DESCRIPTION

Title of Invention: JIG FOR USE IN DETECTING ACCELERATION IN SHIELD BORING MACHINE

Technical Field

[0001]

The present invention relates to a jig for use in detecting acceleration in a shield boring machine, and more particularly to a jig for use in detecting acceleration in a closed-type shield boring machine, the jig being for fixing an acceleration sensor integrally to a bit for detecting acceleration attached to a front plate of a cutterhead of the closed-type shield boring machine by working from the back surface side of the front plate.

Background Art

[0002]

In urban areas, for example, there has been a demand for constructing shield tunnels over longer distances in recent years, due to problems with construction sites for vertical shafts and the congestion of underground structures. When a shield tunnel is constructed over a long distance, the geological properties of the ground in the tunnel face often vary as the ground is excavated by a shield boring machine. In addition, when a shield boring machine advances through, for example, a boundary between different types of ground portion layered in the vertical direction or the horizontal direction, the ground portions having different geological properties can be simultaneously present in the same tunnel face to be cut.

[0003]

When the shield boring machine advances through the boundary between the ground portions having different geological properties, one of the ground portions may be bedrock or the like that is significantly harder than the other portion, for example. In such a case, the shield boring machine is likely to veer upward over the hard ground portion or slide sideways, unless the ground conditions in the tunnel face are appropriately grasped. This makes it difficult to accurately maintain a vertical alignment and a horizontal

alignment of the shield tunnel. For this reason, there is a demand for the development of a technology that enables stable management of the excavation by the shield boring machine in a manner appropriate to the ground conditions, while controlling the shield boring machine so as not to veer up over the hard ground portion or slide sideways. The control of the shield boring machine may specifically be achieved by grasping the ground conditions in the tunnel face planarly (or in other words, two-dimensionally in the tunnel face) to increase the amount of overcut by a copy cutter in the hard ground portion, for example.

[0004]

Particularly, in a known closed-type shield boring machine that is configured to advance while cutting a tunnel face by rotating a cutterhead thereof provided at the leading end portion of the shield body, typically, the properties of the cutting muck discharged from a chamber are examined and the earth pressure to the tunnel face and the cutter torque value of the cutterhead are measured, in order to check variations in the geological properties of the ground portions in the tunnel face. However, it is difficult to grasp, by such a check method, the geological properties of the ground portions in the tunnel face planarly to appropriately determine the distribution of the different geological properties of the ground portions in the tunnel face.

[0005]

In view of the above, the applicant of the present application proposed, for example, in Patent Literature 1 below, a system for determining the distribution of geological properties of the ground in a tunnel face by a shield boring machine. The system has a simple configuration to accurately grasp the ground conditions planarly in the tunnel face being cut by a cutterhead in real time when a shield tunnel is constructed, so that management of excavation by the shield boring machine can be more stably performed.

[0006]

The system disclosed in Patent Literature 1 includes an acceleration sensor attached to the outer peripheral portion of a cutterhead and a computer connected to the acceleration sensor. The computer includes a vibration data storage unit and a vibration data display unit. The vibration data storage unit stores cutting vibration data at every

predetermined rotation angle of the cutterhead, and the cutting vibration data is obtained when the tunnel face is cut by a bit and sent from the acceleration sensor. The vibration data display unit displays cutting vibration data at every predetermined rotation angle stored in the vibration data storage unit, and in the display unit, the cutting vibration data is displayed as cutting vibration distributions in the circumferential direction of a circle simulating the cross section as the tunnel face. A boundary between different types of ground portion in the tunnel face can be determined from a point at which the wave representing the distribution of cutting vibration fluctuates in the circumferential direction in the distribution displayed by the vibration data display unit.

Citation List

Patent Literature

[0007]

Patent Literature 1: JP 6342723 B

Summary of Invention

[0008]

However, in the system disclosed in Patent Literature 1, the acceleration sensor is attached to the outer peripheral edge portion of the cutterhead away from the bits so that only the vibration from the bits at the outer peripheral portion is mainly measured. Also, since these found values in measurement include vibrations transmitted through the cutterhead from other bits around the bits on the outer peripheral portion, the vibrations are difficult to accurately detect, depending on the ground. Thus, there is a technical problem with this system, and therefore, there is a demand for fixing the acceleration sensor integrally to an acceleration-detecting bit itself, at which vibrations are measured, to thereby enable accurate direct measurement of the vibrations of the acceleration-detecting bit during cutting of the ground.

[0009]

On the other hand, a conceivable method for fixing an acceleration sensor integrally to a bit attached to the front plate of a cutterhead includes, before attaching a bit to a cutterhead, fixing an acceleration sensor to the bit to use the resultant as an acceleration-detecting bit and fixing the acceleration-detecting bit at a predetermined position of the front plate of the cutterhead. However, heat and electricity are produced

when the acceleration-detecting bit is fixed to the front plate of the cutterhead by welding or other means, and the effects of the heat and electricity may cause a fault in the acceleration sensor that has been fixed integrally to the bit in advance.

[0010]

Regarding this, it is conceivable to first fix, to the front plate of the cutterhead, a bit for detecting acceleration to measure vibrations by welding or other means and then fix an acceleration sensor integrally to the attached bit by working from the back side of the front plate. However, working on the back side of the front plate needs to be performed in a narrow workspace inside the cutter spoke of the cutterhead, for example. Thus, there is a demand for easily fixing an acceleration sensor integrally to a bit for detecting acceleration while the acceleration sensor is positioned in a predetermined orientation by a simpler method even in a narrow working space.

[0011]

For example, the acceleration sensor may be a three-axis sensor. Particularly, in that case, to effectively detect the vibration of the acceleration-detecting bit by the acceleration sensor, it is necessary to arrange the acceleration sensor such that one detection direction of the acceleration sensor is preferably aligned with the circumferential rotation path in the circumferential direction of the acceleration-detecting bit moving in conjunction with the rotation of the cutterhead. Thus, there is a demand for the development of technology for easily and smoothly fixing an acceleration sensor integrally to a bit for detecting acceleration in a state where the acceleration sensor is disposed such that one detection direction of the acceleration sensor is aligned with a predetermined direction in the bit.

[0012]

An object of the present invention is to provide a jig for use in detecting acceleration in a shield boring machine that allows for easily and smoothly fixing, by simple working from the back side of the front plate of the cutterhead, an acceleration sensor integrally to a bit for detecting acceleration attached to the front plate in a state where the acceleration sensor is disposed such that one detection direction is aligned with a predetermined direction in the bit.

[0013]

To achieve the object described above, the present invention provides a jig for use in detecting acceleration in a closed-type shield boring machine that comprises a cutterhead configured to rotate and provided at a leading end portion of a shield body and that is configured to advance while cutting a tunnel face with a plurality of bits attached to the cutterhead,

the jig allowing for fixing an acceleration sensor integrally to a bit for detecting acceleration attached to a front plate of the cutterhead by working from a back side of the front plate, to accurately detect vibration acceleration of the acceleration-detecting bit during cutting,

the jig comprising: a joining base portion, and a standing portion for mounting, the standing portion formed integrally with the joining base portion and standing upright from the joining base portion,

wherein the jig is used in a state where, at an attachment position of the acceleration-detecting bit in the front plate of the cutterhead, the standing portion is inserted and fixed in a mounting hole extending through the front plate and further extending through to a depth of a fixing base portion of the acceleration-detecting bit, and in a state where the joining base portion is joined to the back side of the front plate, and

wherein by a means for positioning and joining, the position of the joining base portion in the circumferential direction centered on the mounting hole is fixed on the back side of the front plate; and on that occasion, the orientation of the acceleration sensor with respect to the positioning and joining means of the joining base portion is adjusted so that one direction for obtaining the cutting vibration data by the acceleration sensor housed in an internal leading end portion of the standing portion is aligned with the circumferential direction when the acceleration-detecting bits rotationally move, and in that orientation-adjusted state of the acceleration sensor, the acceleration sensor is fixed to the internal leading end portion of the standing portion.

[0014]

In the jig according to the present invention, the means for positioning and joining preferably includes bolt insertion holes and fastening bolts, wherein

the bolt insertion holes are formed at least at two locations in the outer peripheral region surrounding the standing portion in the joining base portion, such that the bolt insertion holes are aligned with bolt fastening holes formed at least at two locations in the

outer peripheral region surrounding the mounting hole at the attachment position of the acceleration-detecting bit in the front plate of the cutterhead, and

the fastening bolts are inserted and tightened in the bolt fastening holes and the bolt insertion holes that are aligned with each other.

[0015]

In the jig according to the present invention, the acceleration sensor preferably has a hexahedral shape and is fitted and attached to a sensor mounting portion with a quadrangular hollow cross-sectional shape formed in the internal leading end portion of the standing portion, to thereby fix the position of the acceleration sensor in the circumferential direction in the standing portion.

[0016]

In the jig according to the present invention, preferably, two paired bolt insertion holes are respectively formed on both sides of the standing portion in an imaginary plane parallel with a predetermined side face of the acceleration sensor with a hexahedral shape fitted and attached in the sensor mounting portion.

[0017]

In the jig according to the present invention, a connection cable connected to the acceleration sensor is preferably disposed in a hole for inserting wiring or a groove for arranging wiring formed inside the standing portion.

[0018]

In the jig used according to the present invention, it is preferable that the hole for inserting wiring or the groove for arranging wiring in which the connection cable is disposed is filled with a curable sealing material, and that the curable sealing material is solidified.

Brief Description of Drawings

[0020]

FIG. 1 is an explanatory diagram illustrating the configuration of a system for determining the distribution of the geological properties of the ground in a tunnel face by

a shield boring machine in which a jig according to a preferred embodiment of the present invention is used.

FIG. 2 is a front view of the shield boring machine.

FIG. 3 is an enlarged cross-sectional view taken along line A-A of FIG. 2.

FIG. 4(a) is a partially cutaway front view for illustrating an acceleration-detecting bit to which an acceleration sensor is fixed integrally with a jig according to a preferred embodiment of the present invention; FIG. 4(b) is a cross-sectional view taken along line B-B in FIG. 4(a); and FIG. 4(c) is a top view of the attachment structure shown in FIG. 4(a) as seen from above.

FIG. 5(a) is a cross-sectional view of a jig according to a preferred embodiment of the present invention before a cover plate is attached, taken along line C-C of FIG. 5(b); FIG. 5(b) is a cross-sectional view of the jig with the cover plate attached, taken along D-D of FIG. 5(a); FIG. 5(c) is an enlarged cross-sectional view of the jig with the cover plate attached, taken along E-E of FIG. 5(a); and FIG. 5(d) is an enlarged cross-sectional view of jig taken along F-F of FIG. 5(a).

FIG. 6(a) is a front view for illustrating an acceleration sensor; FIG. 6(b) is a side view of the acceleration sensor of FIG. 6(a) as seen from the left direction; FIG. 6(c) is a side view of the acceleration sensor shown of FIG. 6(a) as seen from the right direction; and FIG. 6(d) is a top view of the acceleration sensor of FIG. 6(a) as seen from above.

FIG. 7 is an explanatory diagram illustrating an example of a display screen including a vibration data display unit and a boundary line display unit.

Description of Embodiments

[0021]

A jig for use in detecting acceleration, 44 of a preferred embodiment of the present invention (see FIGS. 4(a) and 4(b) and FIGS. 5(a) and 5(b)) is used, for example, in a system 10 for determining the distribution of geological properties of the ground in a tunnel face of the shield boring machine illustrated in FIG. 1, as a jig for fixing an acceleration sensor 14 (see FIGS. 6(a) to 6(d)) integrally to a bit for detecting acceleration, 41, 42 (see FIG. 2) attached to a cutterhead 13 of a shield boring machine 11 (the jig for use in detecting acceleration, 44 will also be referred simply to as the jig 44). In the present embodiment, the system 10 can be used in the construction of a shield tunnel by an earth pressure balance shield boring machine, which is an example of a closed-type shield boring machine, as the shield boring machine 11. Specifically, for example, in a case where the shield boring machine 11 advances through boundaries

between the ground portions 12a, 12b, and 12c having different geological properties, the ground portion 12a may be bedrock or the like that is significantly harder than the ground portions 12b and 12c that may be sandy soil, clay soil, or the like. Even in such a case, the system 10 enables accurate planar grasp of the conditions of the ground portions 12a, 12b, and 12c in the tunnel face 12 being cut in real time. The shield boring machine 11 is then controlled by, for example, increasing the amount of overcut by a copy cutter 16a (see Fig. 2) in the hard ground portion 12a, so that the shield boring machine 11 does not veer up over the hard ground portion 12a or slide sideways. The system 10 thus performs a function to enable more stable management of the excavation in a manner appropriate to the conditions of the ground portions 12a, 12b, and 12c.

[0022]

In urban areas, for example, there are problems with construction sites for vertical shafts and the congestion of underground structures, and accordingly, there is a demand for constructing shield tunnels over long distances not only in cases where a large diameter shield boring machine is used but also in cases where a small or medium diameter shield boring machine is used. In the case of the construction of a shield tunnel over a long distance, it is expected that the shield boring machine 11 will often excavate through boundaries between the layered ground portions 12a, 12b, and 12c having different geological properties. Thus, in the present embodiment, the system 10 can appropriately grasp the conditions of the ground portions 12a, 12b, and 12c in the tunnel face 12 even if the ground portions 12a, 12b, and 12c with different geological properties appear at the same time in one tunnel face 12 to be cut, so that the shield boring machine 11 can avoid veering up over the hard ground portion 12a or sliding sideways, meaning that the vertical alignment and the horizontal alignment of the shield tunnel can be accurately maintained.

[0023]

As illustrated in FIGS. 2 and 4(a) to 4(c), the system 10 uses an acceleration sensor 14 (see FIGS. 4(a) and 4(b)) integrally provided on a bit 16 (acceleration-detecting bit 41, 42) attached to the cutterhead 13 of the shield boring machine 11 to more accurately and meticulously grasp the conditions of the ground portions 12a, 12b, and 12c in the tunnel face 12 being cut by the cutterhead 13 planarly in real time, while preferably referencing to a columnar section of the surrounding ground.

[0024]

In other words, as illustrated in FIGS. 1 to 4, the system 10 can be provided in the shield boring machine 11 of closed-type to determine the distribution of the geological properties of the ground portions 12a, 12b, and 12c in the tunnel face 12. The shield boring machine 11 of closed-type includes the cutterhead 13 configured to rotate and provided on the leading end portion of a shield body 15, and advances while cutting the tunnel face 12 with the plurality of bits 16 attached to the cutterhead 13. The system 10 also includes the acceleration sensors 14 (see FIGS. 4(a) and 4(b)) and a computer 20 (see FIG. 1) connected to the acceleration sensors 14. The acceleration sensor 14 is attached integrally to each of the two or more bits for detecting acceleration (acceleration-detecting bits 41 and 42 (see FIG. 2)) selected from the plurality of bits 16, and the bits 16 are fixed to the front plate 43a of the cutter spoke 43 of the cutterhead 13 and project forward from the front plate 43a. The two or more acceleration-detecting bits 41 and 42 include the outer peripheral acceleration-detecting bit 41 disposed in the outer peripheral portion of the cutterhead 13 and the intermediate acceleration-detecting bit 42 disposed in the intermediate region between the central portion and the outer peripheral portion of the cutterhead 13. The computer 20 includes a vibration data storage unit 21 and a vibration data display unit 22. The vibration data storage unit 21 stores, at every predetermined rotation angle of the cutterhead, cutting vibration data obtained when the tunnel face 12 is cut by the acceleration-detecting bits 41 and 42 and sent from the acceleration sensor 14 attached to each of the outer peripheral acceleration-detecting bit 41 and the intermediate acceleration-detecting bit 42. The vibration data display unit 22 displays the cutting vibration data at every predetermined rotation angle from the outer peripheral acceleration-detecting bit 41 and the intermediate acceleration-detecting bit 42, the cutting vibration data being stored by the vibration data storage unit 21, and in the display unit 22, the cutting vibration data is displayed as a plurality of concentric annular cutting vibration distributions 23a and 23b in the circumferential direction of a circle simulating the cross section as the tunnel face (see FIG. 7). The boundaries between the ground portions 12a, 12b, and 12c having different geological properties in the tunnel face 12 can be determined from fluctuation points 24a and 24b at which the waves each representing the distribution of cutting vibration fluctuate in the cutting vibration distributions 23a and 23b in the circumferential direction displayed by the vibration data display unit 22.

[0025]

In the system 10, the vibration data display unit 22 can display the distribution of the vibration acceleration (acceleration of the ground response when cutting) at every predetermined rotation angle as a plurality of concentric annular cutting vibration distributions 23a and 23b.

[0026]

As illustrated in FIG. 1, it is also preferable in the system 10 that a partition 17 should be provided as an inner wall in the shield body 15, and that an auxiliary acceleration sensor 18 should be attached to the back side of the partition 17 and connected to the computer 20. The vibration data display unit 22 can be configured to display the cutting vibration data at every predetermined rotation angle as a plurality of concentric annular cutting vibration distributions 23a and 23b with the noise and mechanical vibration removed on the basis of the vibration data of the body sent from the auxiliary acceleration sensor 18.

[0027]

In the present embodiment, the shield boring machine 11 may be, for example, a known earth pressure balance shield boring machine, which is a closed-type shield boring machine. In the earth pressure balance shield boring machine as the shield boring machine 11, the partition 17 for defining a chamber 19 to which earth pressure will be applied is provided behind the cutterhead 13 at the leading end portion of the shield body 15, and a center shaft 13a of the cutterhead 13 is attached to the partition 17 and supported by the partition 17. Inside the shield body 15, there are provided a mud discharge mechanism (not shown), a rotational drive motor (not shown), a shield jack (not shown), an erector (not shown), and others.

[0028]

The computer 20 included in the system 10 for determining the distribution of geological properties of the ground in the tunnel face may be a known type that functions as a database server, and a personal computer or the like can be used, for example. The database server corresponding to the computer 20 includes a CPU, a ROM, a RAM, an I/F, a storage unit, an input unit, a display unit, and an output unit. The CPU of the database server controls the overall operation of the database server in accordance with a control program embedded in the ROM while using the RAM as a working area. The

CPU, together with various types of computer programs embedded in the ROM, causes the storage unit, the input unit, the display unit, the output unit, and others to function. Thus, the vibration data storage unit 21 stores the data on the cutting vibration sent from the acceleration sensor 14 together with the rotation angle of the cutterhead 13, and the cutting vibration data stored in the vibration data storage unit 21 is displayed as the cutting vibration distributions 23a and 23b in the circumferential direction on a display 20a by the vibration data display unit 22, and can also be output from a printer (not shown).

[0029]

In the computer 20, a known shield excavation management system is installed that can centrally manage found values collected from various measuring instruments relating to the shield construction method and survey values input as data via the input unit. The shield excavation management system performs, for example, a function to assist with management of the construction site by centrally managing found values collected from the various measuring instruments relating to the shield construction method, organizing such information, and providing it to a technician or worker; a function to infer the ground conditions, the conditions of excavated muck, additional status of the shield boring machine, and others, on the basis of the change over time or statistical processing results; and a function to obtain a deviation from a baseline by inputting the measurement results and calculating the position of the shield boring machine or segment. As the shield excavation management system, the “shield excavation management system” available from ENZAN KOUBOU CO., LTD. can be preferably used.

[0030]

The computer 20 is installed in an operation management room 30 build above ground. The computer 20 installed in the operation management room 30 is connected to various measuring instruments and also the acceleration sensor 14 and the auxiliary acceleration sensor 18 described later, via a known transmission system 29 including PCLs serving as a control console 26, a sequencer console 27, a remote control console 28, and others and also via acceleration sensor amplifiers 25a and 25b.

[0031]

The acceleration sensor 14 and the auxiliary acceleration sensor 18, together with the computer 20, thus compose the system 10, and as the acceleration sensor 14 and the auxiliary acceleration sensor 18, various types of known acceleration sensors can be used. The acceleration sensor is for detecting acceleration, which is the rate of change of speed over time (time derivative). The acceleration sensor is used to measure a value of acceleration itself or detect application of an external force, according to a physical law that says acceleration acting on an object is proportional to the external force applied. As the acceleration sensor 14 and the auxiliary acceleration sensor 18, it is possible to use any of various acceleration sensors including those for scientific experiments requiring highly accurate measurement, those for gravitational measurement or seismic measurement and also acceleration sensors that can detect inclination, vibration, movement, impact, drop, and so on. More specifically, it is possible to use as such a various acceleration sensor any of various types of 3-axis piezoelectric acceleration detectors, which can accurately detect the magnitude, frequency, and others of vibrations, including those available from Showa Sokki Co., Ltd.

[0032]

The acceleration sensor 14 is attached and fixed to integrally to the bit 16 disposed on the cutterhead 13 of the shield boring machine 11, preferably to each of an outer peripheral bits and an intermediate bit for detecting acceleration (the outer peripheral acceleration-detecting bit 41 and the intermediate acceleration-detecting bit 42) (see FIG. 2), with the jig for use in detecting acceleration, 44 of a preferred embodiment of the present invention (see FIGS. 5(a) to 5(d)) according to an attachment structure for an acceleration sensor, 40 illustrated in FIGS. 4(a) to 4(c).

[0033]

Namely, the structure for attaching an acceleration sensor, 40 in a shield boring machine is a structure for attaching and fixing the acceleration sensor 14 integrally to the bit 16 (acceleration-detecting bit 41, 42) disposed on the cutterhead 13 (see FIG. 2) in the shield boring machine 11 including the system 10 for determining the distribution of geological properties of the ground in a tunnel face (see FIG. 1), the system 10 including the acceleration sensor 14 attached to the cutterhead 13 and the computer 20 connected to the acceleration sensor 14. In the structure 40, the acceleration-detecting bits 41 and 42 to which the acceleration sensors 14 are attached are fixed to and project forward from the

front plate 43a of the cutter spoke 43 (see FIG. 2) of the cutterhead 13, as illustrated in FIGS. 3, 4(a), and 4(b). As illustrated in FIGS. 5(a) to 5(d), the acceleration sensor 14 is attached integrally to a bit for detecting acceleration (the acceleration-detecting bit 41, 42) via the jig 44. The jig 44 includes a base portion for joining, 45 made of metal and a standing portion for mounting, 46 made of metal, the standing portion 46 standing upright from the base portion for joining, 45 (hereinafter, the base portion for joining, 45 and the standing portion for mounting, 46 are referred to as the joining base portion 45 and the standing portion 46, respectively), and the acceleration sensor 14 is fixed and housed in the internal leading end portion of the jig 44 of the present embodiment. In the front plate 43a of the cutter spoke 43, a hole for mounting the standing portion, 43b in which the standing portion 46 of the jig 44 is inserted and fixed is formed at the position at which the acceleration-detecting bit 41, 42 is attached (hereinafter, the hole for mounting the standing portion, 43b is also referred to as the mounting hole 43b; and the position at which the acceleration-detecting bit 41, 42 is attached is also referred to as the attachment position of the acceleration-detecting bit 41, 42), and the mounting hole 43b extends through to the depth of the base portion for fixing, 41a, 42a of the acceleration-detecting bit 41, 42 (hereinafter, the base portion for fixing, 41a, 42a is also referred to as the fixing base portion 41a, 42a). Also, a plurality of bolt fastening holes 43c are formed in the outer peripheral region surrounding the mounting hole 43b on the back side. In the joining base portion 45 of the jig 44, a plurality of bolt insertion holes 45a are formed in the outer peripheral region surrounding the standing portion 46. The standing portion 46 is inserted and mounted in the mounting hole 43b, and also, the front plate 43a is overlaid with the joining base portion 45 on the back side of the front plate 43a while the bolt insertion holes 45a are aligned with the bolt fastening holes 43c. In this state, the jig 44 is fastened and fixed to the front plate 43a with fastening bolts 47 to thereby attach the acceleration sensor 14 integrally to the fixing base portion 41a, 42a of the acceleration-detecting bit 41, 42.

[0034]

In the present embodiment, a connection cable 48, which is wiring connected to the acceleration sensor 14, is disposed inside the standing portion 46 via a connector 49 attached to the joining base portion 45 of the jig 44, and is also extended through a hollow inside 43d (see FIG. 3) of the cutter spoke 43 to be connected to the computer 20.

[0035]

In the present embodiment, the acceleration-detecting bit 41, 42 to which the acceleration sensor 14 is attached correspond to a leading bit 16b that is fixed to the front side of the front plate 43a of the cutter spoke 43 and cuts the ground first.

[0036]

In the present embodiment, as illustrated in FIG. 2, the cutterhead 13 to which the acceleration sensor 14 is attached has a circular shape in a front view with a radius of approximately 6800 mm, for example, and includes a disc-shaped center drum 13b and twelve cutter spokes 43. The center drum 13b is provided with a fishtail bit 13c and is jointed integrally with the center shaft 13a (see FIG. 1). The twelve cutter spokes 43 are integrally disposed and each extend radially outward from the center drum 13b. The twelve cutter spokes 43 are connected to each other at their radial distal end portions via an annular outer peripheral support ring 13d disposed concentrically with the center drum 13b, so that the cutter spokes 43 are integrally connected to each other and can firmly support a rotational reaction force generated when the ground portions 12a, 12b, and 12c are cut. In the cutterhead 13, each opening region surrounded by pairs of adjacent cutter spokes 43, the center drum 13b, and the outer peripheral support ring 13d serves as an opening 13e for taking in muck. The cutting muck generated by cutting the ground portion 12a, 12b, and 12c in the tunnel face 12 by the plurality of bits 16 attached to the cutterhead 13 is taken into the back chamber 19 through the openings 13e.

[0037]

As illustrated in FIG. 3, each of the twelve cutter spokes 43 in the present embodiment has a hollow cross-sectional shape of an isosceles trapezoid, for example, and the hollow inside 43d of the cutter spoke 43 preferably has a space large enough for a worker to enter. Thus, if necessary, a worker can perform a predetermined task in the hollow inside 43d, and various types of wiring and piping can also be disposed in the hollow inside 43d. The hollow inside 43d of each cutter spoke 43 is in communication with the insides of the center drum 13b and the center shaft 13a, and the various types of wiring and piping disposed can be extended behind the partition 17 via a known rotary joint provided in the center shaft 13a, for example.

[0038]

In the present embodiment, a plurality of bits 16 are disposed in predetermined positions on each of the cutter spokes 43 and the outer peripheral support ring 13d and attached integrally thereto using a known joining method. The bits 16 are of various known types, including a main bit, a trim bit, a scraper bit, and the copy cutter 16a, and also the leading bit 16b fixed to the front side of the front plate 43a and cutting the ground before the other bits 16.

[0039]

In the present embodiment, the plurality of leading bits 16b fixed to the front side of the front plate 43a of each of the cutter spokes 43 are arranged consecutively at a predetermined interval in the radial direction in two staggered rows, as illustrated in FIG. 2. Also, as illustrated in FIGS. 3 and 4(a) and 4(b), the fixing base portion of each leading bit is fixed to the front plate 43a of the cutter spoke 43 (see FIG. 2) by welding or other means so that the leading bit 16b is attached to the front plate 43a of the cutter spoke 43 and projects forward from the front plate 43a. In the present embodiment, from among the leading bits 16b, a leading bit 16b at one selected position disposed in the outer peripheral portion of the cutterhead 13 in, for example, one or two cutter spokes 43 corresponds to the outer peripheral acceleration-detecting bit 41, and preferably in the same cutter spoke 43, leading bit(s) 16b at one or two selected positions disposed in the intermediate region between the central portion and the outer peripheral portion of the cutterhead 13 correspond(s) to the intermediate acceleration-detecting bit 42. The acceleration sensor 14 is attached integrally to each of these acceleration-detecting bits 41 and 42 by the above-described attachment structure 40 including the jig 44 of the present embodiment. The vibration characteristics of a cutter spoke 43 is different from that of another cutter spoke 43; however, owing to the outer peripheral acceleration-detecting bit 41 and the intermediate acceleration-detecting bit 42 disposed preferably on the same cutter spoke 43, the difference in vibration characteristics is negligible. In the present embodiment, the outer peripheral acceleration-detecting bit 41 at one position and the intermediate acceleration-detecting bit 42 at one position, which correspond to the leading bits 16b, are provided, preferably in each of two selected cutter spokes 43, with the same separation distances from the center in the radial direction, as indicated by the triangle symbol in FIG. 2.

[0040]

Here, the “Stamina Bit” (trade name, available from Okumura Corporation), which has a configuration of a cutter bit for an excavator of Japanese Design Registration No. 1533573, can be preferably used as the plurality of leading bits 16b, some of which serve as the acceleration-detecting bits 41 and 42. The leading bit 16b (acceleration-detecting bit 41 and 42) corresponding to the “Stamina Bit” includes tip portions 41b and 42b made of super alloy and shank portions 41c and 42c made of steel, and has a function to hit and disturb the ground by the tip portions 41b and 42b. The acceleration-detecting bits 41 and 42 corresponding to the leading bits 16b include the fixing base portions 41a and 42a made of the same steel material as that of the shank portions 41c and 42c. The fixing base portion 41a, 42a is joined by welding or other means at the positions where the acceleration-detecting bit 41, 42 are to be attached, and specifically, at the positions where the mounting hole 43b and the bolt fastening holes 43c are formed in the front plate 43a of the cutter spoke 43. Thus, the acceleration-detecting bits 41 and 42 corresponding to the leading bits 16b are firmly fixed and attached integrally to the cutter spoke 43. The mounting hole 43b formed at the attachment position of the acceleration-detecting bit 41, 42 in the front plate 43a of the cutter spoke 43 is, for example, a circular through-hole having a diameter of approximately 30 mm. The bolt fastening holes 43c formed on the back side of the front plate 43a of the cutter spoke 43 are female screw holes with a thread diameter of approximately 12 mm, for example, and the bolt fastening holes 43c are at four locations in the outer peripheral region surrounding the mounting hole 43b, preferably with an even angular pitch of 90° in the circumferential direction. In the central portion of the bottom surface of the fixing base portion 41a, 42a of the acceleration-detecting bit 41, 42, a cutting-in hole 41d, 42d preferably having the same inner diameter to the mounting hole 43b is formed as an opening, and the cutting-in hole 41d, 42d serves as a part of the mounting hole 43b.

[0041]

The acceleration-detecting bits 41 and 42 are placed at the respective positions where they are to be attached on the front plate 43a of the cutter spoke 43, such that the longitudinal directions L of the fixing base portions 41a and 42a are matched with the circumferential direction of the cutterhead 13 (see FIG. 2), and also, such that the cutting-in holes 41d and 42d of the fixing base portions 41a and 42a are aligned with the mounting holes 43b of the front plate 43a. In this state, the acceleration-detecting bits 41

and 42 are fixed to the front plate 43a by welding or other means. Accordingly, in a state where the acceleration-detecting bits 41 and 42 are attached to the front plate 43a of the cutter spoke 43, the mounting hole 43b in which the standing portion 46 of the jig 44 is inserted and fixed extends to a depth all the way to the cutting-in hole 41d, 42d in the fixing base portion 41a, 42a of the acceleration-detecting bit 41, 42.

[0042]

Also, in the present embodiment, as illustrated in FIGS. 4(a) to 4(c) and FIGS. 5(a) to 5(d), the acceleration sensor 14 is housed in the internal leading end portion of the jig 44 of the present invention, and in this state, the acceleration sensor 14 is fixed and attached integrally to the acceleration-detecting bit 41, 42 with the jig 44. The jig 44 includes the joining base portion 45 and the standing portion 46 made of metal. The jig 44 is preferably a metallic hardware made of steel, and the joining base portion 45 has a disc shape with, for example, a diameter of approximately 100 mm and a thickness of approximately 16 mm. A circular fitting hole 45b is formed so as to extend through the central portion of the joining base portion 45, and into the circular fitting hole 45b, a standing base end portion 46a of the standing portion 46 is fitted and fixed. The bolt insertion holes 45a described above are formed at four locations (see FIG. 5(b)) in the outer peripheral region surrounding the fitting hole 45b and the standing base end portion 46a of the standing portion 46 fitted into the fitting hole 45b, preferably at an even angular pitch of 90° in the circumferential direction.

[0043]

The standing portion 46 of the jig 44 includes the standing base end portion 46a with a cylindrical shape and a leading end portion 46b with a notched cross-sectional shape (hereinafter also referred to as the leading end notched portion 46b). The leading end notched portion 46b is located on the leading end side of the standing base end portion 46a and has a notched cross-sectional shape formed by cutting off a side portion of a circular cross-section into an arcuate-shape. The standing portion 46 is joined to the joining base portion 45 by bonding or welding in a state in which the base end side portion of the standing base end portion 46a is fitted into the fitting hole 45a of the joining base portion 45. Thus, the standing portion 46 and the joining base portion 45 integrally form the jig 44 in a state in which the leading end side portion of the standing

base end portion 46a and the leading end notched portion 46b stand upright from the joining base portion 45.

[0044]

A hole for connector, 46c is formed in the base end side portion of the standing base end portion 46a, which is of the standing portion 46 and is embedded in the joining base portion 45, and the hole 46c has a female threaded protrusion, for example (hereinafter the hole for connector, 46c is also referred to as the connector hole 46c). The connecter hole 46c is used to connect the connector 49 for retracting the connection cable 48 inside the jig 44, the connection cable 48 extending through the hollow inside 43d of the cutter spoke 43. A hole for inserting wiring, 46e (see FIG. 5(d)) is formed in the leading end side portion of the standing base end portion 46a projecting from the joining base portion 45. The hole for inserting wiring, 46e is on the opposite side of a top member 46d to the connector hole 46c and has a semi-elliptical cross section, for example. A groove for arranging the wiring, 46f (see FIG. 5(c)) is formed in the notched face of the leading end notched portion 46b of the standing portion 46 except at the leading end portion of the standing portion 46 (hereinafter the groove for arranging the wiring, 46f is also referred to as the wiring arrangement groove 46f). The wiring arrangement groove 46f has a semi-elliptical cross-section, for example, and is continuous with the hole for inserting wiring, 46e of the standing base end portion 46a. A portion for mounting a sensor, 46g is formed at the leading end of the wiring arrangement groove 46f of the leading end notched portion 46b (hereinafter the portion for mounting a sensor, 46g is also referred to as the sensor mounting portion 46g). The sensor mounting portion 46g has a quadrangular hollow cross-sectional shape such that the acceleration sensor 14 preferably having a hexahedral shape can be positioned and housed therein in a non-rotatable state.

[0045]

A band-shaped opening of the wiring arrangement groove 46f extends in the standing direction in the central portion of the notched face in the arcuate shape in the leading end notched portion 46b of the standing portion 46. Screw holes 46h with a thread diameter of approximately 2 mm are formed at, for example, three locations with a predetermined interval in the standing direction on each of both sides of the wiring arrangement groove 46f, or i.e., at six locations in total. For example, by working in the

hollow inside 43d of the cutter spoke 43, the connection cable 48 disposed in the hollow inside 43d is drawn up through the connector 49 and the top member 46d to the wiring inserting hole 46e and wiring arrangement groove 46f side (see FIGS. 4(a) and 4(b)); the acceleration sensor 14 is attached at the leading end portion of the connection cable 48; the band-shaped opening of the wiring arrangement groove 46f is then covered with a cover plate 46i (see FIGS. 5(b) and 5(c)); and the cover plate 46i is attached by tightening fixing screws 46j into the screw holes 46h on both sides of the wiring arrangement groove 46f, with the connection cable 48 and the acceleration sensor 14 housed in the wiring arrangement groove 46f and the sensor mounting portion 46g. Accordingly, the acceleration sensor 14 connected to the computer 20 via the connection cable 48 can be housed and fixed integrally inside the jig 44 including the metal-made joining base portion 45 and the metal-made standing portion 46 standing upright from the joining base portion 45, while the acceleration sensor 14 is accurately and stably positioned at the leading end portion of the standing portion 46.

[0046]

In the present embodiment, as described above, the hole for inserting wiring, 46e of the standing base end portion 46a and the wiring arrangement groove 46f of the leading end notched portion 46b are formed inside the standing portion 46; the connection cable 48 and the acceleration sensor 14, which are connected to the computer 20, are disposed therein; and the band-shaped opening of the wiring arrangement groove 46f is covered with the cover plate 46i. Then, preferably, the hole for inserting wiring, 46e and the wiring arrangement groove 46f can be filled with a curable sealing material, and the curable sealing material can be solidified (cured) so that no gaps are formed around the connection cable 48 and the acceleration sensor 14. Thus, the acceleration sensor 14 and the connection cable 48 can be accurately positioned and fixed inside the jig 44 in a more stable state.

[0047]

In the present embodiment, the acceleration sensor 14 is a three-axis piezoelectric acceleration detector, for example, and can obtain cutting vibration data in three directions preferably including at least two directions perpendicular to each other. For example, as illustrated in FIGS. 6(a) to 6(d), the acceleration sensor 14 has a hexahedral shape having six faces disposed at right angles to each other and can obtain

cutting vibration data in each of three directions: the X direction, the Y direction, and the Z direction perpendicular to each face. The acceleration sensor 14 is housed in the sensor mounting portion 46g having a quadrangular hollow cross-sectional shape, which is in the leading end portion of the wiring arrangement groove 46f formed in the leading end notched portion 46b of the jig 44. On this occasion, for example, the acceleration sensor 14 is positioned and fixed such that the Z direction is aligned with the direction perpendicular to the standing direction of the standing portion 46, which is along the notched face of the leading end notched portion 46b; the X direction is aligned with the standing direction of the standing portion 46, which is along the notched face of the leading end notched portion 46b; and the Y direction is aligned with the direction perpendicular to the notched face of the leading end notched portion 46b.

[0048]

In this embodiment, as described above, the bolt insertion holes 45a are formed at four locations in the outer peripheral region surrounding the fitting hole 45b in the central portion of the joining base portion 45 and the standing base end portion 46a of the standing portion 46 fitted thereinto. As illustrated in FIG. 5(b), of the four bolt insertion holes 45a, two bolt insertion holes 45a, as one pair, are on both sides, respectively, of the fitting hole 45b and the standing base end portion 46a of the standing portion 46, in the face parallel with the notched face of the notched cross-sectional shape portion 46b; and the other two bolt insertion holes 45a, as the other pair, are on both sides, respectively, of the fitting hole 45b and the standing base end portion 46a of the standing portion 46, in the face perpendicular to the notched face of the notched cross-sectional shape portion 46b.

[0049]

On the other hand, at the attachment position of the acceleration-detecting bit 41, 42 in the front plate 43a of the cutter spoke 43, the bolt fastening holes 43c are formed at four locations in the outer peripheral region of the mounting hole 43b, in which the standing portion 46 of the jig 44 is inserted and fixed. Of the four bolt fastening holes 43c, two bolt fastening holes 43c, as one pair, are respectively on both sides of the mounting hole 43b, in a plane perpendicular with a longitudinal direction L of the acceleration-detecting bit 41, 42; and the other two bolt fastening holes 43c, as the other

pair, are respectively on both sides of the mounting hole 43b in a plane parallel with the longitudinal direction L of the acceleration-detecting bit 41, 42.

[0050]

Thus, according to the present embodiment, the leading bits 16b including the acceleration-detecting bits 41 and 42 are attached to the cutter spoke 43 of the cutterhead 13, and the mounting hole 43b and the bolt fastening holes 43c are formed in the front plate 43a at the attachment positions of the acceleration-detecting bits 41 and 42; in such a state, the standing portion 46 of the jig 44 with the acceleration sensor 14 housed in the internal leading end portion thereof is inserted and mounted in the mounting hole 43b such that the leading end portion of the jig 44 reaches the depth of the cutting-in holes 41d and 42d, and also, the joining base portion 45 is fastened with the fastening bolts 47 to the front plate 43a of the cutter spoke 43 from the back side to thereby fix the jig 44 to the front plate 43a. According to the present embodiment, such working can be easily and smoothly performed by a worker in the hollow inside 43d of the cutter spoke 43 that is preferably large enough for the worker to enter. Also, the acceleration sensor 14 can thus be easily and smoothly attached and fixed integrally to each of the acceleration-detecting bits 41 and 42 in the following preferable state: the Z direction as the first detection direction is aligned with the longitudinal direction L of the acceleration-detecting bit 41, 42, which corresponds to the rotation direction of the cutterhead 13, and at the same time, the X direction as the second detection direction is aligned with the projection direction of the acceleration-detecting bits 41 and 42 perpendicular to the front plate 43a of the cutter spoke 43 providing the head surface of the cutterhead 13, which corresponds to the direction of the advance of the cutterhead 13.

[0051]

In summary, the jig for use in detecting acceleration, 44 in a shield boring machine, which is of the present embodiment, is a jig used in a closed-type shield boring machine that includes the cutterhead 13 configured to rotate and provided at the leading end portion of the shield body 15 and that is configured to advance while cutting a tunnel face with the plurality of bits 16 attached to the cutterhead 13, and the jig 44 allows for fixing the acceleration sensor 14 integrally to a bit for detecting acceleration (the acceleration-detecting bit 41, 42) attached to the front plate 43a of the cutter spoke 43 of the cutterhead 13 by working from the back side of the front plate 43a, to accurately

detect the vibration acceleration of the acceleration-detecting bit 41, 42 during cutting. The jig 44 includes the joining base portion 45 and the standing portion 46 formed integrally with the joining base portion 45 and standing upright from the joining base portion 45. At the attachment position of the acceleration-detecting bit 41, 42 in the front plate 43a of the cutter spoke 43 of the cutterhead 13, the standing portion 46 is inserted and fixed in the mounting hole 43b extending through the front plate 43a and further extending through to the depth of the fixing base portion 41a, 42a of the acceleration-detecting bit 41, 42, and the joining base portion 45 is joined to the back side of the front plate 43a. In such a state, the jig 44 is used. For example, the bolt insertion holes 45a and the fastening bolts 47 can serve as a means for positioning and joining, and by this means, the position of the joining base portion 45 in the circumferential direction centered on the mounting hole 43b can be fixed on the back side of the front plate 43a. On that occasion, the orientation of the acceleration sensor 14 with respect to the means for positioning and joining (bolt insertion hole) 45a of the joining base portion 45 is adjusted by, for example, the hexahedral shape of the acceleration sensor 14 and the quadrangular hollow cross-sectional shape of the sensor mounting portion 46g so that the Z direction, which is one direction (first detection direction) for obtaining the cutting vibration data by the acceleration sensor 14 housed in the internal leading end portion of the standing portion 46, is aligned with the circumferential direction when the acceleration-detecting bits 41 and 42 rotationally move in conjunction with the rotation of the cutterhead 13. In that orientation-adjusted state of the acceleration sensor, the acceleration sensor 14 is fixed to the internal leading end portion of the standing portion 46.

[0052]

In the jig 44 of the present embodiment, preferably, the means for positioning and joining includes the bolt insertion holes 45a and the fastening bolts 47, as described above. The bolt insertion holes 45a are formed at least at two locations in the outer peripheral region surrounding the standing portion 46 in the joining base portion 45, such that the bolt insertion holes 45a are aligned with the bolt fastening holes 43c formed at least at two locations in the outer peripheral region surrounding the mounting hole 43b, preferably at the attachment position of the acceleration-detecting bit 41, 42 in the front plate 43a of the cutter spoke 43 of the cutterhead 13. The fastening bolts 47 are inserted and tightened in the bolt fastening holes 43c and the bolt insertion holes 45a that are aligned with each other.

[0053]

Further, as described above, it is preferable in the jig 44 of the present embodiment that the acceleration sensor 14 should have a hexahedral shape and be fitted and attached to the sensor mounting portion 46g with a quadrangular hollow cross-sectional shape formed in the internal leading end portion of the standing portion 46. Thus, the position of the acceleration sensor 14 in the circumferential direction in the standing portion 46 is fixed.

[0054]

As described above, in the jig 44 of the present embodiment, two paired bolt insertion holes 45a are respectively formed on both sides of the standing portion 46 in an imaginary plane parallel with a predetermined side face of the acceleration sensor with a hexahedral shape (a plane parallel with the plane along C-C of FIG. 5, for example), which is preferably fitted and attached in the sensor mounting portion 46g.

[0055]

Further, in the present embodiment, the standing portion 46 of the jig 44 can be inserted and mounted in the mounting hole 43b preferably in a state where the entire outer circumferential surface of the standing portion 46 is coated with or filled with an adhesive. Accordingly, the acceleration sensor 14 can be accurately positioned in the acceleration-detecting bit 41, 42 and firmly and integrally fixed in a stable state, preferably with the Z direction aligned with the longitudinal direction L of the acceleration-detecting bits 41 and 42, which is the rotation direction of the cutterhead 13.

[0056]

Thus, due to use of the jig 44 of the present embodiment, the acceleration sensor 14 can be easily and smoothly fixed integrally to the bit for detecting acceleration (the acceleration-detecting bit 41, 42) attached to the front plate 43a by simple working from the back side of the front plate 43a of the cutter spoke 43 of the cutterhead 13, in a state where the acceleration sensor 14 is positioned such that the detection direction Z, which is one of the detection directions, is aligned with a predetermined direction in the acceleration-detecting bit 41, 42, preferably with the direction along the rotation path of the circumferential direction in which the acceleration-detecting bits 41 and 42

rotationally move. In that simple working, for example, the standing portion 46 is inserted and mounted in the mounting hole 43b, and the jig 44 is fastened and fixed to the front plate 43a with the fastening bolts 47 in a state where the joining base portion 45 is overlaid with the front plate 43a from the back side with the bolt insertion holes 45a aligned with the bolt fastening holes 43c.

[0057]

For example, in a case where it is difficult to secure a space for a worker to enter in the hollow inside 43d of the cutter spoke 43, an openable and closable work window (not shown) may be appropriately provided in a region corresponding to the portion where the acceleration-detecting bits 41 and 42 are attached, preferably in a back plate 43e (see FIG. 3) of the cutter spoke 43. Accordingly, in a state where the leading bits 16b including the bits for detecting acceleration (the acceleration-detecting bits 41 and 42) are attached to the cutterhead 13 with the mounting hole 43b and the bolt fastening holes 43c formed at the attachment positions of the acceleration-detecting bits 41 and 42, the working can be performed smoothly via the openable and closeable window. In the working in this occasion, the jig 44 described above with the acceleration sensor 14 housed in the internal leading end portion of the standing portion 46 thereof is fixed by inserting the standing portion 46 in the mounting hole 43b to reach the depth of the cutting-in hole 41d, 42d, and fastening the joining base portion 45 to the front plate 43a of the cutter spoke 43 with the fastening bolts 47 from the back side.

[0058]

Further, it is preferable in the present embodiment that the Z direction described above as the first detection direction of the acceleration sensor 14 should be aligned with the longitudinal direction L of the acceleration-detecting bits 41 and 42, which is a direction following the rotational circumferential direction of the cutterhead 13, and that the X direction described above as the second detection direction of the acceleration sensor 14 should be aligned with a direction following the excavation direction, which is perpendicular to the head surface of the cutterhead 13. In this manner, the acceleration of the ground response in the rotational circumferential direction can be efficiently measured in the first detection direction Z, and the acceleration of the ground response of the excavation direction can be efficiently measured in the second detection direction X. Also, from the accelerations of the response detected by the outer peripheral acceleration-

detecting bit 41 and the intermediate acceleration-detecting bit 42, the plurality of concentric annular cutting vibration distributions 23a and 23b (see FIG. 7) can be obtained with better accuracy.

[0059]

In this embodiment, the auxiliary acceleration sensor 18 is attached to the back side of the partition 17, which serves as an inner wall of the shield body 15 to divide the chamber 19, as illustrated in FIG. 1. As with the acceleration sensor 14, the auxiliary acceleration sensor 18 is a 3-axis piezoelectric acceleration detector and is attached to the back side of the partition 17, preferably in a state where the first detection direction is aligned with the rotational circumferential direction of the cutterhead 13 and the second detection direction is aligned with the excavation direction of the shield boring machine 11. This makes it possible to efficiently and accurately measure the vibration specific to the shield body 15 to obtain data thereon during the operation of the shield boring machine 11. The auxiliary acceleration sensor 18 is connected to the acceleration sensor amplifier 25b via a connection cable. When the vibration data of the body is sent from the auxiliary acceleration sensor 18 to the computer 20 via the acceleration sensor amplifier 25b and the transmission system 29, the vibration data display unit 22 can display the cutting vibration data at every predetermined rotation angle sent from the acceleration sensor 14 as the plurality of concentric annular cutting vibration distributions 23a and 23b in which noise and mechanical vibration are removed.

[0060]

Further, in the present embodiment, a rotation meter (not shown) including a rotary encoder, for example, is attached to the center shaft 13a of the cutterhead 13. The rotation angle measured by the rotation meter is sent to the computer 20 via the transmission system 29, whereby the cutting vibration data obtained by the acceleration sensor 14 when the tunnel face 12 is cut can be stored in the vibration data storage unit 21 at every predetermined rotation angle.

[0061]

Here, according to the present embodiment, the frequency $\Delta\theta$, at which the acceleration sensor 14 performs measurement in the circumferential direction, is

determined by the calculation equation $\Delta\theta = r/60 \times \Delta t \times 360°$, where Δt is the time interval of data collection and r (ppm) is the rotation speed of the cutterhead 13. For example, in the case where the shield boring machine 11 is a small-diameter boring machine having an excavation outer diameter of approximately 2360 mm and a higher rotation speed of r = 2.3 (ppm) with a measurement time interval Δt of 0.1 seconds, solving $\Delta\theta = 2.3/60 \times 0.1 \times 360°$ results in a frequency $\Delta\theta$ of 1.38°, and thus the measurement by the acceleration sensor 14 is performed at every 1.38°.

[0062]

Also, in the present embodiment, for the purpose of grasping a position $\theta°$ in the circumferential direction of the acceleration sensor 14 in the cutterhead 13, a contact switch (not shown) may be installed in the center shaft 13a of the cutterhead 13. On this occasion, the top end of the shield boring machine 11, for example, can be defined as the zero point, whereby a reset can be performed every time the acceleration sensor 14 passes the zero point.

[0063]

In the present embodiment, the cutting vibration data obtained at every predetermined rotation angle by the acceleration sensor 14 is output via the dedicated amplifiers for the acceleration sensors, 25a and 25b, preferably together with the vibration data of the body obtained by the auxiliary acceleration sensor 18 at the same time when the cutting vibration data is obtained by the acceleration sensor 14. The output signal is sent through the control console 26 and the sequencer console 27, and thus, the output signal is sent to the operation management room 30 via the same transmission system 29 as for the other excavation management data.

[0064]

In the present embodiment, the computer 20 included in the system 10 of a shield boring machine for determining the distribution of the geological properties of the ground in the tunnel face includes the vibration data storage unit 21 and the vibration data display unit 22 as described above. The vibration data storage unit 21 stores the cutting vibration data at every predetermined rotation angle of the cutterhead 13, the cutting vibration data being obtained when the tunnel face 12 is cut by the cutter bits 16 and sent from the

acceleration sensor 14 to the computer 20 via the amplifier for the acceleration sensor, 25a and the transmission system 29. Also, the vibration data storage unit 21 stores the vibration data of the body at every predetermined rotation angle of the cutterhead 13, the vibration data of the body being obtained when the tunnel face 12 is cut by the cutter bits 16 and sent from the auxiliary acceleration sensor 18 to the computer 20 via the amplifier for the acceleration sensor, 25b and the transmission system 29. The vibration data of the body is data on the vibration of the shield body 15 itself caused by, for example, the driving of the motor for rotary driving. In the computer 20, a known management system for shield excavation is installed, and in the management system, the cutting vibration data and the vibration data of the body are integrated, in time series, with found values collected from various measuring instruments for the shield construction method, and can be preferably stored as data linked to the ring number of each ring into which segments are assembled.

[0065]

The vibration data display unit 22 displays the cutting vibration data at every predetermined rotation angle stored in the vibration data storage unit 21 as the plurality of concentric annular cutting vibration distributions 23a and 23b in which the cutting vibrations are visually shown in a distributed manner in the circumferential direction of the circle simulating the cross section as the tunnel face. Specifically, as illustrated in FIG. 7, the vibration data display unit 22 can display the cutting vibration data at every predetermined rotation angle in the form of a plurality of concentric annular cutting vibration distributions 23a and 23b on, for example, the display 20a connected to the computer 20, and the concentric annular cutting vibration distributions 23a and 23b preferably show the distribution of vibration accelerations (accelerations of the ground response at the time of cutting), in terms of magnitude, at every predetermined rotation angle in which noise and mechanical vibration are removed on the basis of the vibration data of the body sent from the auxiliary acceleration sensor 18.

[0066]

Also, the computer 20 includes a boundary line display unit 31 (see FIG. 1) for determining the boundary between the ground portions 12a, 12b, and 12c having different geological properties in the tunnel face 12, and the boundary is determined from the fluctuation points 24a and 24b at which the waves representing the distribution fluctuate

in the circumferential direction in the cutting vibration distributions 23a and 23b displayed by the vibration data display unit 22. As illustrated in FIG. 7, the boundary line display unit 31 preferably displays, as the boundary between the ground portions having different geological properties in the tunnel face, a connecting line 50 that is a polygonal line sequentially connecting the adjacent pairs of fluctuation points 24a, 24b, 24b, 24a at which the waves representing the distribution fluctuate in the plurality of concentric annular cutting vibration distributions 23a and 23b displayed by the vibration data display unit 22. The boundary line display unit 31 can also display, as the boundary between the ground portions having different geological properties in the tunnel face, a connecting line 51 that is a linear line connecting the midpoints of the adjacent pairs of fluctuation points 24a and 24b on both sides in the plurality of concentric annular cutting vibration distributions 23a and 23b displayed by the vibration data display unit 22.

[0067]

The cutting vibration distributions 23a and 23b illustrated in FIG. 7 are distributions of the vibration acceleration, in terms of magnitude, from the data on the cutting vibration preferably in the Z direction, which is the rotational circumferential direction of the cutterhead 13, and the Z direction here corresponds to the direction for obtaining the cutting vibration data by the acceleration sensors 14 attached to the outer peripheral acceleration-detecting bit 41 and the intermediate acceleration-detecting bit 42. The cutting vibration distributions 23a and 23b are displayed on the display 20a, preferably in which noise and mechanical vibration are removed on the basis of the vibration data of the body in the first detection direction obtained by the auxiliary acceleration sensor 18, the first detection direction being the rotational circumferential direction of the cutterhead 13. Accordingly, the cutting vibration distributions 23a and 23b displayed can more accurately reflects the conditions of the ground portions 12a, 12b, and 12c in the tunnel face 12 during cutting by the cutterhead 13.

[0068]

For a shield tunnel, segments are assembled into a ring, and rings constitute the shield tunnel. Regarding the excavation span corresponding to one ring, the cutting vibration data for the cutting vibration distributions 23a and 23b as illustrated in FIG. 7 can be obtained in the following manner, for example. Measurement of the cutting vibrations is started at the time when the jack stroke of the shield jack or the thrust jack

has advanced 100 mm after the start of excavation for an excavation span corresponding to one ring; the cutting vibration is continuously measured while the cutterhead 13 rotates five times; and the average for five rotations is used as the cutting vibration data.

[0069]

Further, the cutting vibration data for the cutting vibration distributions 23a and 23b as illustrated in FIG. 7 is data obtained by the outer peripheral acceleration-detecting bit 41 and the intermediate acceleration-detecting bit 42 attached to one of two selected cutter spokes 43 each having the outer peripheral acceleration-detecting bit 41 and the intermediate acceleration-detecting bit 42. The accuracy of the cutting vibration distributions 23a and 23b can be confirmed by additionally obtaining the cutting vibration distributions 23a and 23b from the cutting vibration data obtained by the outer peripheral acceleration-detecting bit 41 and the intermediate acceleration-detecting bit 42 attached to the other cutter spoke 43. It is also preferable that the cutting vibration distributions 23a and 23b should be obtained from the average of the cutting vibration data obtained by the outer peripheral acceleration-detecting bits 41 and the intermediate acceleration-detecting bits 42 of the two cutter spokes 43.

[0070]

According to the above-described system for determining the distribution of the geological properties of the ground in a tunnel face by a shield boring machine, the boundary between the ground portions 12a, 12b, and 12c having different geological properties in the tunnel face 12 can be easily determined from the plurality of concentric annular cutting vibration distributions 23a and 23b as illustrated in FIG. 7 displayed by the vibration data display unit 22. Specifically, in the present embodiment, the fluctuation points 24a and 24b of vibrations, at which the tendency of the distribution of vibrations is clearly changed, can be easily determined by observing the displayed concentric cutting vibration distributions 23a and 23b in the circumferential direction. In the cutting vibration distributions 23a and 23b illustrated in FIG. 7, the fluctuation points 24a and 24b of vibrations can be identified at one location each on the left and right sides. Further, the layered structure of the ground portions 12a, 12b, and 12c in the tunnel face 12 can be determined by drawing the polygonal connecting line 50 or the linear connecting line 51 in the above-described manner on the basis of the fluctuation points 24a and 24b on the left and right sides, and preferably, the geological property of each layer of the layered

structure determined can be easily identified with reference to the columnar section of the surrounding ground.

[0071]

Further, the system for determining the distribution of the geological properties of the ground in a tunnel face includes the boundary line display unit 31, which displays the lines 50 and 51 connecting the pairs of the fluctuation points 24a and 24b on the left and right sides as the boundary between the ground portions 12a, 12b, and 12c having different geological properties in the tunnel face 12. Accordingly, the boundary between ground portions having different geological properties in the tunnel face 12 and the layered structure of the ground portions 12a, 12b, and 12c can be more easily grasped from the connecting lines 50 and 51 displayed on the boundary line display unit 31.

[0072]

The present invention is not limited to the embodiments described hereinabove, and various modifications can be made. For example, the unit for positioning and joining need not necessarily include bolt insertion holes at the attachment position of the acceleration detection bit and fastening bolts, the bolt insertion holes being formed at least at two locations in the outer peripheral region surrounding the standing portion in the joining base portion such that the bolt insertion holes are aligned with bolt fastening holes formed at least at two locations in the outer peripheral region surrounding the mounting hole. Using any other various units for positioning and joining, the orientation of the acceleration sensor with respect to the joining base portion can be adjusted so that one direction for obtaining the cutting vibration data by the acceleration sensor is aligned with the circumferential direction of when the acceleration detection bit rotationally moves. The acceleration sensor need not necessarily have a hexahedral shape, and the position of the acceleration sensor in the circumferential direction in the standing portion may be fixed by a method other than the above-described method including fitting the acceleration sensor into the sensor mounting portion having a quadrangular hollow cross-sectional shape.

[0073]

In the present embodiment described above, the cutterhead is a spoke type;

however, the present invention can be applied to, for example, a case where the cutterhead is a face plate type. When the cutterhead is a face plate type, the cutter spokes correspond to the main frame of the cutter face plate. If a bit needs to be replaced during the excavation work, the replacement can be performed in the same manner as in the embodiments described above; specifically, after a bit is attached first by welding or other means to the front plate of the cutter spoke, the standing portion of a jig housing an acceleration sensor is inserted and mounted in the mounting hole of the front plate, and also the base portion of the jig is fixed to the front plate with fixing bolts, to thereby attaching the acceleration sensor.

Industrial Applicability

[0019]

The jig for use in detecting acceleration in a shield boring machine according to the present invention allows for easily and smoothly fixing, by simple working from the back side of the front plate of the cutterhead, an acceleration sensor integrally to a bit for detecting acceleration attached to the front plate in a state where the acceleration sensor is disposed such that one detection direction is aligned with a predetermined direction in the bit.

CLAIMS

[Claim 1]

A jig for use in detecting acceleration in a closed-type shield boring machine that comprises a cutterhead configured to rotate and provided at a leading end portion of a shield body and that is configured to advance while cutting a tunnel face with a plurality of bits attached to the cutterhead,

the jig allowing for fixing an acceleration sensor integrally to a bit for detecting acceleration attached to a front plate of the cutterhead by working from a back side of the front plate, to accurately detect vibration acceleration of the acceleration-detecting bit during cutting,

the jig comprising: a joining base portion, and a standing portion for mounting, the standing portion formed integrally with the joining base portion and standing upright from the joining base portion,

wherein the jig is used in a state where, at an attachment position of the acceleration-detecting bit in the front plate of the cutterhead, the standing portion is inserted and fixed in a mounting hole extending through the front plate and further extending through to a depth of a fixing base portion of the acceleration-detecting bit, and in a state where the joining base portion is joined to the back side of the front plate, and

wherein by a means for positioning and joining, the position of the joining base portion in the circumferential direction centered on the mounting hole is fixed on the back side of the front plate; and on that occasion, the orientation of the acceleration sensor with respect to the positioning and joining means of the joining base portion is adjusted so that one direction for obtaining the cutting vibration data by the acceleration sensor housed in an internal leading end portion of the standing portion is aligned with the circumferential direction when the acceleration-detecting bits rotationally move, and in that orientation-adjusted state of the acceleration sensor, the acceleration sensor is fixed to the internal leading end portion of the standing portion.

[Claim 2]

The jig according to claim 1, wherein

the means for positioning and joining comprises bolt insertion holes and fastening bolts,

the bolt insertion holes are formed at least at two locations in the outer peripheral region surrounding the standing portion in the joining base portion, such that the bolt insertion holes are aligned with bolt fastening holes formed at least at two locations in the outer peripheral region surrounding the mounting hole at the attachment position of the acceleration-detecting bit in the front plate of the cutterhead, and

the fastening bolts are inserted and tightened in the bolt fastening holes and the bolt insertion holes that are aligned with each other.

[Claim 3]

The jig according to claim 1 or 2, wherein

the acceleration sensor has a hexahedral shape and is fitted and attached to a sensor mounting portion with a quadrangular hollow cross-sectional shape formed in the internal leading end portion of the standing portion, to thereby fix the position of the acceleration sensor in the circumferential direction in the standing portion.

[Claim 4]

The jig according to claim 3, wherein

two paired bolt insertion holes are respectively formed on both sides of the standing portion in an imaginary plane parallel with a predetermined side face of the acceleration sensor with a hexahedral shape fitted and attached in the sensor mounting portion.

[Claim 5]

The jig according to claim 1 or 2, wherein

a connection cable connected to the acceleration sensor is disposed in a hole for inserting wiring or a groove for arranging wiring formed inside the standing portion.

[Claim 6]

The jig according to claim 5, wherein

the hole for inserting wiring or the groove for arranging wiring in which the connection cable is disposed is filled with a curable sealing material, and the curable sealing material is solidified.