitted from the control unit 22 to the output device 23 by wireless communication.

[0051]

By checking, for example, the screen display shown on the display unit 23a of the output device 23, it is possible for an operator to monitor the state of the segment SPE held by the holding unit 8 of the erector device 3. That is, by checking, for example, the screen display shown on the display unit 23a of the output device 23, it is possible for the operator to monitor specific numerical values of the opening amount and the misalignment amount between the segment SPE and the existing segment SP adjacent to the segment SPE in the sensing target areas LP1 to LP7. In addition, by checking, for example, the screen display

shown on the display unit 23a of the output device 23, it is possible for the operator to monitor, in images, the opening status and the misalignment status between the segment SPE and the existing segment SP adjacent to the segment SPE in the imaging target areas IQ1 to IQ5.

5 [0052]

Thus, during the segment assembling process, it is possible for the operator to modify the operation of the erector device 3 to minimize the opening amount and the misalignment amount between the segment SPE and the existing segment SP adjacent to the segment SPE, based on, for example, the screen display shown on the display unit 23a of the output device 23.

[0053]

FIG. 7 is a table showing an example of measurement results of the abovementioned opening amount and misalignment amount that may be displayed on the screen of the output device 23. In this example, the existing segment SP is located next to the edges $\alpha 1$ and $\alpha 2$ of the segment SPE shown in FIG. 4, whereas no segment SP exists next to the edges $\alpha 3$ and $\alpha 4$ of the segment SPE.

[0054]

Returning to FIG. 6, the abovementioned signals corresponding to the distances to the sensing target transmitted from the first distance sensors P1 to P7 and the second distance sensors 16a, 16b to the control unit 22, are appropriately processed by the existing ring shape determining unit 22d, the first new ring shape prediction unit 22e, and the second new ring shape prediction unit 22f, and then, the obtained processing results are transmitted from the control unit 22 to the output device 23 by wireless communication.

[0055]

By checking, for example, the screen display shown on the display unit 23a of the

output device 23, it is possible for the operator to monitor the assembly precision of the segment SPE held by the holding unit 8 of the erector device 3. For example, to monitor the assembly precision, the screen display indicating a shape 31 of an existing segment ring 30, and a first predicted shape 41 and a second predicted shape 42 of a new segment ring 40, which will be described below, may be used. Details thereof will be described below with reference to FIGS. 8 to 17.

[0056]

Thus, during the segment assembling process, it is possible for the operator to modify the operation of the erector device 3 to improve the assembly precision of the segment SPE, based on, for example, the screen display shown on the display unit 23a of the output device 23.

[0057]

Next, a method for building a new segment ring 40 (segment assembling method) using the segment assembly assisting device 20 will be described with reference to FIGS. 8 to

FIG. 8 is a view showing the existing segment ring 30. FIG. 9 is a view relating to FIG. 8 and showing the shape 31 of the existing segment ring 30 displayed on the screen of the display unit 23a. FIG. 10 is a view showing the completed assembly of a third segment SP3 of the new segment ring 40. FIG. 11 is a view relating to FIG. 10 and showing the shape 31 of the existing segment ring 30 and the first predicted shape 41 of the new segment ring 40, displayed on the screen of the display unit 23a. FIG. 12 is a view showing an assembling state of a fourth segment SP4 of the new segment ring 40. FIG. 13 is a view relating to FIG. 12 and showing the shape 31 of the existing segment ring 30, the first predicted shape 41 of the new segment ring 40, and the second predicted shape 42 of the new segment ring 40, displayed on the screen of the display unit 23a. FIG. 14 is a view showing the completed assembly of the fourth segment SP4 of the new segment ring 40. FIG. 15 is a

view relating to FIG. 14 and showing the shape 31 of the existing segment ring 30, the first predicted shape 41 of the new segment ring 40, and the second predicted shape 42 of the new segment ring 40, displayed on the screen of the display unit 23a.

[0058]

5 In the present embodiment, the new segment ring 40 is built adjacent to the existing segment ring 30 on the tunnel face side thereof. Here, the existing segment ring 30 is an ($N-1$)th built segment ring SR, and the new segment ring 40 is an N th built segment ring SR (N is an integer of 2 or more).

[0059]

10 In the method for building the new segment ring 40, first, as shown in FIG. 8, the shape (hollow shape) 31 of the existing segment ring 30 is sensed by the second distance sensors 16a, 16b. In this step, the measurement results of the second distance sensors 16a, 16b are appropriately processed by the existing ring shape determining unit 22d of the control unit 22, and then, the obtained results are transmitted to the output device 23 so that the shape
15 31 of the existing segment ring 30 is displayed on the display unit 23a of the output device 23 (see FIG. 9).

[0060]

 In the present embodiment, the existing ring shape determining unit 22d corresponds to a “ring shape determining unit” of the present invention. The shape 31 of the existing
20 segment ring 30 may correspond to a “shape of a reference segment ring” of the present invention.

[0061]

 Next, the propelling jacks of the shield machine 1 are extended. This pushes out the existing segment ring 30 behind the rear portion 2a of the skin plate 2. The reaction force
25 thereof propels the shield machine 1 forward.

[0062]

Next, the erector device 3 is used to assemble a predetermined number of segments SP, which constitutes the new segment ring 40. Herein, the “predetermined number” is a number necessary for creating the first predicted shape 41 of the new segment ring 40, which will be described below, and is set in advance. In the present embodiment, the predetermined number is set to three, and three segments SP (from a first segment SP1 to a third segment SP3) are assembled (see FIG. 10). However, it should be apparent that the predetermined number is not limited to three. Furthermore, during the segment assembling process, the propelling jacks may be retracted as appropriate so as not to interfere with the segment assembly.

[0063]

During the assembling process of the segments SP1 to SP3, it is possible for the operator to modify the operation of the erector device 3 to minimize the abovementioned opening amount and misalignment amount between segments, based on, for example, the screen display shown on the display unit 23a of the output device 23.

[0064]

When the assembly of the segment SP3 is completed, the shape (hollow shape) defined by the segments SP1 to SP3 joined to the existing segment ring 30 is sensed by the second distance sensor 16b (here, if necessary, the second distance sensor 16a may be additionally used). Then, the measurement results obtained thereby are appropriately processed by the first new ring shape prediction unit 22e of the control unit 22 to create the first predicted shape 41 of the new segment ring 40. The result of the processing is then transmitted to the output device 23 so that the first predicted shape 41 of the new segment ring 40 is displayed on the display unit 23a of the output device 23 together with the shape 31 of the existing segment ring 30 (see FIG. 11). Here, the first predicted shape 41 of the new

segment ring 40 is a shape (hollow shape) of the new segment ring 40 predicted based on the segments SP1 to SP3 joined to the existing segment ring 30. The first predicted shape 41 of the new segment ring 40 may correspond to the “shape of the reference segment ring” of the present invention.

5 [0065]

Here, an example of the creating process of the first predicted shape 41 of the new segment ring 40, carried out by the first new ring shape prediction unit 22e, will be described with reference to FIG. 16.

FIG. 16 is a view for explaining an example of the creating process of the first
10 predicted shape 41 of the new segment ring 40. FIG. 16 shows a case in which, among multiple segments SP constituting the new segment ring 40, the segments SP1 to SP3 have been assembled and the remaining segments SP are not yet assembled.

[0066]

In this case, the assembled portion (the portion corresponding to the segments SP1 to
15 SP3) 41a of the first predicted shape 41 of the new segment ring 40 is determined based on the measurement result obtained by the second distance sensor 16b (here, if necessary, the second distance sensor 16a may be additionally used). On the other hand, since an unassembled portion 41b of the first predicted shape 41 of the new segment ring 40 corresponds to the remaining segments SP, it is assumed that a circumference (length) (in
20 other words, the arc length) L1 is constant in the present process. By changing (varying) a curvature (diameter) R1 of the circumference with respect to the circumference (length) L1 of the unassembled portion 41b, ends 41bt1 and 41bt2 of the unassembled portion 41b are aligned with ends 41at1 and 41at2 of the assembled portion 41a, respectively. Thus, by predicting the shape of the unassembled portion 41b in this way, the first predicted shape 41
25 of the new segment ring 40 is created.

[0067]

Next, the erector device 3 is used to assemble a fourth segment SP4, which constitutes the new segment ring 40 (see FIGS. 12 and 14). During the assembling process of the segment SP4, it is possible for the operator to modify the operation of the erector device 3 to minimize the abovementioned opening amount and misalignment amount between segments, based on, for example, the screen display shown on the display unit 23a of the output device 23.

[0068]

As shown in FIG. 12, in the middle of the assembly of the segment SP4 (that is, in a state in which the segment SP4 is held by the holding unit 8 of the erector device 3), the second new ring shape prediction unit 22f of the control unit 22 appropriately processes the abovementioned measurement results of the shape (hollow shape) of the segments SP1 to SP3 obtained by the second distance sensors 16a, 16b and the measurement results of distances from the first distance sensors P1 to P7 to the inner surface of the segment SP4 obtained by the first distance sensors P1 to P7, to create the second predicted shape 42 of the new segment ring 40. The result of the processing is then transmitted to the output device 23 so that the second predicted shape 42 of the new segment ring 40 is displayed on the display unit 23a of the output device 23 together with the shape 31 of the existing segment ring 30 and the first predicted shape 41 of the new segment ring 40 (see FIG. 13). In the present embodiment, the second new ring shape prediction unit 22f corresponds to a “ring shape prediction unit” of the present invention.

[0069]

Here, an example of the creating process of the second predicted shape 42 of the new segment ring 40, carried out by the second new ring shape prediction unit 22f, will be described with reference to FIG. 17.

FIG. 17 is a view for explaining an example of the creating process of the second predicted shape 42 of the new segment ring 40. FIG. 17 shows a case in which, among multiple segments SP constituting the new segment ring 40, the segments SP1 to SP3 have been assembled, the segment SP4 is in the middle of the assembly (i.e., the segment SP4 is held by the holding unit 8 of the erector device 3), the remaining segments SP are not yet assembled.

[0070]

In this case, the assembled portion (the portion corresponding to the segments SP1 to SP3) 42a of the second predicted shape 42 of the new segment ring 40 is determined based on the measurement result obtained by the second distance sensor 16b (here, if necessary, the second distance sensor 16a may be additionally used). On the other hand, since a during-assembly and/or unassembled portion 42b of the second predicted shape 42 of the new segment ring 40 corresponds to the segment SP4 and the remaining segments SP, it is assumed that a circumference (length) (in other words, the arc length) L2 is constant in the present process. By changing (varying) a curvature (diameter) R2 of the circumference with respect to the circumference (length) L2 of the during-assembly and/or unassembled portion 42b, taking into account the measurement results of the first distance sensors P1 to P7, ends 42bt1 and 42bt2 of the during-assembly and/or unassembled portion 42b are aligned with ends 42at1 and 42at2 of the assembled portion 42a, respectively. Thus, by predicting the shape of the during-assembly and/or unassembled portion 42b in this way, the second predicted shape 42 of the new segment ring 40 is created.

[0071]

In addition, the second new ring shape prediction unit 22f may also use the measurement results of the abovementioned opening amount and misalignment amount obtained by the first distance sensors P1 to P7, to create the second predicted shape 42 of the

new segment ring 40. Furthermore, no measurement results of the shapes of the segments SP1 to SP3 obtained by the second distance sensors 16a, 16b, described above, may be used to create the second predicted shape 42. That is, when creating the second predicted shape 42, at least the measurement results of the first distance sensors P1 to P7 are used. Here, the second predicted shape 42 of the new segment ring 40 is a shape (hollow shape) of the new segment ring 40 predicted based on at least the measurement results of the first distance sensors P1 to P7.

[0072]

In the present embodiment, it is possible to monitor the location and attitude of the segment SP4 during assembly based on the measurement results of the distances from the first distance sensors P1 to P7 to the inner surface of the segment SP4 obtained by the first distance sensors P1 to P7, the measurement results of the abovementioned opening amount and misalignment amount, a rotational angle of the rotary ring 4 of the erector device 3, an amount of extension and contraction of the elevating jacks 5, and the amount of extension and contraction of the axial jacks 7. In other words, the abovementioned segment state sensing device may be configured so as to sense the position and attitude of the segment SP4 during assembly, as a state of the segment SP4 during assembly. The second new ring shape prediction unit 22f may use the obtained location and attitude of the segment SP4 during assembly to create the second predicted shape 42 of the new segment ring 40. Furthermore, when creating the second predicted shape 42 of the new segment ring 40, a sensing means other than the first distance sensors P1 to P7 may be used to sense the location and attitude of the segment SP4 during assembly.

[0073]

The second predicted shape 42 of the new segment ring 40 displayed on the screen on the display unit 23a of the output device 23 changes in response to a change in state of the

segment SP4 during assembly (e.g., a change in location and attitude of the segment SP4 during assembly). That is, in response to a change in, for example, location and attitude of the segment SP4 during assembly, the screen display indicating the second predicted shape 42 of the new segment ring 40 changes in real time.

5 [0074]

The operator modifies the operation of the erector device 3 so as to change the location and attitude of the segment SP4 during assembly in a manner such that the second predicted shape 42 of the new segment ring 40 displayed on the screen of the display unit 23a of the output device 23 approaches at least one of the shape 31 of the existing segment ring 30 and the first predicted shape 41 of the new segment ring 40 (see FIGS. 12 to 15). In this way, the segment assembly assisting device 20 assists the assembly of the segment SP4.

[0075]

When the assembly of the segment SP4 is completed, the shape (hollow shape) defined by the segments SP1 to SP4 joined to the existing segment ring 30 is sensed by the second distance sensors 16a, 16b. Then, the measurement results of the second distance sensors 16a, 16b are appropriately processed by the first new ring shape prediction unit 22e of the control unit 22 to update the first predicted shape 41 of the new segment ring 40. The result of the processing is then transmitted to the output device 23 so that the first predicted shape 41 of the new segment ring 40 is displayed on the display unit 23a of the output device 23 together with the shape 31 of the existing segment ring 30 and the second predicted shape 42 of the new segment ring 40.

[0076]

Fifth and subsequent segments SP constituting the new segment ring 40 are also assembled in the same manner as the fourth segment SP4 is assembled, as described above. In this respect, it should be apparent that the segment assembly assisting device 20 assists the

assembly of the fifth and subsequent segments SP. In this way, the new segment ring 40 is built.

[0077]

FIG. 18 is a view showing a modified example of a screen display shown on the display unit 23a of the output device 23. FIG. 18 shows a designed value 50 of the shape (hollow shape) of the segment ring SR, in addition to the shapes shown in FIG. 15, specifically, the shape 31 of the existing segment ring 30, and the first predicted shape 41 and the second predicted shape 42 of the new segment ring 40. This designed value 50 may correspond to the “shape of the reference segment ring” of the present invention.

[0078]

It is possible for the operator to modify the operation of the erector device 3 so as to change the location and attitude of the segment SPE (in FIG. 18, segment SP4) in a manner such that the second predicted shape 42 of the new segment ring 40 displayed on the screen of the display unit 23a of the output device 23 approaches at least one of the shape 31 of the existing segment ring 30, the first predicted shape 41 of the new segment ring 40, and the designed value 50.

[0079]

Here, in addition to the screen display as shown in FIG. 15, FIG. 18 also shows the screen display indicating the segments SP joined to the existing segment ring 30 (in FIG. 18, segments SP1 to SP3) and the segment SPE held by the holding unit 8 of the erector device 3 (in FIG. 18, the segment SP4). Regarding the screen display indicating the segment SPE held by the holding unit 8 of the erector device 3, it is preferable that the screen display indicating the segment SPE change in response to a change in location and attitude of the segment SPE.

[0080]

Furthermore, in FIGS. 15 and 18, the screen display indicating at least one of the elevating jacks 5, the arm 6, and the holding unit 8 of the erector device 3 may be added. It is preferable that this screen display also change in response to a change in location and attitude.

5 [0081]

According to the present embodiment, the segment assembly assisting device 20 is for use in shield tunneling. The segment assembly assisting device 20 includes the ring shape prediction unit (second new ring shape prediction unit 22f) configured to predict the shape (second predicted shape 42) of the new segment ring 40 including the segment SPE that is held by the holding unit 8 of the erector device 3 of the shield machine 1, based on the state of the segment SPE. Therefore, even during building of the new segment ring 40, it is possible to confirm the assembly precision of segment SP constituting the new segment ring 40.

[0082]

15 Furthermore, according to the present embodiment, the segment assembly assisting device 20 further includes the display unit 23a that displays the predicted shape (second predicted shape 42) of the new segment ring 40. Therefore, even during building of the new segment ring 40, it is possible for the operator to easily confirm the assembly precision of segment SP constituting the new segment ring 40 by checking the display unit 23a.

20 [0083]

Furthermore, according to the present embodiment, the display unit 23a further displays the shape of the reference segment ring. The shape of the reference segment ring includes, for example, at least one of the shape 31 of the existing segment ring 30, the first predicted shape 41 of the new segment ring 40, and the designed value 50. Thus, it is possible for the operator to modify the operation of the erector device 3 so as to change the

location and attitude of the segment SPE in a manner such that the second predicted shape 42 of the new segment ring 40 displayed on the display unit 23a approaches the shape of the reference segment ring. Here, it is preferable that the display unit 23a display the second predicted shape 42 of the new segment ring 40 and the shape of the reference segment ring, described above, in a superposed manner.

[0084]

Furthermore, according to the present embodiment, the segment assembly assisting device 20 further includes the ring shape determining unit (existing ring shape determining unit 22d) configured to determine the shape of the existing segment ring 30. The shape of the reference segment ring, described above, includes the shape 31 of the existing segment ring 30 determined by the ring shape determining unit (existing ring shape determining unit 22d). Thus, it is possible for the operator to modify the operation of the erector device 3 so as to change the location and attitude of the segment SPE in a manner such that the second predicted shape 42 of the new segment ring 40 displayed on the display unit 23a approaches the shape 31 of the existing segment ring 30.

[0085]

Furthermore, according to the present embodiment, the segment assembly assisting device 20 further includes: a shape sensing unit (second distance sensors 16a, 16b) that senses the shape of a segment SP which is joined to the existing segment ring 30, among the segments SP constituting the new segment ring 40 (e.g., the segments SP1 to SP3 in FIGS. 10 and 12); and an additional ring shape prediction unit (first new ring shape prediction unit 22e) configured to predict the shape (first predicted shape 41) of the new segment ring 40 based on the measurement results obtained by the shape sensing unit. The shape of the reference segment ring, described above, includes the shape of the new segment ring 40 (first predicted shape 41) predicted by the additional ring shape prediction unit (first new ring shape

prediction unit 22e). Thus, it is possible for the operator to modify the operation of the erector device 3 so as to change the location and attitude of the segment SPE in a manner such that the second predicted shape 42 of the new segment ring 40 displayed on the display unit 23a approaches the first predicted shape 41 of the new segment ring 40.

5 [0086]

Furthermore, according to the present embodiment, the segment assembly assisting device 20 further includes the segment state sensing device configured to sense the state of the segment SPE that is held by the holding unit 8 of the erector device 3. This segment state sensing device includes distance sensors (first distance sensors P1 to P7) disposed on the
10 erector device 3. It is preferable that each of the distance sensors (first distance sensors P1 to P7) include an irradiation unit that emits a line laser beam toward the corresponding sensing target area LP1 to LP7, and the light receiving unit that receive reflected light of the line laser beam.

[0087]

15 Furthermore, according to the present embodiment, the segment assembly assisting method is a method for assisting the assembly of the segment SP during shield tunneling. This segment assembly assisting method includes the step of predicting the shape (second predicted shape 42) of the new segment ring 40 including the segment SPE that is held by the holding unit 8 of the erector device 3 of the shield machine 1, based on the state of the
20 segment SPE. Therefore, even during building of the new segment ring 40, it is possible to confirm the assembly precision of segment SP constituting the new segment ring 40.

[0088]

Furthermore, according to the present embodiment, the segment assembly assisting method further includes the step of displaying the predicted shape (second predicted shape
25 42) of the new segment ring 40 on the screen of, for example, the display unit 23a.

Therefore, even during building of the new segment ring 40, it is possible for the operator to easily confirm the assembly precision of segment SP constituting the new segment ring 40 by checking the screen display.

[0089]

5 Furthermore, according to the present embodiment, the segment assembling method includes the step of modifying the operation of the erector device 3 based on the predicted shape (second predicted shape 42) of the new segment ring 40 predicted in the abovementioned segment assembly assisting method. Therefore, since this makes it possible to modify the location and attitude of the segment SPE during building of the new segment
10 ring 40, it is possible to build the new segment ring 40 at high precision.

[0090]

 Furthermore, according to the present embodiment, the segment assembling method includes the step of modifying the operation of the erector device 3 based on the screen display shown on the display unit 23a of the output device 23 of the segment assembly
15 assisting device 20. Thus, by checking the display shown on the display unit 23a of the output device 23, it is possible for the operator to monitor the assembly precision of the segment SPE, and to utilize it for the operation of the erector device 3.

[0091]

 The abovementioned second distance sensors 16a, 16b may function as a distance
20 sensor for use in a method for measuring a tail clearance in the shield machine, disclosed in JP 2015-030994 A. That is, the second distance sensors 16a, 16b may be used not only for confirming the assembly precision of segment SP and for monitoring the shape of segment ring SR (e.g., monitoring the roundness), but also for measuring the tail clearance of the shield machine.

25 [0092]

Although, in the present embodiment, the laser distance sensors, each using a line laser beam, have been described as the first distance sensors P1 to P7, the configurations of the first distance sensors P1 to P7 are not limited thereto. For example, for each of the first distance sensors P1 to P7, an imaging device including, for example, a CCD camera or a CMOS camera may be employed, and various distance measurements (dimension measurements) in the sensing target areas LP1 to LP7 may be performed based on image data acquired by the imaging device.

[0093]

Although, in the present embodiment, the laser distance sensors have been described as the second distance sensors 16a, 16b, the configurations of the second distance sensors 16a, 16b are not limited thereto. For example, for each of the second distance sensors 16a, 16b, an imaging device (e.g., a CCD camera or a CMOS camera) capable of moving a predetermined imaging target area at least in the tunnel circumferential direction may be employed, and a distance may be measured based on image data acquired by the imaging device.

[0094]

Although, in the present embodiment, an example is shown in which the cross-sectional shapes of the skin plate 2 and the segment ring SR are circular, the cross-sectional shapes of the skin plate 2 and the segment ring SR are not limited to the circular shape. For example, the cross-sectional shapes of the skin plate 2 and the segment ring SR may be an ellipse or a rectangle.

[0095]

The embodiment as shown in the drawings is merely intended to illustrate the present invention, and it is a matter of course that the present invention encompasses various improvements and modifications that may be made by one skilled in the art within the scope

of the appended claims, in addition to those directly illustrated by the embodiment described above.

What is claimed is:

1. A segment assembly assisting device for use in shield tunneling, comprising:
a ring shape prediction unit configured to predict a shape of a new segment ring
5 including a during-assembly segment that is held by a holding unit of an erector device
of a shield machine; and
a segment state sensing device configured to sense location and attitude of the
during-assembly segment,
wherein the ring shape prediction unit is further configured to change a curvature
10 of a circumference of a during-assembly and unassembled portion of the shape of the new
segment ring depending on the location and attitude of the during-assembly segment to
predict the shape of the new segment ring.
2. The segment assembly assisting device according to claim 1, further comprising
15 a display unit configured to display the predicted shape of the new segment ring.
3. The segment assembly assisting device according to claim 2, wherein the display
unit further configured to display a shape of a reference segment ring.
- 20 4. The segment assembly assisting device according to any one of claims 1 to 3,
wherein the segment state sensing device includes a plurality of distance sensors
disposed on the erector device,
wherein each of the plurality of distance sensors is configured to measure an
opening amount and a misalignment amount between an edge of the during-assembly
25 segment and an edge of an existing segment adjacent to the during-assembly segment,
and

wherein the segment state sensing device is configured to sense the location and attitude of the during-assembly segment based on the opening amount and the misalignment amount.

- 5 5. A segment assembly assisting method for use in shield tunneling, comprising the steps of:

sensing location and attitude of a during-assembly segment that is held by a holding unit of an erector device of a shield machine; and

- changing a curvature of a circumference of a during-assembly and unassembled
10 portion of a shape of a new segment ring including the during-assembly segment
depending on the location and attitude of the during-assembly segment to predict the
shape of the new segment ring.

6. The segment assembly assisting method according to claim 5, further comprising
15 the step of displaying the predicted shape of the new segment ring on a screen.