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Design of a Multi-pipe Driller for Deep Lunar Soil Sampling

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Abstract

According to the condition that people only know about the lunar soil between the depths 0 and 3 meters and the existing drillers can't collect the deeper lunar soil, a new lunar soil driller that can collect the lunar soil between the depths 0 and 5 meters is to be presented in this paper. The driller needs the accommodation of great power and the help of astronauts. And it realizes the goals of deep lunar soil sampling by the interconnection and the coinstantaneous contra-rotation of the inside drill pipes and the outside drill pipes. The driller is consist of a lunar soil drilling mechanism, a mechanism recovering samples , a mechanism fixing drill pipes, a mechanism interchanging drill pipes and some drill tools. After the interconnection of 5 groups of drill pipes, the target of deep soil sampling can be realized. What's more, the samples collected by the driller can keep the sequence information. The driller has the advantages of small structure and it can collect much more lunar soil. So this kind of driller can give some technical supports to the study of deep lunar soil sampling.

Keywords: Lunar exploration, Lunar soil, Drill sampling, Interconnection of drill pipes.

Introduction

The problem of resource crisis is getting worse with the development of our society. But the moon is rich in mineral resources; it contains all the elements in the crust. And it has about 60 kinds of mineral deposits and a large amount of helium fusion material called He-3. In order to solve the earth's resource crisis, many countries have set their sights on the moon. However, now the understanding of the lunar soil compositions and the geological structures is limited to the depth from the surface of the moon to 3 meters below the surface. It is far from our goals and requirements to know about the geological structures of the moon and to exploit the lunar resources. What's more, the small explorers' low load operation platform and the output of energy of low power density, the reliability problems of automatic system have limited the implementation of deep lunar soil sampling. So, it will be a long and arduous task to know about the lunar soil compositions and the geological structures in the future.

With the implementation of China's lunar exploration project, it

will be our next goal landing astronauts on the moon. Based on the project landing the astronauts on the moon, we will get many foundations of exploration. Such as, the bigger explorers can provide heavy load operation platforms, and its output power is higher, the astronauts can provide important manipulative abilities to help lunar soil sampling. All these foundations can make the deep lunar soil sampling come true. So based on the project landing astronauts on the moon, a multi-pipe driller which can collect the lunar soil of 5meters deep and the soil can keep the sequence information is presented in this paper.

Solutions of the difficulties of deep lunar soil sampling and the overall scheme of the system

Solutions of the difficulties of deep lunar soil sampling

The moon has a bad environment with low gravity, vast dust, strong radiation and the volatile temperature. From the surface of the moon to the deep of the moon, the cohesion and density of lunar soil increases with the increase of the depths [1-3]. There are many difficulties for the deep lunar soil sampling because of the bad environment, the characteristics of lunar soil and the development of the explorers. Aiming at these difficulties, a detailed analysis and a reasonable solution scheme have been proposed in this paper.

Restriction of the size and output power of the detectors

Because the cohesion and density of lunar soil increases with the increase of the depths, so the drilling pressure and the drilling power will increase gradually in the process of deep lunar soil sampling. What's more, the gravity on the moon is lower. These things require the detectors to provide enough pressure and output power. But the existing detectors in the world have the imitations of small size and low output power. For example, the Apollo spacecraft of America drilled the soil by astronauts carrying the driller, the max power of the driller is 456w, and the drilling pressure was provided by the gravity of astronaut, so the drilling pressure does not exceed150N (Assuming that the astronaut's weight is 75 kg); the former Soviet Union's Luna spacecraft collected the soil by automatic driller whose power was about 150w [4-6]. It can't meet the requirements of deep lunar soil sampling.

With the development of China's space technology, landing astronauts on the moon is our next plan of exploration. At that time, our country will launch a detector that has a larger size, and it can provide higher output power. The driller will be fixed on the detector, so the detector can provide a heavy load platform by its own gravity. Thus, the driller will have enough drilling pressure and power to realize the goal of deep lunar soil sampling.

Restriction of the method of drilling core

The length of the drill pipe should be 5 meters in order to collect the lunar soil for 5 meters deep, but now we can't transport a drill pipe whose length is 5 meters to the moon because of the restrictions of the size of the detector. So the goal of deep lunar soil sampling is to realize by means of the interconnection of drill pipes. In the successful sampling cases of the United States and the former Soviet Union, the America used a rigid pipe that was pressed into the soil to collect the samples; the former Soviet Union used a soft bag that was folded inward to collect the samples. The rate of core of the former is low because of the chain effect between the particles of lunar soil, we could only get few samples. The latter needs a wire rope to pull out the bags, which can't be applied to the way of the interconnection of drill pipes. What's more, other existing ways for drilling core are not suitable for the deep lunar soil sampling either [4-6]. There is a need to find a suitable method of drilling core, which is suitable in the way of the interconnection of drill pipes.

Aiming at this problem, a new method of drilling core was given in this paper. The drill tools in this method are consist of the inside drill pipes and the outside drill pipes. The outside drill pipes are hollow rods, there are spirals on the outside walls and spline structure on the inside walls of outside drill pipes. The inside drill pipes are solid rods, there are spirals on the outside walls of the inside drill pipes. Both the inside drill pipes and the outside drill pipes need to interconnect at first when the driller works. Then the lunar soil is transported from the gap between the inside drill pipes and the outside drill pipes to the surface of the moon. At last, the samples will be transported to the sample bags.

Reliability problems of the system because of the hard environment of the moon

The driller has many roboticized modules. The hard environment of the moon, low gravity, vast dust, strong radiation and the volatile temperature, has many bad effects on the driller. It is difficult to make sure that the driller works normally in the rugged environment.

In order to solve this problem, China will send astronauts to the moon, the astronauts help to carry out the deep lunar soil sampling. The fully automated system can reduce to semiautomatic system. The reliability of the system is improved by the simplification of system. Besides, when the system has some problems, the astronauts can try to solve the problem. For example, when the system failed to interconnect the drill pipes, the astronauts can control the driller to interconnect the drill pipes again. With the help of astronauts, the risk of the failure of deep lunar soil sampling can decline a lot.

Functions and components of the sampling system

The driller has many functions, such as lunar soil drilling, the recovery of samples, the fixedness of drill pipes, the interchange

of drill pipes and the support of the frame. In order to realize these functions, the machine is consist of a lunar soil drilling mechanism, a mechanism recovering soil samples, a mechanism fixing drill pipes, a mechanism interchanging drill pipes and the support frame. The functions and components of sampling system are shown in Figure 1.

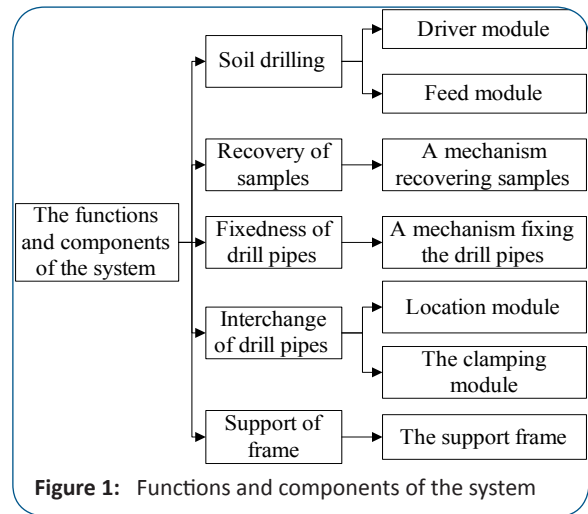


Figure 1: Functions and components of the system

The structure of the system was designed according the functions and components of the sampling system. The structure of the whole system is shown in Figure 2.

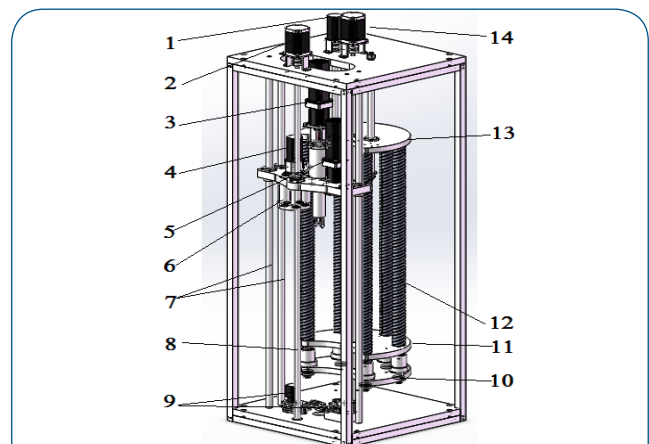


Figure 2: Structure of the sampling system

- 1-motor driving the mechanism fixing the drill pipes
- 2-motor driving the feed module
- 3-motor and reducer driving the movement of inside drill pipes
- 4-motor driving the mechanism recovering samples
- 5-motor driving the movements of outside drill pipes
- 6-mechanism recovering samples
- 7-guide pillar
- 8-ball screw
- 9-clamping module
- 10-below location mechanism
- 11-above location mechanism
- 12-groups of drill pipes
- 13-structure fixing the drill pipes
- 14-motor driving the mechanism interchanging drill pipes

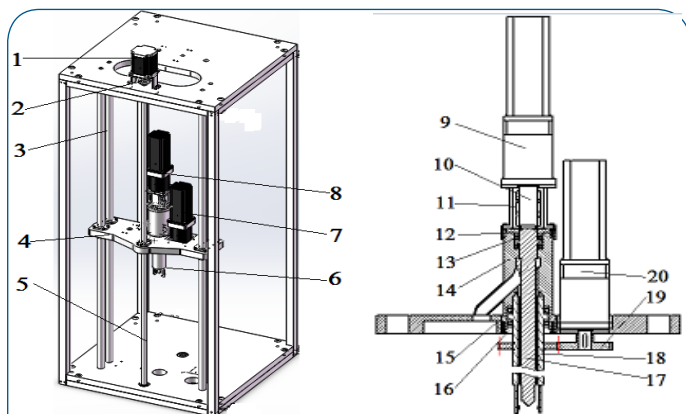
Design of the key modules of the system

Lunar soil drilling mechanism

The function of the lunar soil sampling mechanism is to drill the soil. And it is consist of the driver module and the feed module. It's shown in Figure 3a.

In the feed module, the stepper motor drives the driver module fixed on the screw nut to move up and down by driving the ball screw pair. Besides, four guide pillars were added to the feed mechanism for the purpose of balancing the overturning moment.

The dirver module is mainly used to drive the pipes to rotate. At the same time, there is a channel for the transportation of samples in the driver modul. And the driver modul is shown in Figure 3b.



A) The overall structure b) The structure of the drive module

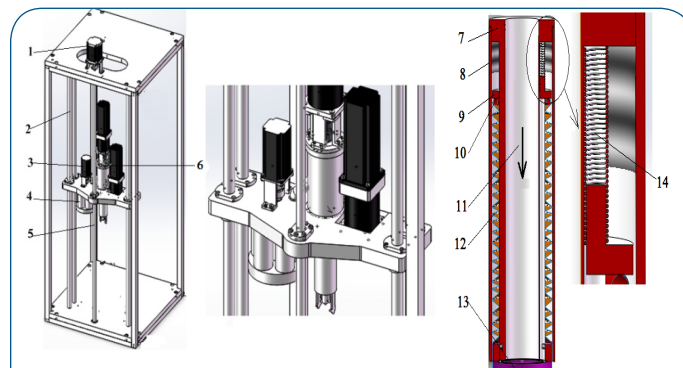
Figure 3: Lunar soil sampling mechanism

- 1-motor driving the feed module
- 2, 11-connector
- 3-frame of system
- 4-plate fixing the driver module
- 5-ball screw
- 6-drilling joints
- 7, 20-motor and reducer driving the outside drill pipes
- 8, 9-motor and reducer driving the inside drill pipes
- 10-motor base
- 13, 15-thrust bearings
- 14-channel of samples transportation
- 16-below bearing caps
- 17-driving joint of inside drill pipes
- 18-driving joint of outside drill pipes
- 19-gear pair

When the system works, the drill pipes accomplish the interconnection at first, then the inside drill pipe rotates anticlockwise and the outside drill pipe rotates clockwise. The feed module drives the driver module to move down. The function of the lunar soil drilling is realized in this way. The lunar soil samples are transported from the gap between the inside and outside drill pipes to the mechanism of the recovery of samples by the coordination of the inside and outside drill pipes.

Mechanism recovering the samples

The function of the mechanism recovering the samples is to package and recover the samples. It is mainly consist of 1 stepper motor, 5 tubes (there is a bag in every tube), a structure reserving the tubes, 1 motor base and 1 connector. And the mechanism is fixed on the driver module. The mechanism is shown in Figure 4.



a) The overall structure b) The detail view c) The structure of tubes

Figure 4: Mechanism recovering the samples

- 1-motor driving the feed module
- 2-guide pillar
- 3-motor driving the mechanism recovering the samples
- 4-tubes
- 5-ball screw
- 6-driver module
- 7-endotheca
- 8-mantle
- 9-plate compressing the bags collecting the samples
- 10-structure of self-constriction
- 11-direction of transportation of lunar soil
- 12-sample bag
- 13-bottom of the bag
- 14-spring

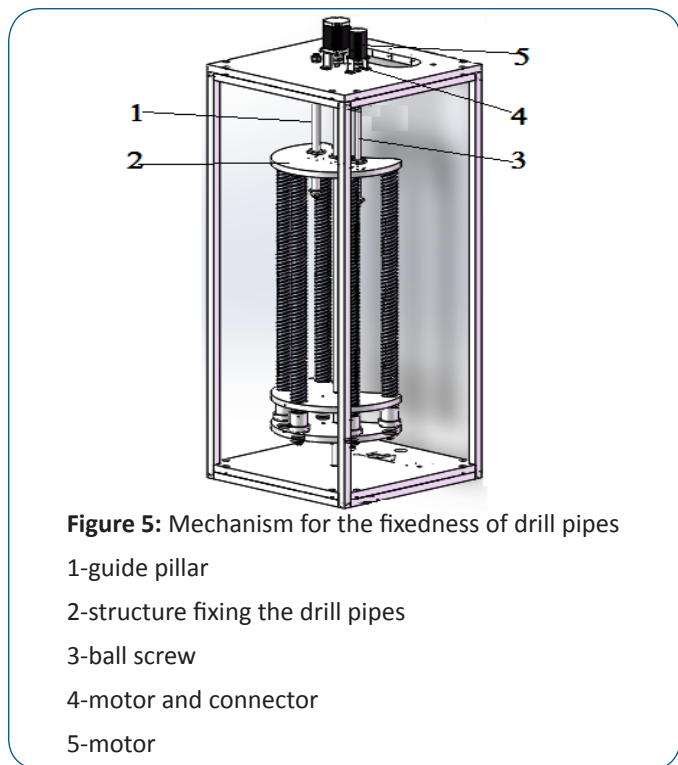
When system is in the initial state, the bags folded are reserved in the tubes. It's shown in Figure 4c. Sample bags are always pressed by the plate under the pressure of spring. When the first group of drill pipes accomplish the interconnection and the driller begins to drill the soil, the astronaut starts to pull the bottom of the sample bag, making the sample bag spread out gradually. The samples fill in the bottom of the sample bag at first, then fill upwards gradually. The astronaut can pull out the bag from the sampling tube when the driver module moves down to a certain distance, the structure of self-constriction on the bag can package the bag automatically. Then the mechanism rotates 72 degrees after the interconnection of next drill pipes. The next bag begins to work in the same way until the finishment of our task. And 5 times later, the samples can be collected.

The sample bags being spread out gradually has some advantages .such as, the soil can keep the sequence information and it is easy for the samples to fill in the bags.

Mechanism fixing the drill pipes

The driller is fixed on the outside wall of the explorer. The explorer will occur severe vibration in the process that the

explorer launches from the earth and lands on the moon. In order to prevent the damage of the location of drill pipes and other modules of the driller in the violent vibration, there is a need to design a drill pipe clamping mechanism to fix the drill pipes. The drill pipes clamping mechanism is shown in Figure 5. The mechanism will clamp the pipes along the direction of the axis of the pipes when the system is transported. When the driller begins to work, the drill pipes will be loosened.



Mechanism interchanging the drill pipes

The mechanism interchanging the drill pipes is used to locate the pipes and to change the position of the pipes. It consists of a stepper motor, connector, the axis, the location module, and the module clamping the pipes. It is shown in Figure 6.

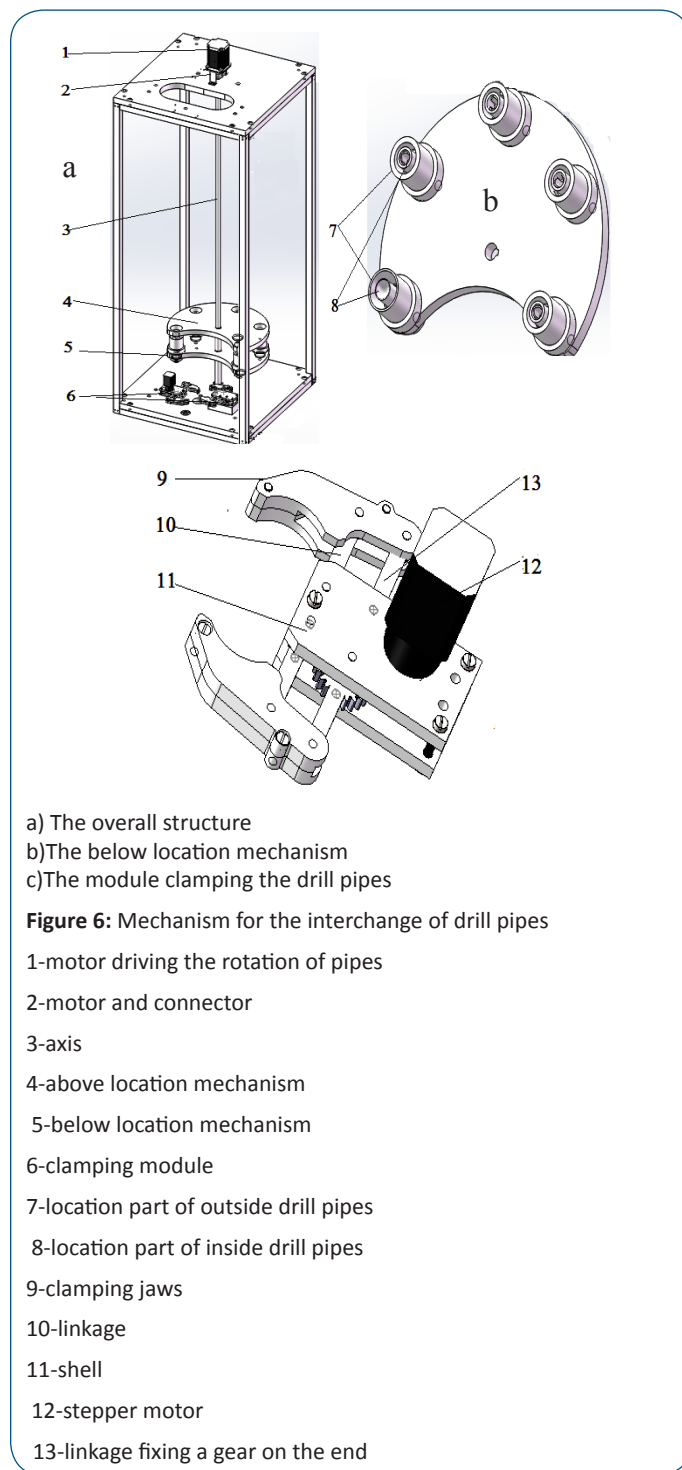
The function of the rotation of drill pipes can be realized by the way that the stepper motor drives the location module fixed on the axis to rotate. And it's shown in Figure 6a.

The location module consists of the above location mechanism and the below location mechanism. Figure 6 illustrates that the above location mechanism has five positioning holes to achieve the radial position of the outside drill pipe, and another empty position is used to provide space for the drive module to move up and down.

As shown in Figure 6b, the location parts of the inside drill pipes and outside drill pipes are fixed on the below location mechanism. Their locating surface can contact the drilling joints completely because of their alike shape. The locating part of the inside drill pipes connects the below location mechanism through the spline structure. Besides, a spring which makes the locating part of the inside drill pipes move down under a certain pressure was added. In the initial state, the position of the locating part of the inside drill pipes is higher than the locating part of the outside drill pipes. When the drill pipes begin to interconnect, the locating part of the inside drill pipe moves down under the pressure of driving joints until the inside drill pipes and outside drill pipes are in the same

horizontal plane. The purpose is to make sure the reliable contact between driving joints and drill pipes.

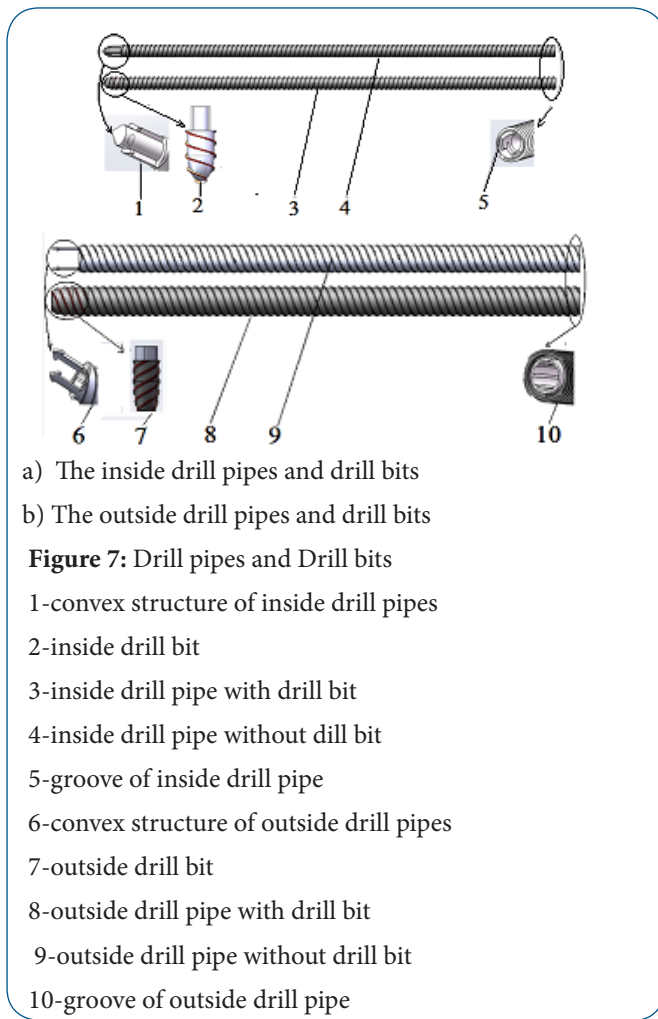
Figure 6c shows the module clamping the drill pipes. The open and close of clamping jaws is realized by the way that the stepper motor drives the gear pair.



The Drill pipes and drill bits

The drill pipes can be divided into two categories, the inside drill pipes and the outside drill pipes. Each category consists of the pipes with drill bits and the pipes without drill bits. And the drill bits also are divided into two categories, the inside drill bits and the outside drill bits. It is shown in Figure 7.

As shown in Figure 7, the drill pipes use the convex structures and grooves to interconnect with each other. When the drill pipes interconnect, the convex structure inserts into the groove and rotates a certain degrees. And they will separate if the convex structure inverts the same degrees and moves up.



a) The inside drill pipes and drill bits

b) The outside drill pipes and drill bits

Figure 7: Drill pipes and Drill bits

1-convex structure of inside drill pipes

2-inside drill bit

3-inside drill pipe with drill bit

4-inside drill pipe without drill bit

5-groove of inside drill pipe

6-convex structure of outside drill pipes

7-outside drill bit

8-outside drill pipe with drill bit

9-outside drill pipe without drill bit

10-groove of outside drill pipe

The helix angles of drill pipes and drill bits have a great influence on the transportation of lunar soil. According to the study, the outside drill pipes adopt the four head spiral structure. The lead angle is 20°. The inside drill pipes adopt the two head spiral structure. The lead angle is 15°. The wear of drill bits is not very serious if the acquisition target currently is only for the lunar soil (not including lunar rocks). Now, our acquisition target currently is only for the lunar soil (not including lunar rocks), so the drill bits Bit use the spiral wing after heat treatment as the cutting edge.

The Work flow of the system

The whole system need to work according to certain processes. And its working process is as follows,

- (1) The mechanism fixing the drill pipes moves to loosen the drill pipes.
- (2) The mechanism interchanging drill pipes drives the location module of drill pipes to rotate 60 degrees. Then the first group of drill pipes is located just below the driving joints.
- (3) Driver module moves down until the axial distance between the driving joints and the outside drill pipes. Then the driving joint of outside drill pipes rotates clockwise for 720°,

then it accomplishes the interconnection of driving joint and outside drill pipe; The driving joint of inside drill pipes rotates counterclockwise for 720°, then it accomplishes the interconnection of the driving joint and inside drill pipe.

- (4) The feed module moves up for a certain distance, then the mechanism interchanging drill pipes recovers to its initial state. Next, the first group of drill pipes and the mechanism recovering samples begin to work.
- (5) The clamping mechanism of outside drill pipes clamps the outside drill pipe after the condition that the first group of drill pipes moves down for a certain distance. Then the driving joint of outside drill pipes rotates counterclockwise for a certain degrees. Next, the driver module drives the inside drill pipes to rotate clockwise(the driving joint of outside drill pipes don't rotate). At the same time, the feed module moves up. When the feed module moves up for a certain distance, the driving joint of outside drill pipes and the outside drill pipe separate with each other. Then the clamping mechanism of inside drill pipes clamps the inside drill pipe and the driving joint of inside drill pipes rotates counterclockwise for a certain degrees. Next, the feed module moves up, the driving joint of inside drill pipes and the inside drill pipe separate with each other.
- (6) The driver module recovers to its original state. Then the next group of drill pipes begin to work. After the interconnection of drill pipes for 5 times, our target of deep lunar soil sampling is realized.

Conclusion and Outlook

This paper presented the difficulties of deep lunar soil sampling and give the solutions of the problems. Then a new type of lunar soil sampler which can drill 5 meters deep and keep the sequence information of lunar soil was proposed. What's more, its working principle was introduced in detail.

The simulation of kinematics and dynamics will be carried out in the next step, and after the simulation, we will produce the principle prototype to carry out experiments.

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