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Research on key technologies of drilling auxiliary robots for geothermal drilling platforms

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Abstract: *Aiming at the problems of low automation level, high labor intensity, and large investment capital for the overall upgrade of the traditional geothermal drilling platform faced by the exploitation of traditional geothermal resources, a drilling auxiliary robot consisting of a mechanical assistant and a rotary buckling robot is designed. According to the functional requirements, the overall structural design of the drilling assistant robot for geothermal drilling platform is carried out, and the three-dimensional digitized design of the mechanical assistant and the rotary buckle manipulator is given. The results of the study contribute greatly to reducing the labor force of geothermal drilling operations and provide a reference for the automation design of geothermal drilling rig platforms.*

Keywords: *Drilling platform, Robot, Space requirements, Structural design*

1. Introduction

Since the 21st century, the development of renewable energy sources has been advocated worldwide as the growing demand for primary energy, which is currently supplied by about 78% mainly by fossil fuels [1], raises issues related to sustainable energy development, energy security, affordability, environmental protection, and global greenhouse gas (GHG) emissions. And the whole world is advocating the development of renewable energy [2-3]. Geothermal, with its abundant resources [4-5], has the potential to provide green energy to meet some of the major global energy needs, replace the use of fossil fuels and help reduce greenhouse gas emissions [6-7]. In China, the reserves of geothermal resources are very large, accounting for about 1/6 of the global resources. 250 geothermal fields have been identified, more than 2,000 hot springs have been identified, and the number of geothermal wells has reached 6,000, which has led to the rapid development of geothermal mining equipment [8-9]. At present, the drilling platforms used for geothermal development are mainly used for lifting the main drilling tools up and down the drilling platform by winches, and although the buttons on the drilling rods are docked with semi-automated tools such as hydraulic tongs, it is still necessary to manually pull the rods over, which is labor-intensive for the workers, and at the same time the automation degree is low, which is a potential safety hazard [10-11]. Moreover, the existing geothermal drilling rigs have low automation level, high labor intensity and poor safety, which has become the bottleneck of speeding up and improving efficiency of drilling, and there is an urgent need for the research and development of geothermal drilling rigs with high automation level and easy dismantling and installation to satisfy such a broad geothermal development market [12-13]. This paper takes geothermal drilling platform KV3000 as the research basis, and in response to the problems of low automation level and high labor intensity of geothermal drilling platforms, it researches a set of drilling auxiliary robots instead of manual operation, which greatly reduces the labor force and ensures the safety and stability of drilling operations. On the other hand, the drilling auxiliary robot is of great significance to realize the automation of geothermal drilling equipment, which expands the application prospect of geothermal drilling automation.

2. Overall program design

2.1. General functional analysis

The drill pipe auxiliary robot is one of the important wellhead mechanization, the robot mainly completes the delivery of drill pipe and the upper unloading buckle docking work. The geothermal drilling platform KV3000 is used for geothermal drilling by Hebei Land and Sea Drilling Co., Ltd. and its nominal drilling depth can reach 3,000 m. When determining the functional requirements of the

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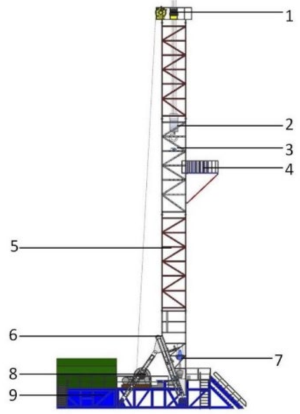
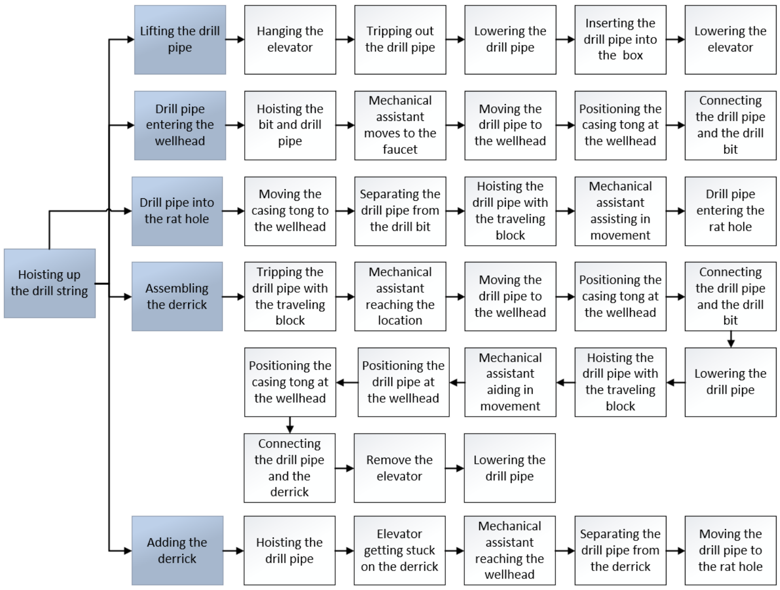
drilling auxiliary robot, it is necessary to firstly understand the operating procedures of the platform and the main functional requirements of the drilling auxiliary robot. After a site visit and organizing the data, the modeling of the geothermal drilling platform KV3000 was completed, as shown in Figure 1.



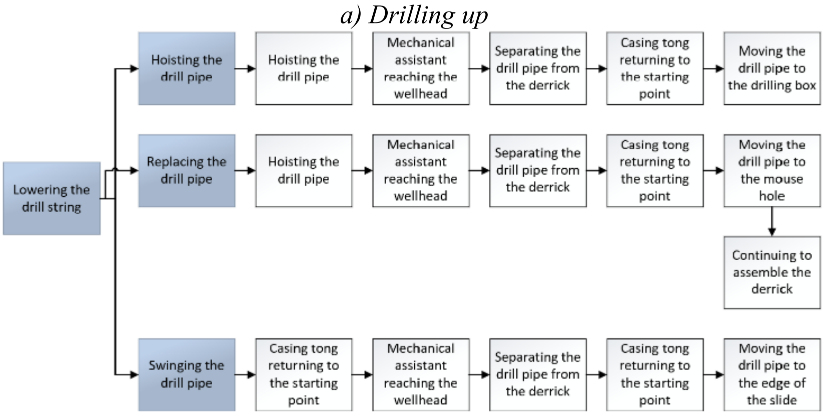
1- Overhead crane; 2- Big hook; 3- Hook; 4- Second floor platform;
5-Derrick; 6-Beam; 7-Power tap; 8-Winch; 9-Base

Figure 1: Geothermal drilling rig KV3000

After reviewing the information related to the drilling process, the process flow of drilling rod operation of the drilling auxiliary robot was added on its basis, as shown in Figure 2:



a) Drilling up



b) Drilling down

Figure 2: Drill assist robot drill pipe operation process flow

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Combined with the process flow of geothermal drilling, the main work of the drilling auxiliary robot is to improve the automation level of the first layer and realize the unmanned discharge and docking of the first layer of drill pipe. The workflow diagram of the drilling auxiliary robot is shown in Figure 3.

Firstly, the rotary platform and electric actuator of the mechanical assistant will transport the drill pipe and drilling tools to the wellhead position, then the rotary buckle manipulator will align the rotary buckle pliers and clamps to the drill pipe through the slide rail, the clamps will clamp the drill pipe below, and the rotary buckle pliers will rotate to drive the drill pipe above, to complete the docking of the drill pipe and drilling tools, and the mechanical assistant and the rotary buckle manipulator will work together to complete the automation of unloading and unloading of the drill pipe. The mechanical assistant mainly transports the drill pipe, while the rotary buckling manipulator completes the work of docking the drill pipe.

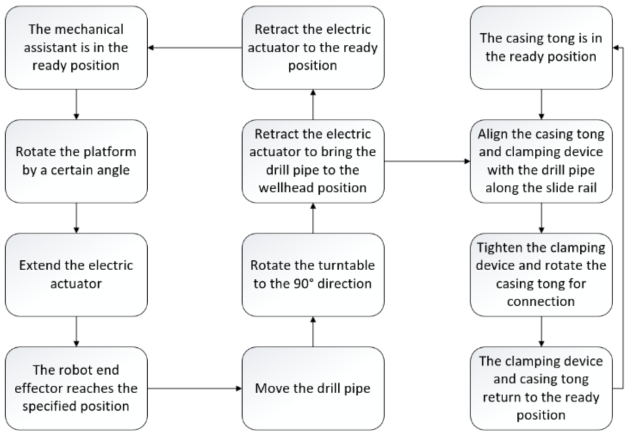

Figure 3: Workflow diagram

2.2. Layout program design

The drilling assistant robot, as a part of the geothermal drilling platform KV3000 to deal with the drill pipe, is mainly composed of two parts, the mechanical assistant and the spinning robot. According to the functional requirements, the mechanical assistant is mainly used to complete the movement of the drill pipe, and the spinning robot is used to complete the uploading and unloading of the drill pipe for butt jointing, and both of them cooperate with each other to complete the automated handling of one layer of the drill pipe. The designed drilling assistant robot is mainly applied to the geothermal drilling platform KV3000, due to the small space of the drilling platform, the spatial layout of the drilling assistant robot is the most prioritized issue. The spatial layout of the drilling assistant robot is the highest priority, and the influence of some parts on the original geothermal drilling platform on the drilling assistant robot in terms of distance or space is also taken into consideration. Combined with the 3D modeling of the geothermal drilling platform KV3000, all the parts that may have an impact on the robot are placed on the base, and then its projection is used to study the position of each point, and the plane of the geothermal drilling platform is shown in Figure 4.

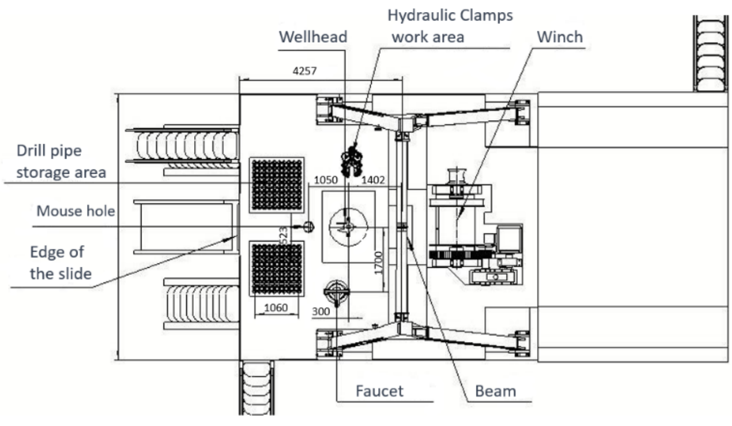

Figure 4: Rig X-Y (top-down) plan

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Due to the narrow space of the geothermal drilling platform, the mechanical assistant of this design is suspended on the crossbeam, and the rotary buckling manipulator is placed on the side of the wellhead where there is no power faucet, and the overall layout is shown in Figure 5. After the geothermal drilling platform is assembled, the drilling starts, at this time, the mechanical assistant is in the zero position, the worm gear reducer of the mechanical assistant works firstly to turn the mechanical assistant to the working point position, then realizes the transportation of the drilling rod through the rotating platform and the electric actuator, and then realizes the docking of the drilling rod through the rotary buckle manipulator.

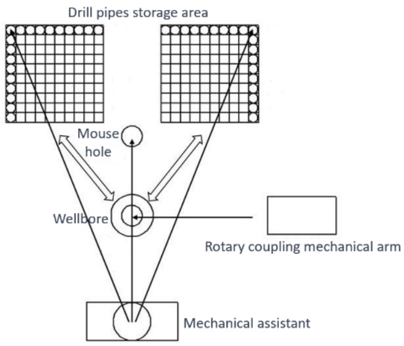

Figure 5: General Layout

3. Design of mechanical assistant

3.1. Work requirements of Mechanical assistant

The drilling mechanical assistant has the task of transporting the drill pipe to the drill box, chute edge, borehole and rathole locations while assisting in the movement of the drill pipe, as well as returning to the point of origin. The points to be reached by each mechanical assistant are defined according to the coordinate system in the spatial layout of the platform. The zero point is located at the midpoint of the crossbeam, because the mechanical assistant mainly assists in accomplishing the work of moving the drill pipe, so the mechanical assistant only accomplishes the work of translating, so the coordinates in the Z direction can be ignored and the drill pipe in the drill box is numbered, as shown in Figure 6.

Since only one plane of motion is involved in this case, and the number of drill pipe is large, therefore, in order to facilitate the recording of the position of the drill rods, the upper right-angle coordinate system is changed to a polar coordinate system, as shown in Figure 7.

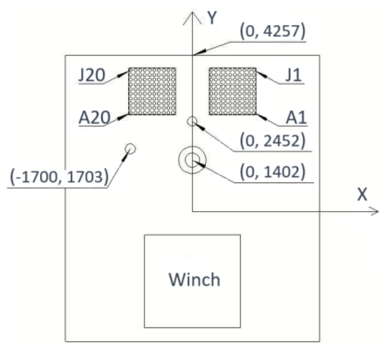

Figure 6: Cartesian coordinate system

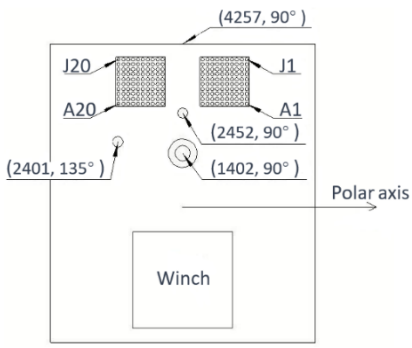

Figure 7: Polar Coordinate System

When loading the drill pipe, the mechanical assistant starts to work, the mechanical assistant starts from the zero position, grasps the drill pipe in the drill pipe box, moves the drill pipe to the position of the borehole, repeats the step after the drill pipe docking is completed, and the mechanical assistant returns to the home position after the work is completed. When unloading the drill pipe, the mechanical assistant reaches the position of the borehole first and moves the drill pipe into the drill box. When dumping drill pipe the mechanical assistant moves the drill pipe to the edge of the chute. If any drill pipe is damaged during the work, the mechanical assistant needs to move the drill pipe from the borehole position to the rathole, temporarily store the drill pipe, and then continue the up-drilling work.

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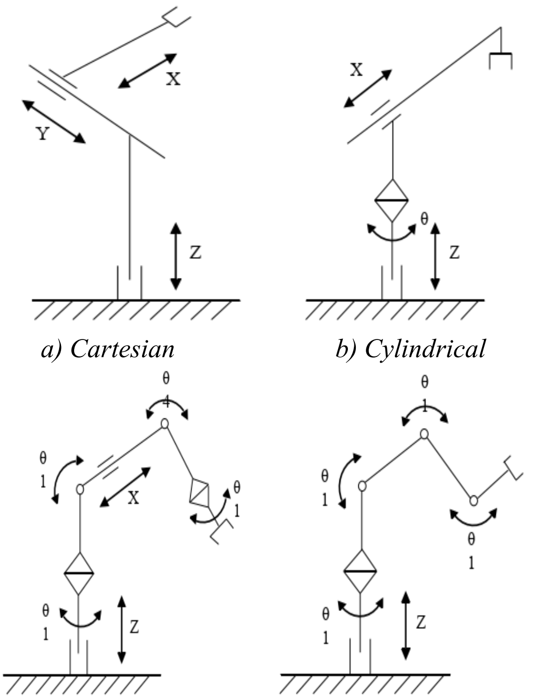
3.2. Selection of degrees of freedom and coordinate forms for mechanical assistants

The structure form of the mechanical assistant directly affects its driving mode and working performance, and its structure type depends on the coordinate form, which can be categorized into four types, namely, right-angle coordinate type, cylindrical coordinate type, spherical coordinate type and articulated type [14-15]. The motion of the required manipulator can be determined according to the production equipment and the positional arrangement of each modular mechanism, and the structural sketches of different coordinate forms are shown in Figure 8. For the mechanical assistant, the drill pipe is its main working object, can be adjusted by the angle and position of the mechanical assistant to complete the transfer of the drill pipe, by comparing the various coordinate forms of the robot, and at the same time, according to the analysis of the previous workflow and spatial layout, the design of the mechanical assistant selected the cylindrical coordinate type of the coordinate form.



a) Cartesian *b) Cylindrical*

c) Spherical coordinates *d) Articular coordinates*

Figure 8: Schematic diagrams of manipulators with different coordinate forms

Before designing the mechanical assistant, we need to understand clearly the degrees of freedom of the mechanical assistant which will be designed. The designed mechanical assistant mainly consists of two directions of motion, which are the forward expansion and contraction as well as the translation motion parallel to the horizontal plane. Therefore, there are a total of two degrees of freedom in this designed mechanical assistant, as shown in Figure 9, T1 represents the telescopic motion of the mechanical assistant, R1 represents the translational motion of the mechanical assistant, and the point P represents the position of the drill pipe which is placed at a certain point under the polar coordinates of the drill pipe.

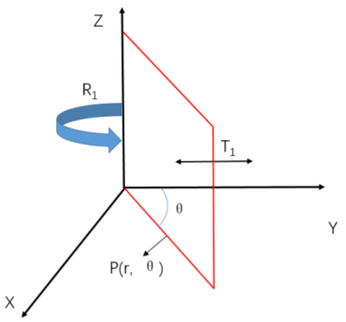


Figure 9: Degrees of freedom of the mechanical assistant

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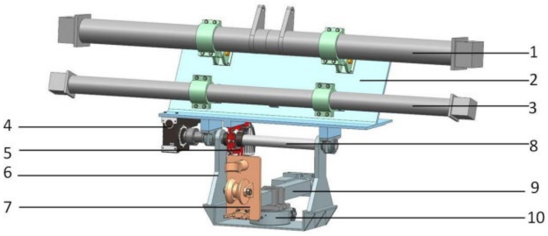
3.3. Overall structural design of the mechanical assistant

After determining the spatial layout and working form of the mechanical assistant, the structural design of the mechanical assistant is carried out, as shown in Figure 10. The mechanical assistant adds a new beam on the basis of the existing drilling platform beam, and the whole device consists of a drilling platform beam, a new beam, a power shaft, a worm gear reducer, a braking device, a robot end-effector, a motorized actuator, and a rotating platform, etc. The whole device is rotated to the back of the crossbeam with the worm gear reducer as the power to drive the power shaft when it is not working, and when it is in the working condition, the rotating platform rotates first while the electric actuator extends out and drives the robot end-effector to work. At the same time, the robot end-effector consists of mud-cleaning hand, V-wheel, clamping hand and robot fixed plate. It not only has the functions of mud cleaning, positioning and clamping, but also has a modularized design for easy disassembly. In addition, a braking device is installed which is safe and reliable, it can play a role in the working state or non-working state to minimize the damage to the worm gear reducer, and there is also a power failure holding.



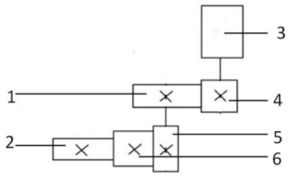
1- Rig beam; 2-Suspended lifting plate; 3-Newly added beam; 4-Reducer; 5-Brake, 6-Rotating platform seat; 7-Robot end-effector; 8-Power shaft; 9-Motorized actuator; 10-Rotating platform

Figure 10: Overall structure of mechanical assistant

4. Design of spin buckle manipulators

4.1. Transmission Program Design

Since the final torque required by the output gear is the tightening torque of the drill pipe, the required torque is very large, so the power source of this program adopts a hydraulic motor with two stages of gear reduction, the hydraulic motor transmits the rotational speed and torque to the high-speed stage gears for deceleration to increase the torque, and then passes through the low-speed stage gears to the output gears of the transmission program. The schematic diagram of the transmission scheme is shown in Figure 11.



1- High speed stage large gear; 2-Output gear; 3-Hydraulic motor; 4-High-speed stage pinion gear; 5-Intermediate shaft pinion gear; 6-Idler pulley

Figure 11: Transmission Scheme

4.2. Design of the slide mechanism

For the problem of the movement of the rotary buckle manipulator, a slide mechanism is chosen to complete, the schematic diagram of the slide mechanism is shown in Figure 12. The whole mechanism consists of a slide, slider, support plate, movable feet, rack and pinion, gears, aluminum frame. The upper part of the support plate is responsible for connecting with the clamp of the rotary button manipulator and the rotary button clamp, the lower part is connected with the slider and the gear, the slider is mounted on the slide rail, the gear is connected with the rack and pinion, the rack and the slide rail are fixed to the aluminum frame, and the movable foot is fixed to the plane of the base of the drill table. The gear of the whole device is the active member, driven by the motor to rotate the gear, the gear rotation drives the rotary buckle robot to advance along the direction of the rack, to complete the rotary buckle robot automatic docking task.

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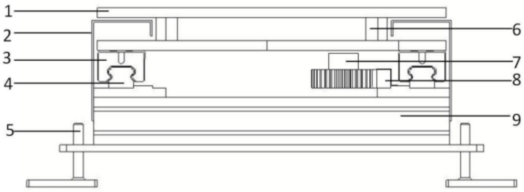
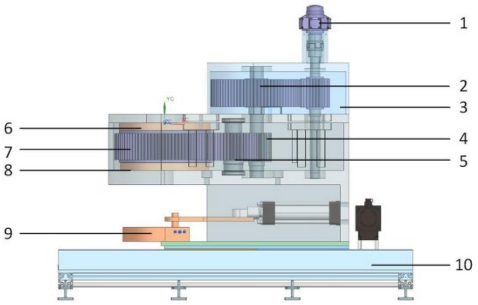


1- Mounting plate; 2-Guide protection cover; 3-Slider; 4-Linear guide; 5-Adjustable foot; 6-Support force plate; 7-Spur gear; 8-Rack; 9-Aluminum profile frame

Figure 12: Schematic diagram of slide mechanism

4.3. Overall structural design of spin buckle manipulator

Spin buckle manipulator is mainly used to cooperate with the drilling machinery assistant to complete the up and down unloading work of the drill pipe, so it is necessary to complete the work of docking the drill pipe as well as cooperate with the drilling machinery assistant. The structure is simple and easy to dismantle. The rotary buckle manipulator to complete the up and down unloading drill pipe work requires two parts of the main structure of the clamp and the rotary buckle clamp, and in order to facilitate the automatic movement of the rotary buckle manipulator docking work, the lower part of the installation of the slide device. As shown in Figure 13, the whole device is mainly composed of three parts: rotary buckle clamp, clamp and slide rail. When the mechanical assistant assists in sending the drilling tool to the wellhead position, the slide rail first starts to work and sends the rotary buckle manipulator to the wellhead position, and the rotary buckle clamp and clamp work at the same time to tighten the upper and lower drilling tools respectively, and then the hydraulic motor input is transmitted to the open gear through the gear transmission mechanism, and the open gear rotates to docking, complete the docking work of the drill pipe.



1- Hydraulic motor; 2-Intermediate large gear; 3-Spinning buckle clamp; 4-Intermediate pinion; 5-Idler wheel; 6-Upper jaw plate; 7-Open large gear; 8-Lower jaw plate; 9-Clamping device; 10-Slide device

Figure 13: Three views of the rotary lever manipulator

5. Conclusion

Aiming at the development status of geothermal drilling platform at the present stage, this paper designs a drilling auxiliary robot with geothermal drilling platform KV3000 as the research environment, and the main research results are as follows:

(1) Completed the overall program design of the drilling auxiliary robot. According to the platform layout and functional requirements of the KV3000 drilling, the workflow of the drilling auxiliary robot is formulated, and then the space layout scheme of the drilling auxiliary robot is formulated in combination with the actual situation and design requirements, and the overall scheme design of the drilling auxiliary robot is completed.

(2) The overall structural design of the mechanical assistant of the drilling assistant robot is completed. According to the working requirements of the mechanical assistant and the choice of degrees of freedom and coordinate forms, combined with the spatial layout of the drilling auxiliary robot, the scheme design of the mechanical assistant is completed, and then the design of the three-dimensional digital model of the mechanical assistant of the drilling auxiliary robot is completed.

(3) Completed the overall structural design of the snap manipulator of the drilling auxiliary robot.

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According to the working requirements of the snap manipulator, the transmission scheme of the snap manipulator is designed; for the problem of the movement of the snap manipulator, a slide device is designed; and the design of the three-dimensional digitized model of the snap manipulator of the drilling auxiliary robot is finally completed.

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