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(54) ROBOT-SUPPORTED FLEXIBLE-ARM BORING MACHINE CAPABLE OF EXCAVATING TUNNEL WITH ARBITRARY CROSS SECTION

(57) Disclosed is a robot (4)-supported flexible-arm boring machine capable of excavating a tunnel with any cross-section, comprising a cutterhead and cutter system (1) and a main beam (6). A rear portion of the main beam (6) is connected to a front portion of a rear gripper (8) by means of a thrust cylinder (7); a rear portion of the rear gripper (8) is connected to a rear support (9); and a front portion of the main beam (6) is flexibly connected to the cutterhead and cutter system (1) by means of a robot (4).

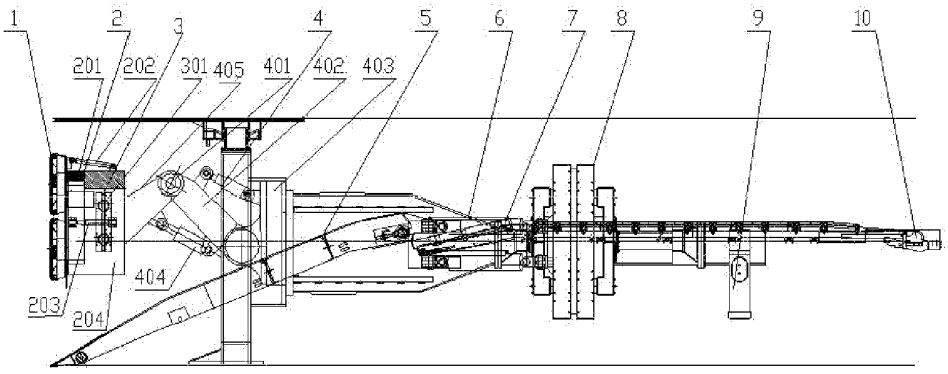

FIG. 1

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Description

Technical Field

[0001] The present invention relates to the field of rock tunnel boring machines (TBMs) for use in tunnel construction, and in particular to a robot-supported flexible-arm boring machine (Robot-TBM) capable of excavating a tunnel with any cross-section, which realizes the excavation of a tunnel with any cross-sectional shape within a certain range.

Background Art

[0002] Rock tunnel boring machines (TBMs) are tunnel excavation equipment integrating multidisciplinary techniques such as optical, mechanical, electrical and hydraulic techniques, which play an important role in the construction of projects such as hydraulic tunnels, railway tunnels, urban rail transit tunnels and comprehensive pipe galleries.

[0003] At present, such boring machines mainly utilize the rotation of a cutterhead for rock breaking and excavation, excavation cross-sections of the boring machines are mostly circular, so the boring machines are difficult to adapt to tunnel projects with the requirements for horseshoe-shaped, rectangular-like and other diverse cross-sections. Although there are a few project cases where the boring machines may cooperate with other apparatuses in excavation to implement rectangular, horseshoe-shaped and other specially-shaped cross-sections, these specially-shaped cross-sections are all applied to the excavation of soft ground tunnels, and are rarely reported in construction cases in rock tunnel engineering.

[0004] In addition, once the excavation cross-section of the tunnel boring machines is determined, it is difficult to change again, the excavation cross-section thereof is single in shape and is limited in application range, so that it is hard to satisfy the requirements for different cross-sections of different projects and even for different cross-sections of the same project, and an idle state of the tunnel boring machines after project completion occurs occasionally.

[0005] Currently, for rock tunnels, there are more and more roads, railways and other traffic tunnel projects where formed cross-sections use double-circular, rectangular, horseshoe-shaped and other specially-shaped cross-sections. If a conventional circular boring machine is used for excavation, the excavation amount of a project will be increased inevitably, and the extra excavated part also needs secondary backfilling, so that the project cost is increased, manpower and material resources are wasted, and the construction period is prolonged. Therefore, it is urgent to design a novel hard rock boring machine capable of meeting the engineering requirements for different excavation cross-sections.

[0006] At present, since cutterheads of the tunnel boring machines (shield tunneling machines and TBMs) are all fixed, the cutterheads can only be pitched and yawed in a small range to adjust a tunneling direction, and the shape of the excavation face is limited. Once the excavation cross-section of the tunnel boring machines is determined, it is difficult to change again, the excavation cross-section thereof is single in shape and poor in excavation flexibility, and is limited in application range, so that it is hard to satisfy the requirements for different cross-sections of different projects and even for different cross-sections of the same project. A new boring machine needs to be redesigned to perform excavation with cross-sections in different shapes, causing that the cost is high, the period is long, and the lack of flexibility under complex geological conditions influences the construction progress. At present, the boring machine works with a single cutterhead, limiting the working efficiency, and the single cutterhead structure may generate a large reactive torque during excavation, so that the boring machine always works under the action of a large stress. Up to now, the strength of the boring machine is improved mainly by increasing the size and the thickness of key components such as a main beam thereof, wasting a large amount of manpower and material resources. Now, a robot-supported multi-cutterhead torque-coupled boring machine capable of forming any cross-section is designed, which realizes excavation of a large cross-section in any shape while using coupled torques of multiple cutterheads to reduce a stress of a key component.

Summary of the Invention

[0007] In order to meet the current excavation requirements for diversified cross-sections of tunnels and overcome the defect of existing tunnel boring machines with a single excavation cross-section, the present invention provides a novel robot-supported multi-cutterhead boring machine capable of forming any cross-section, which realizes the excavation with a large cross-section in any shape while using coupled torques of multiple cutterheads to reduce a stress of a key component.

[0008] In order to solve the above technical problems, a technical solution adopted by the present invention is as follows: a robot-supported flexible-arm boring machine capable of excavating a tunnel with any cross-section, comprising a cutterhead and cutter system and a main beam, a rear portion of the main beam being connected to a front portion of a rear gripper by means of a thrust cylinder, and a rear portion of the rear gripper being connected to a rear support, wherein a front portion of the main beam is flexibly connected to the cutterhead and cutter system by means of a robot.

[0009] The cutterhead and cutter system comprises a cutterhead, and the cutterhead and cutter system is connected to a front portion of the robot by means of a cutterhead torque resisting gripper system.

[0010] The cutterhead and cutter system comprises two cutterheads, which are arranged at the front portion

of the robot in parallel.

[0011] The cutterhead and cutter system comprises at least three cutterheads, and the cutterhead and cutter system is connected to the front portion of the robot by means of the cutterhead torque resisting gripper system.

[0012] The robot comprises a cutterhead posture adjusting mechanism and a robot arm, the cutterhead and cutter system is provided on the cutterhead posture adjusting mechanism in parallel, the robot arm at the rear portion of the cutterhead posture adjusting mechanism is connected to the main beam, and the cutterhead torque resisting gripper system is provided on the cutterhead posture adjusting mechanism.

[0013] The cutterhead posture adjusting mechanism comprises a connecting seat, a front end of the connecting seat is respectively movably connected to a number of cutterhead and cutter sub-systems by means of joint bearings, and pitch cylinders and yaw cylinders are provided outside the connecting seat, with a pitch cylinder and a yaw cylinder being provided between each cutterhead and cutter sub-system and the connecting seat.

[0014] The cutterhead torque resisting gripper system comprises grippers, gripper cylinders and a support seat, wherein the support seat is provided on the cutterhead posture adjusting mechanism, and the grippers are connected to the support seat by means of the gripper cylinders.

[0015] The robot arm is a serial robot arm. The serial robot arm comprises a large robot arm, a small robot arm and a rotating base, wherein the rotating base is provided on the main beam, a front end of the small robot arm is fixedly connected to the connecting seat, a rear end of the large robot arm is hinged to the rotating base by means of a movement joint, and the large robot arm is hinged to the small robot arm; and a telescopic cylinder is provided between the rotating base and the large robot arm and between the large robot arm and the small robot arm respectively.

[0016] The robot arm is a serial-parallel robot arm, the serial-parallel robot arm comprising a rotating frame, a moving frame and a sliding rail, wherein the rotating frame is provided at an upper portion of the moving frame, one side of the moving frame matches the sliding rail, and the sliding rail is provided on the main beam; a first cylinder and a third cylinder are provided on the rotating frame in parallel, the first cylinder is connected to a second cylinder in series by means of a serial joint I, and the third cylinder is connected to a fourth cylinder in series by means of a serial joint II; and the second cylinder and the fourth cylinder are connected to the cutterhead posture adjusting mechanism by means of the connecting seat.

[0017] A muck discharging system is provided below the cutterhead and cutter system, a front end of the muck discharging system extends to a position below the cutterhead and cutter system, and a rear end thereof is connected to a belt conveyor.

[0018] The cutterhead and cutter system comprises a main cutterhead and a number of secondary cutterheads, wherein an outer diameter of the main cutterhead is not smaller than that of the secondary cutterheads, and the secondary cutterheads are provided outside the main cutterhead.

[0019] According to the present invention, the hard rock excavating cutterheads are configured, a flexible structure and a large conversion range of cross-sections are achieved by controlling the positions and the postures of the cutterheads supported by the intelligent serial robot, so that the excavation of a rock tunnel with any cross-section can be really realized.

[0020] The robot (in the form such as series connection, parallel connection, or serial-parallel connection)-supported flexible-cutterhead excavation system of the present invention may excavate a cross-section in any shape; the structure of a combined cutterhead and cutter system with coupled torques of multiple cutterheads offsets a stress generated during working, optimizing the structure and reducing the cost. A novel muck discharging system (including a muck scraping and suctioning system in any form) located at a bottom of a tunnel may clear and output rock muck generated by the boring machine.

[0021] The flexible-arm boring machine (Robot-TBM) of the present invention lies in that a number of groups of hydraulic cylinders are elastically connected between the cutterheads of the boring machine and a support girder, and distances between the cutterheads and the girder change as the excavation position changes.

Brief Description of the Drawings

[0022]

FIG. 1 is a structural schematic diagram of the present invention;

FIG. 2 is a structural schematic diagram of a cutterhead posture adjusting mechanism with a cutterhead torque resisting gripper system of the present invention;

FIG. 3 is a structural schematic diagram of an arrangement of a cutterhead of the present invention;

FIG. 4 is a structural schematic diagram of an arrangement of two cutterheads of the present invention;

FIG. 5 is a structural schematic diagram of an arrangement of three cutterheads of the present invention;

FIG. 6 is a structural schematic diagram of an arrangement of four cutterheads of the present invention;

FIG. 7 is a structural schematic diagram of an arrangement of five cutterheads of the present invention;

FIG. 8 is a structural schematic diagram of a robot arm of the present invention, which is a serial robot arm, in a use state;

FIG. 9 is a structural schematic diagram of a robot arm of the present invention, which is a serial-parallel robot arm, in a use state; and

FIG. 10 is a structural schematic diagram of the serial-parallel robot arm of Embodiment 3 of the present invention.

Detailed Description of Embodiments

[0023] The technical solutions of the embodiments of the present application will be described below clearly and comprehensively in conjunction with the drawings of the embodiments of the present invention. Obviously, the embodiments described are merely some embodiments of the present invention and are not all the possible embodiments. All the other embodiments, which are obtained by a person of ordinary skill in the art based on the embodiments of the present invention without involving any inventive effort, shall fall within the scope of protection of the present invention.

[0024] As shown in FIGS. 1 to 3, a robot-supported flexible-arm boring machine (Robot-TBM) capable of excavating a tunnel with any cross-section comprises a main beam 6, a rear portion of the main beam 6 being connected to a front portion of a rear gripper 8 by means of a thrust cylinder 7, and a rear portion of the rear gripper 8 being flexibly connected to a rear support 9, wherein the front portion of the main beam 6 is flexibly connected to a cutterhead and cutter system 1 by means of a robot 4, the cutterhead and cutter system 1 comprises a cutterhead, and the cutterhead and cutter system is connected to a front portion of the robot by means of a cutterhead torque resisting gripper system.

[0025] As shown in FIG. 4, in a robot-supported flexible-arm boring machine (Robot-TBM) capable of excavating a tunnel with any cross-section, the cutterhead and cutter system 1 comprises two cutterheads, which are arranged at the front portion of the robot 4 in parallel. The two cutterheads are respectively a cutterhead I and a cutterhead II. The cutterhead I and the cutterhead II are provided at a front portion of a cutterhead posture adjusting mechanism 3 in parallel, and a rear portion of the cutterhead posture adjusting mechanism 3 is connected to the main beam 6 by means of a robot arm. According to the present invention, the cutterhead I and the cutterhead II are both complete and independently operable cutterhead systems as shown in FIG. 4, and are mounted on the same support, and the robot 4 controls the positions of the cutterhead systems. The robot 4 may be in a serial connection structure form, a parallel connection structure form or a serial-parallel connection structure form selected according to different engineering requirements, and may plan multi-degree-of-freedom movements of the cutterheads by means of off-line preprogramming, manual teaching and other control methods. The cutterhead posture adjusting mechanism 3 in the present invention may be regarded as a dexterous robot hand and is mainly configured to drive the cutterheads to rotate and adjust postures of the cutterheads. The robot arm is a robot body, may be in a serial connection form, a parallel connection form or a serial-parallel connection form as required in the present invention, is mainly used for adjusting the positions of the cutterhead systems, and may realize the multi-degree-of-freedom movements of the cutterheads and excavation of different cross-sections by using preprogramming, human-machine interaction, or other control methods. The other structures are the same as those in Embodiment 1.

[0026] The cutterhead and cutter system 1 comprises at least three cutterheads, and the cutterhead and cutter system 1 is connected to the front portion of the robot 4 by means of a cutterhead torque resisting gripper system 3.

[0027] The front portion of the robot 4 is provided with the cutterhead torque resisting gripper system 3.

[0028] The robot 4 comprises a cutterhead posture adjusting mechanism 3 and a robot arm, the cutterhead and cutter system 1 is provided on the cutterhead posture adjusting mechanism 3 in parallel, the robot arm at the rear portion of the cutterhead posture adjusting mechanism 3 is connected to the main beam 6, and the cutterhead torque resisting gripper system 3 is provided on the cutterhead posture adjusting mechanism 3. A number of cutterhead and cutter sub-systems 1 form a combined cutterhead system, the size and power of each cutterhead in the combined cutterhead are adjusted according to the desired size of cross-section and working torque, the combined cutterheads are uniformly mounted on a cutterhead support seat, and the robot controls the movements and posture adjustments of the cutterheads. FIGS. 5 to 7 illustrate schematic diagrams of arrangement forms and directions of rotation of three cutterheads, four cutterheads and five cutterheads, respectively, in which a reactive torque generated during boring is offset by adjusting the directions of rotation of the different cutterheads. The excavating cutterheads of the boring machine in the form of multi-cutterhead coupling may be expanded in such a manner that torques are mutually coupled and offset.

[0029] The cutterhead posture adjusting mechanism 3 comprises a connecting seat 204, a front end of the connecting seat 204 is respectively movably connected to a number of cutterhead and cutter sub-systems 1 by means of joint bearings 201, and pitch cylinders 202 and yaw cylinders 203 are provided outside the connecting seat 204, with a pitch cylinder 202 and a yaw cylinder 203 being provided between each cutterhead and cutter sub-system 1 and the connecting seat 204. The pitch cylinder performs up-down pitching actions of the cutterhead, and the yaw cylinder performs left-right yawing actions of the cutterhead. The pitch cylinder 302 is arranged perpendicular to the yaw cylinder 303. A rear portion of each cutterhead is provided with a cutterhead main driving structure, and the pitch cylinder and the yaw cylinder of the cutterhead posture adjusting mechanism 3 are perpendicular and orthogonal to each other to adjust the

posture of the cutterhead.

[0030] The cutterhead torque resisting gripper system 3 comprises grippers 301, gripper cylinders 302 and a support seat 303, wherein the support seat 303 is provided on the cutterhead posture adjusting mechanism 3, and the grippers 301 are connected to the support seat 303 by means of the gripper cylinders 302. The support seat 303 is provided on the connecting seat 204 of the cutterhead posture adjusting mechanism 3. The cutterhead torque resisting gripper system 3 is bracing devices fixed inside the cutterhead, which are symmetrically arranged on two sides of the cutterhead, the grippers 301 may be attached to a tunnel wall, the gripper cylinders 302 are telescopic cylinders and may control extension and retraction of the gripper, the number of the gripper cylinders 302 is two, the two gripper cylinders 302 may be independently controlled, and the support seat 303 is a cylinder support seat located inside the cutterhead. After the arrangement mode of the cutterheads is determined, if torques generated by the cutterheads during boring cannot be completely offset by adjusting the rotating speeds and directions of rotation of the cutterheads, the cutterhead torque resisting gripper system 3 is started. A plurality of gripper cylinders 302 may be provided as required, and the extension of different gripper cylinders 302 may be controlled as required.

[0031] As shown in FIG. 8, the robot arm of the present invention is a serial robot arm 40. The serial robot arm 40 comprises a large robot arm 402, a small robot arm 405 and a rotating base 403, wherein the rotating base 403 is provided on the main beam 6, a front end of the small robot arm 405 is fixedly connected to the connecting seat 204, a rear end of the large robot arm 402 is hinged to the rotating base 403 by means of a movement joint 401, and the large robot arm 402 is hinged to the small robot arm 405; and a telescopic cylinder 404 is provided between the rotating base 403 and the large robot arm 402 and between the large robot arm 402 and the small robot arm 405 respectively. The serial robot arm 4 is a mechanical arm body of a serial robot, wherein the large robot arm 401 is a main force receiving mechanism, the telescopic cylinders 402 are configured to achieve the movement of the robot arm, the movement joint 404 is a rotary joint of the robot, the rotating base 403 is fixed to the main beam to achieve a rotating movement of the robot, and multi-degree-of-freedom movements of the cutterheads may be realized by means of preprogramming, human-machine interaction or other control methods.

[0032] As shown in FIGS. 9 and 10, the robot arm of the present invention is a serial-parallel robot arm 42. The serial-parallel robot arm 42 comprises a rotating frame 421, a moving frame 422 and a sliding rail 423, wherein the rotating frame 421 is provided at an upper portion of the moving frame 422, one side of the moving frame 422 matches the sliding rail 423, and the sliding rail 423 is provided on the main beam 6; a first cylinder 425 and a third cylinder 428 are provided on the rotating frame 421 in parallel, the first cylinder 425 is connected to a second cylinder 427 in series by means of a serial joint I 426, and the third cylinder 428 is connected to a fourth cylinder 420 in series by means of a serial joint II 429; and the second cylinder 427 and the fourth cylinder 420 are connected to the cutterhead posture adjusting mechanism 3 by means of the connecting seat 204. The moving frame 422 is driven by a drive 424. According to the present invention, a plurality of cylinders, such as three, four or five cylinders, may be provided on the rotating frame 301 in parallel as required, facilitating better control over the cutterhead and cutter system. In the present invention, two cylinders are connected in parallel on the rotating frame 301, so that the system is easier and is convenient to control.

[0033] The second cylinder 427 and the fourth cylinder 420 are connected to the cutterhead posture adjusting mechanism 3 by means of the connecting seat 204. In the serial-parallel robot arm 42, the cutterhead posture adjusting mechanism 3 serves as a dexterous hand of the serial-parallel robot and is mainly used for adjusting the postures of the cutterheads. The serial-parallel robot arm 42 serves as the robot body, wherein the rotating frame 421 achieves the rotating movement of the robot, and the moving frame 422 achieves the movement of the robot along the sliding rail 423; the first cylinder 425, the serial joint I 426 and the second cylinder 427, and the third cylinder 428, the serial joint II 429 and the fourth cylinder 420 respectively form two serial mechanisms of the robot; and the first cylinder 425 and the second cylinder 428 are connected in parallel on the rotating frame, so that the multi-degree-of-freedom movements of the cutterheads can be achieved by means of preprogramming, human-machine interactive teaching or other methods to achieve different excavation cross-sections.

[0034] The serial-parallel robot arm 42 of the present invention drives the cutterheads to move back and forth through the extension and retraction of the first cylinder 425 and the third cylinder 428, achieves the up-down movements of the cutterheads through the movement of the moving frame 422 along the sliding rail, drives the cutterheads to rotate through the rotation of the rotating frame 421 itself, and adjusts excavation angles of the cutterheads through the extension and retraction of the second cylinder 427 or the fourth cylinder 420.

[0035] A muck discharging system 5 is provided below the cutterhead and cutter system 1, a front end of the muck discharging system 5 extends to a position below the cutterhead and cutter system 1, and a rear end thereof is connected to a belt conveyor 10. The muck discharging system 5 is a belt conveyor muck discharging system or a screw conveyor muck discharging system, the belt conveyor 10 is provided at a tail portion of the muck discharging system, and the muck discharging system 5 delivers muck below the cutterheads 1 to the outside of the boring machine and conveys the muck out. The other structures are the same as those in Embodiment 1.

[0036] The cutterhead and cutter system 1 of the

present invention comprises a main cutterhead 101 and a number of secondary cutterheads 102, wherein an outer diameter of the main cutterhead 101 is not smaller than that of the secondary cutterheads 102, and the secondary cutterheads 102 are provided outside the main cutterhead 101. When three cutterhead and cutter systems 1 are provided, a main cutterhead and two secondary cutterheads are provided, as shown in FIG. 3, the two secondary cutterheads are provided outside the main cutterhead, a torque generated by the main cutterhead is offset by adjusting the rotating speeds and the directions of rotation of the secondary cutterheads, and if the torque cannot be offset completely, the cutterhead torque resisting gripper system 3 will be started. When four cutterhead and cutter systems 1 are provided, as shown in FIG. 6, the main cutterhead has the same size as the secondary cutterheads, and the rotating speeds and the directions of rotation of the various cutterheads are adjusted to correct the torque of each cutterhead. When five cutterhead and cutter systems 1 are provided, a main cutterhead and four secondary cutterheads are provided, as shown in FIG. 7, the four secondary cutterheads are provided outside the main cutterhead, the torque generated by the main cutterhead is offset by adjusting the rotating speeds and directions of rotation of the secondary cutterheads, and if the torque cannot be completely offset, the cutterhead torque resisting gripper system 3 is started. When more cutterhead and cutter systems 1 are provided, the principle is the same as above, and the aim of offsetting the torque is achieved by adjusting the rotating speeds and directions of rotation. The other structures are the same as those in Embodiment 1.

[0037] In the present invention, during working, comprised are the following steps: 1, designing the number, the size and the directions of rotation of cutterheads in a combined cutterhead and cutter system according to parameters such as excavating torque requirements; 2, preprogramming a movement trajectory of an intelligent robot according to shape requirements of a construction cross-section; 3, bringing a boring machine to a working range of the robot, which brings the cutterheads to designated positions according to the set trajectory; 4, bracing grippers against a tunnel wall, and making thrust cylinders and a main drive work; 5, making a bottom muck discharging system work and conveying out rock muck that has fallen to the bottom of a tunnel by means of a belt conveyor; and 6, after a certain excavation volume is reached, repeating steps 2-4 to perform cycling at a next station.

Claims

1. A robot-supported flexible-arm boring machine capable of excavating a tunnel with any cross-section, comprising a cutterhead and cutter system (1) and a main beam (6), a rear portion of the main beam (6) being connected to a front portion of a rear gripper (8) by means of a thrust cylinder (7), and a rear portion of the rear gripper (8) being connected to a rear support (9), **characterized in that** a front portion of the main beam (6) is flexibly connected to the cutterhead and cutter system (1) by means of a robot (4).

2. The robot-supported flexible-arm boring machine capable of excavating a tunnel with any cross-section according to claim 1, **characterized in that** the cutterhead and cutter system (1) comprises a cutterhead, and the cutterhead and cutter system (1) is connected to a front portion of the robot (4) by means of a cutterhead torque resisting gripper system (3).

3. The robot-supported flexible-arm boring machine capable of excavating a tunnel with any cross-section according to claim 1, **characterized in that** the cutterhead and cutter system (1) comprises two cutterheads, which are arranged at the front portion of the robot (4) in parallel.

4. The robot-supported flexible-arm boring machine capable of excavating a tunnel with any cross-section according to claim 1, **characterized in that** the cutterhead and cutter system (1) comprises at least three cutterheads, and the cutterhead and cutter system (1) is connected to the front portion of the robot (4) by means of the cutterhead torque resisting gripper system (3).

5. The robot-supported flexible-arm boring machine capable of excavating a tunnel with any cross-section according to any one of claims 2-4, **characterized in that** the robot (4) comprises a cutterhead posture adjusting mechanism (2) and a robot arm, the cutterhead and cutter system (1) is provided on the cutterhead posture adjusting mechanism (2) in parallel, the robot arm at a rear portion of the cutterhead posture adjusting mechanism (2) is connected to the main beam (6), and the cutterhead torque resisting gripper system (3) is provided on the cutterhead posture adjusting mechanism (2).

6. The robot-supported flexible-arm boring machine capable of excavating a tunnel with any cross-section according to claim 5, **characterized in that** the cutterhead posture adjusting mechanism (2) comprises a connecting seat (204), a front end of the connecting seat (204) is respectively movably connected to a number of cutterhead and cutter subsystems (1) by means of joint bearings (201), and pitch cylinders (202) and yaw cylinders (203) are provided outside the connecting seat (204), with a pitch cylinder (202) and a yaw cylinder (203) being provided between each cutterhead and cutter sub-system (1) and the connecting seat (204).

7. The robot-supported flexible-arm boring machine capable of excavating a tunnel with any cross-section according to claim 2 or 4, **characterized in that** the cutterhead torque resisting gripper system (3) comprises grippers (301), gripper cylinders (302) and a support seat (303), wherein the support seat (303) is provided on the cutterhead posture adjusting mechanism (2), and the grippers (301) are connected to the support seat (303) by means of the gripper cylinders (302).

8. The robot-supported flexible-arm boring machine capable of excavating a tunnel with any cross-section according to claim 7, **characterized in that** the robot arm is a serial robot arm (40), the serial robot arm (40) comprising a large robot arm (402), a small robot arm (405) and a rotating base (403), wherein the rotating base (403) is provided on the main beam (6), a front end of the small robot arm (405) is fixedly connected to the connecting seat (204), a rear end of the large robot arm (402) is hinged to the rotating base (403) by means of a movement joint (401), and the large robot arm (402) is hinged to the small robot arm (405); and a telescopic cylinder (404) is provided between the rotating base (403) and the large robot arm (402) and between the large robot arm (402) and the small robot arm (405) respectively.

9. The robot-supported flexible-arm boring machine capable of excavating a tunnel with any cross-section according to claim 7, **characterized in that** the robot arm is a serial-parallel robot arm (42), the serial-parallel robot arm (42) comprising a rotating frame (421), a moving frame (422) and a sliding rail (423), wherein the rotating frame (421) is provided at an upper portion of the moving frame (422), one side of the moving frame (422) matches the sliding rail (423), and the sliding rail (423) is provided on the main beam (6); a first cylinder (425) and a third cylinder (428) are provided on the rotating frame (421) in parallel, the first cylinder (425) is connected to a second cylinder (427) in series by means of a serial joint I (426), and the third cylinder (428) is connected to a fourth cylinder (420) in series by means of a serial joint II (429); and the second cylinder (427) and the fourth cylinder (420) are connected to the cutterhead posture adjusting mechanism (2) by means of the connecting seat (204).

10. The robot-supported flexible-arm boring machine capable of excavating a tunnel with any cross-section according to claim 1, **characterized in that** a muck discharging system (5) is provided below the cutterhead and cutter system (1), a front end of the muck discharging system (5) extends to a position below the cutterhead and cutter system (1), and a rear end thereof is connected to a belt conveyor (10).

11. The robot-supported flexible-arm boring machine capable of excavating a tunnel with any cross-section according to claim 4, **characterized in that** the cutterhead and cutter system (1) comprises a main cutterhead (101) and a number of secondary cutterheads (102), wherein an outer diameter of the main cutterhead (101) is not smaller than that of the secondary cutterheads (102), and the secondary cutterheads (102) are provided outside the main cutterhead (101).

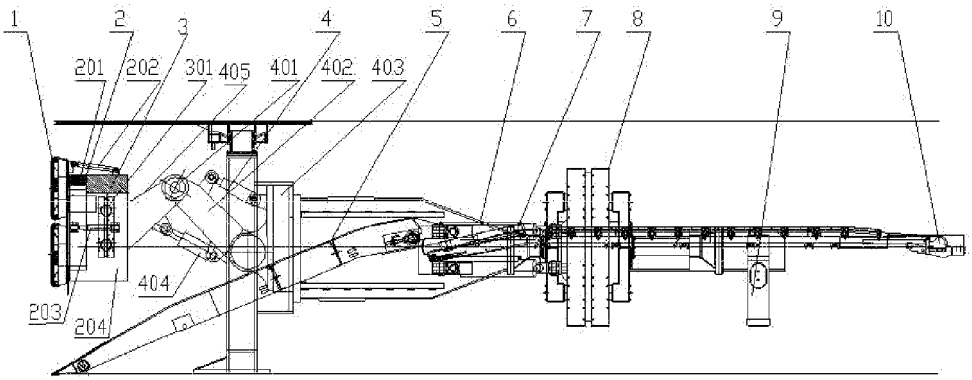
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FIG. 1

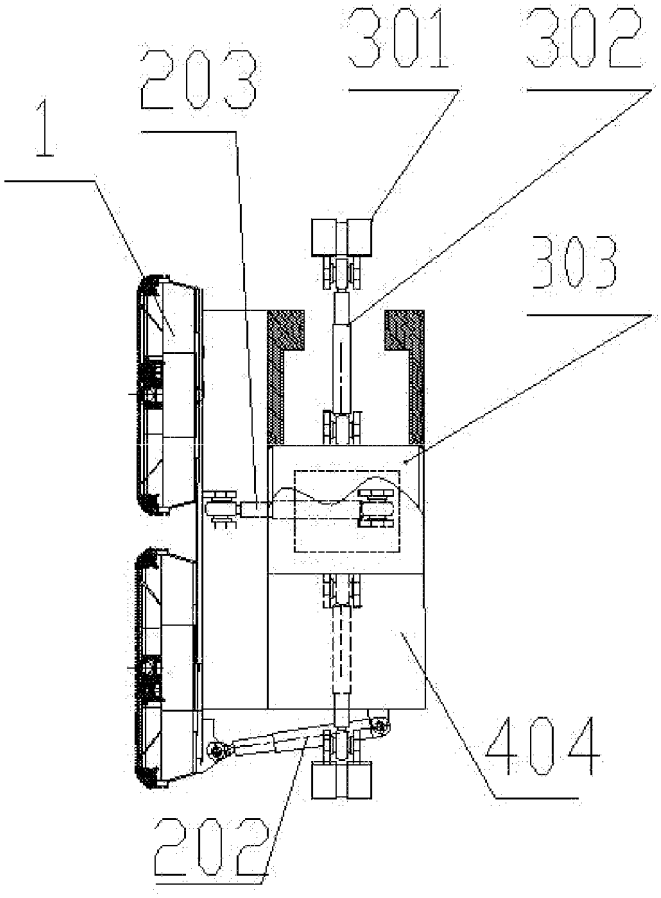
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FIG. 2

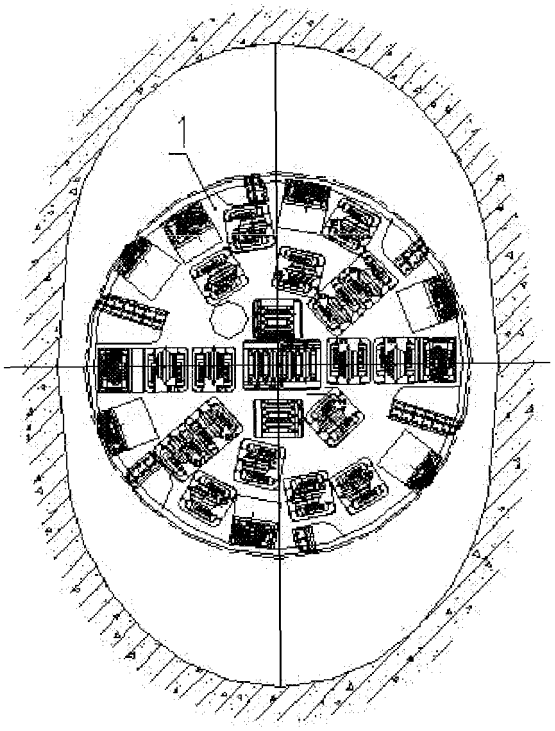

FIG. 3

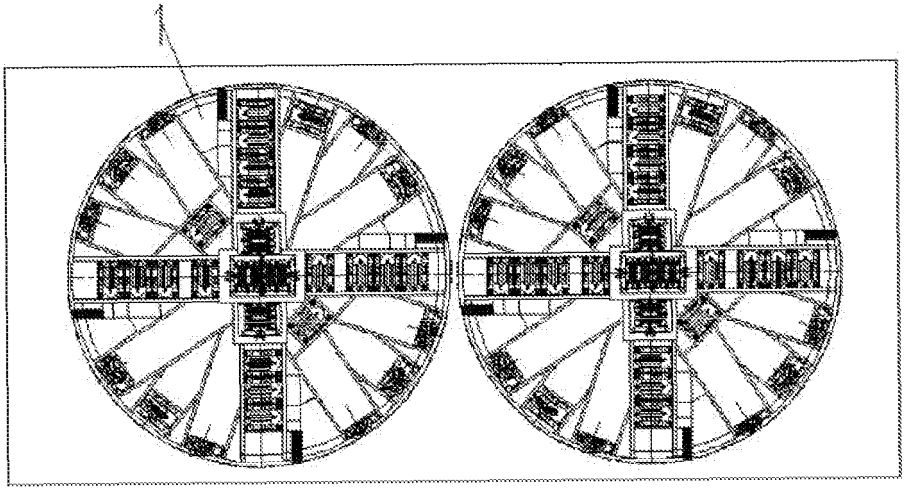

FIG. 4

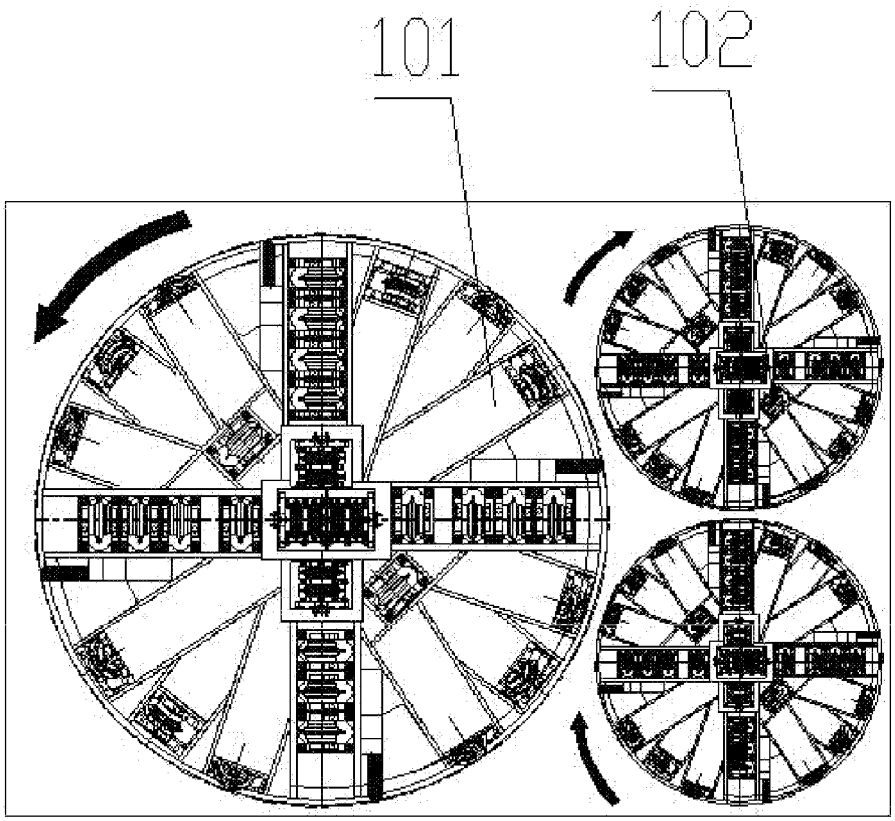

FIG. 5

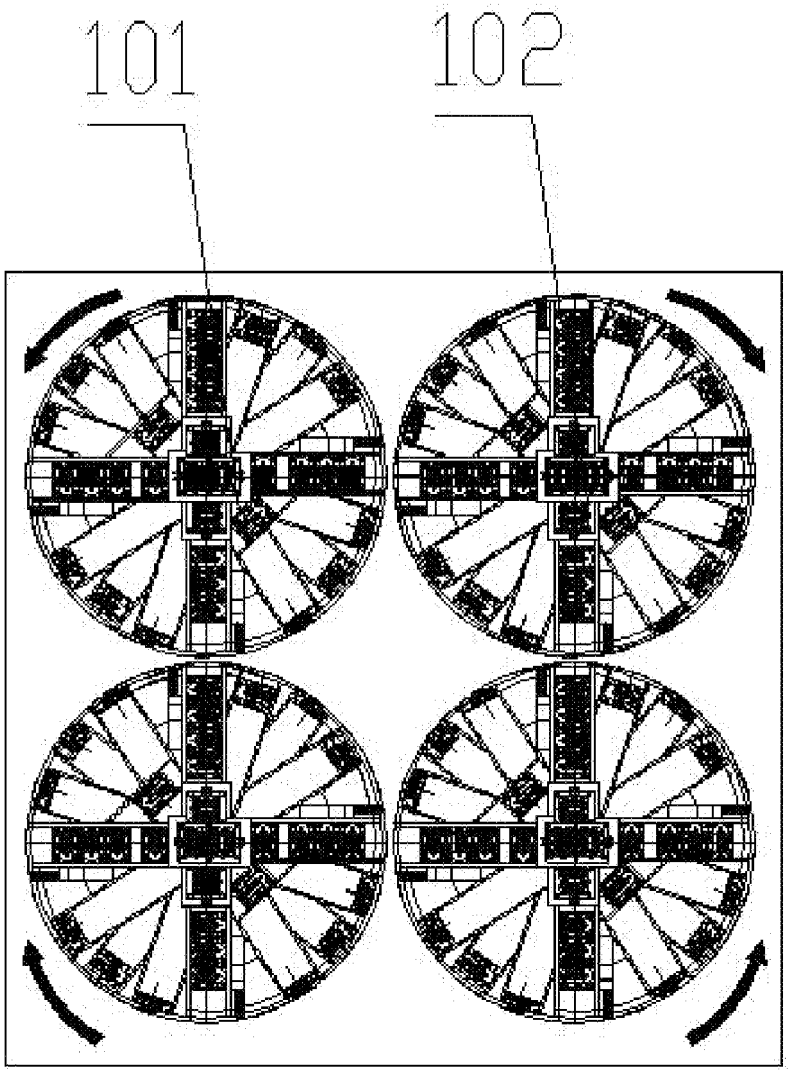

FIG. 6

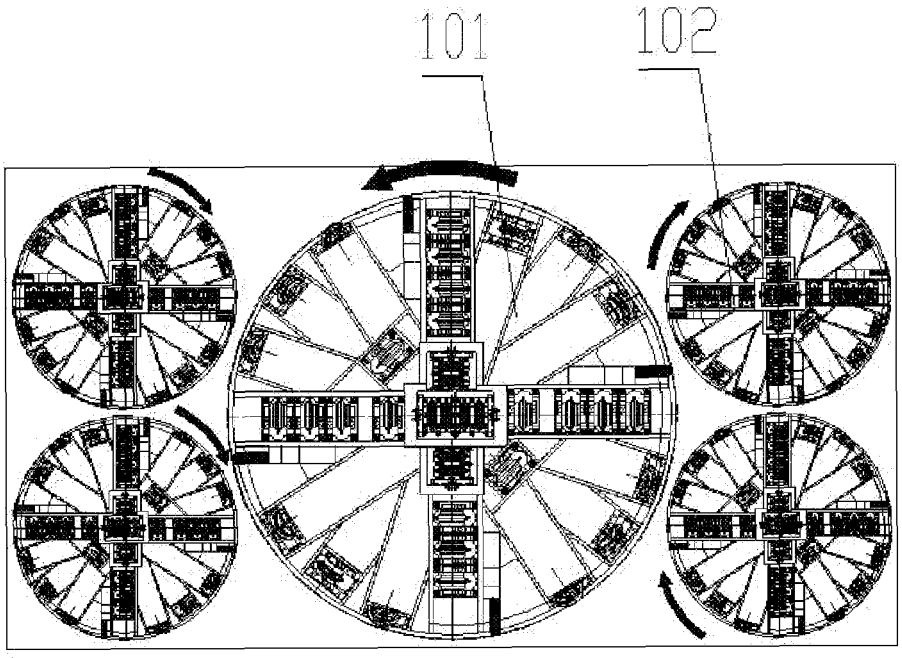

FIG. 7

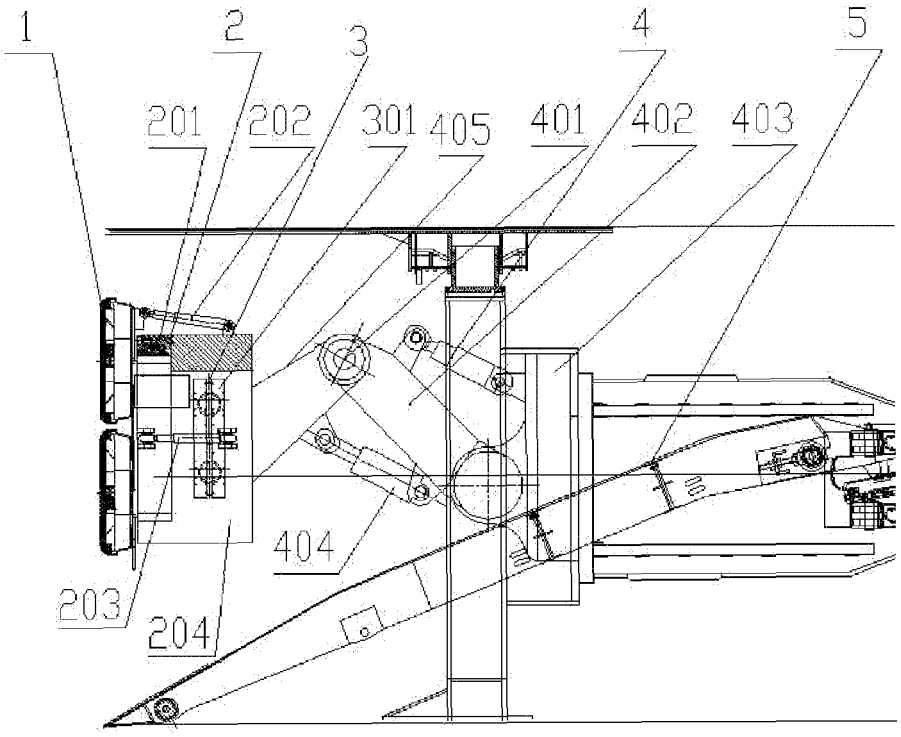

FIG. 8

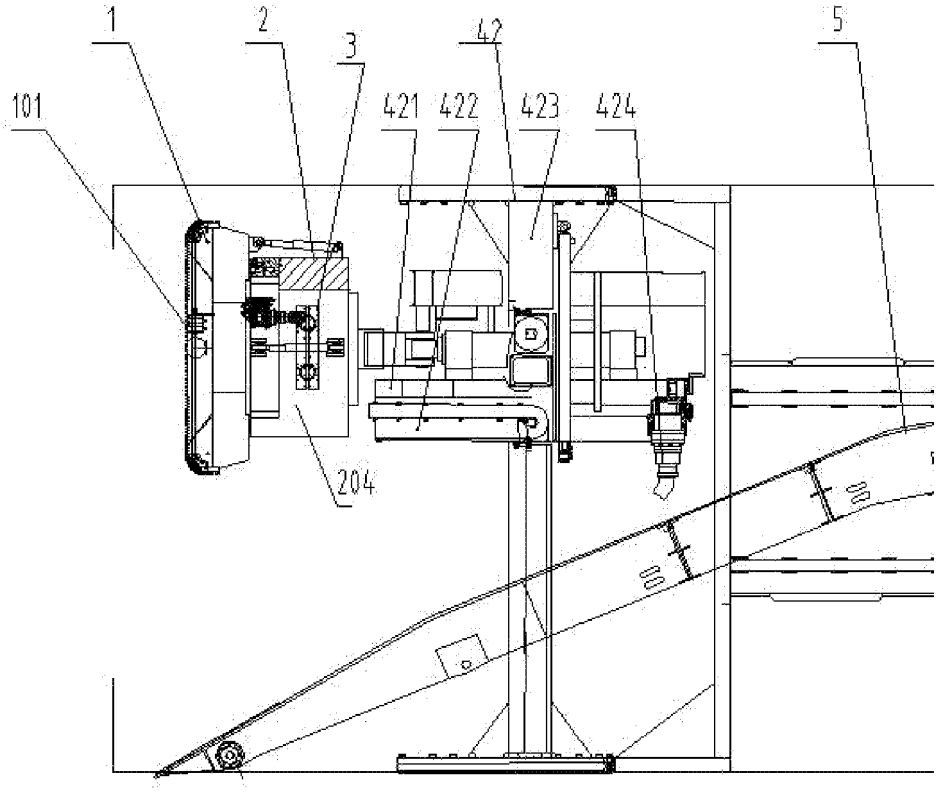

FIG. 9

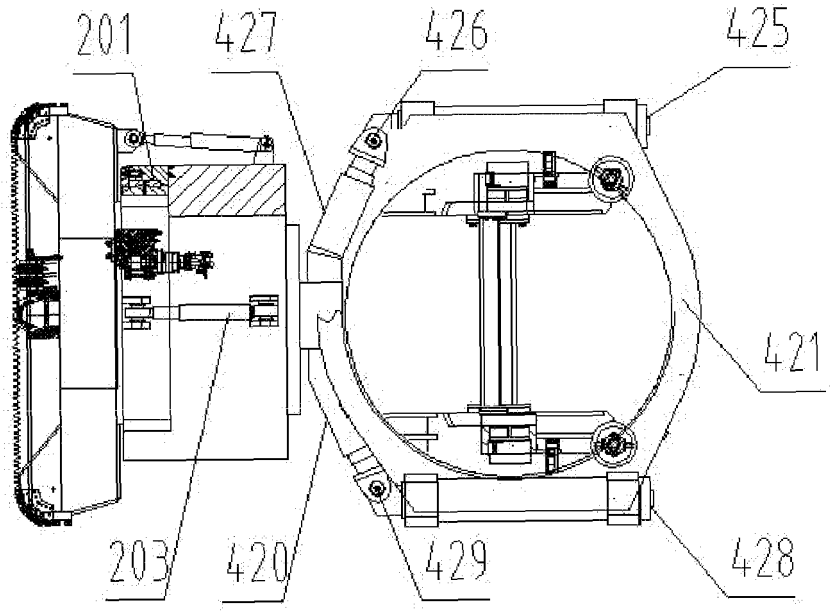

FIG. 10

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CN2019/090461

A. CLASSIFICATION OF SUBJECT MATTER

E21D 9/087(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

E21D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

CNABS; CNTXT; CNKI; VEN; USTXT; WOTXT; EPTXT: 掘进机, 柔臂, 柔性, 油缸, 液压缸, 断面, 撑靴, 刀盘, 扭矩, TBM, robot, cylinder, arm?, cutter?, section, support+, torque

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
PX	CN 109209413 A (CHINA RAILWAY ENGINEERING EQUIPMENT GROUP CO., LTD.) 15 January 2019 (2019-01-15) description, paragraphs [0022]-[0041], and figures 1-14	1-11
PX	CN 109236315 A (CHINA RAILWAY ENGINEERING EQUIPMENT GROUP CO., LTD.) 18 January 2019 (2019-01-18) description, paragraphs [0018]-[0034], and figures 1-14	1-11
PX	CN 109236314 A (CHINA RAILWAY ENGINEERING EQUIPMENT GROUP CO., LTD.) 18 January 2019 (2019-01-18) description, paragraphs [0015]-[0026], and figures 1-4	1, 3, 10
PX	CN 109488323 A (CHINA RAILWAY ENGINEERING EQUIPMENT GROUP CO., LTD.) 19 March 2019 (2019-03-19) description, paragraphs [0017]-[0028], and figures 1-10	1, 3, 10
PX	CN 109236313 A (CHINA RAILWAY ENGINEERING EQUIPMENT GROUP CO., LTD.) 18 January 2019 (2019-01-18) description, paragraphs [0014]-[0026], and figures 1-5	1, 3, 10

☑ Further documents are listed in the continuation of Box C. ☑ See patent family annex.

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
29 July 2019	**29 August 2019**
Name and mailing address of the ISA/CN **China National Intellectual Property Administration (ISA/CN)** **No. 6, Xitucheng Road, Jimenqiao, Haidian District, Beijing 100088** **China**	Authorized officer
Facsimile No. **(86-10)62019451**	Telephone No.

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INTERNATIONAL SEARCH REPORT

International application No.
PCT/CN2019/090461

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
PX	CN 109209420 A (CHINA RAILWAY ENGINEERING EQUIPMENT GROUP CO., LTD.) 15 January 2019 (2019-01-15) description, paragraphs [0019]-[0035], and figures 1-12	1, 3, 10
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Y	JP H0791180 A (MITSUBISHI HEAVY INDUSTRIES, LTD.) 04 April 1995 (1995-04-04) description, paragraphs [0009]-[0015], and figures 1 and 2	1-11
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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/CN2019/090461

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