



Geological Engineering Drilling Technology Conference (IGEDTC), New International Convention Exposition Center Chengdu Century City on 23rd-25th May 2014

The Development of Deep Borehole Permanent-magnet Motor Direct Drive Top-Driving Drilling Rig

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Abstract

At present, in our country the main deep drilling rigs are rotary disk drilling rig, spindle-type drilling rig and full hydraulic motor head drive drilling rig, and most of foreign drilling rig equipment are full hydraulic motor head drive drilling rigs. These rigs have many disadvantages; they cannot meet the demand of deep drilling. As the major breakthroughs were made in the development of high power permanent magnet frequency conversion motor, it is possible to develop the permanent-magnet motor direct drive top-driving drilling rig, so the efficiency of drilling can be improved. In this paper, the difficulties of deep drilling and existing problems of deep drilling rigs are analyzed, and direct drive permanent magnet motor top-driving drilling rig and its parameters and characteristics are introduced. The development of deep borehole permanent-magnet motor direct drive top-driving drilling rig accords with the requirements of drilling technology development and innovation concept, it is the development direction of deep core drill's renewal, will promote the development of geo-drilling technology.

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Selection and peer-review under responsibility of Geological Engineering Drilling Technology

Keywords: Deep Drilling; Permanent-Magnet Motor; Direct Drive Drilling Rig; Frequency Converting Control

1. Introduction

In recent years, with the rapid development of economy, our country pay more attention to resources, energy security, stepped up environmental protection, clean energy exploration and development investment, the mineral resources and clean energy (such as shale gas, hot dry rock geothermal etc.) exploration workload will be increased. Resources survey and exploration work has turned to the deep and the west area, it is predicted that if the depth of

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the exploration and evaluation to under 2000 m underground metallic ore deposits in China and new energy reserves will increase sharply.

In foreign countries, deep boreholes are mostly drilled by full hydraulic motor head drive drilling rig, which are produced by the United States, Canada, Australia, Sweden, Germany etc, can drill at most 2500m with N series caliber. In China, there are commonly two main types deep drilling rig: spindle-type drilling rig and full hydraulic motor head drive drilling rig, which can drill maximum deeply 1500 m with N series caliber.

A spindle-type drilling rig has certain defects: stroke is short, speed range is narrow, intelligent degree is not high; The efficiency of full hydraulic motor head drive drilling rig whose drill stand is short is low. Using these rigs, the drill-pipe stand cannot be used, reaming and back reaming cannot be realized. The efficiency of drilling is low, and they cannot solve complex accidents happened in borehole.

The motor of oil top-drive is excitation frequency conversion motor, its torque is too big, and speed is too low, reduce speed and increase torque through the speed reducer. At low load, ordinary frequency conversion motor the efficiency and power factor is low, fever is serious, the frequency conversion control system is more complex, high cost, top-drive parameters cannot meet the requirements of the core drilling, it is difficult to be applied in geological system.^[1]

In recent years, as the major breakthroughs were made in the development of high power permanent magnet frequency conversion motor, it is possible to develop the control operation simple permanent-magnet motor direct drive top-driving drilling rig.

2. Deep Drilling Difficulties and Top-driving Drilling Rig Design Requirements

2.1. Deep drilling difficulties

Deep core drilling construction cycle is long, and the stability of borehole wall is poor, borehole wall exposed time is long, drilling fluids filtration for long time makes swell of borehole wall and the wall of borehole unsteadily, even blocking or sticking accidents.^[1]

As the drilling deepening, workload of horizontal hole and directional hole also increased, the existing drilling work efficiency is low; at the same time, the increase of weight of drilling tools and number of drilling trip resulted in the damage to the wall of borehole, and increased the unforeseen possibility of drilling accidents.^[1]

During deep borehole directional drilling and horizontal drilling, accidents frequently occur would greatly increase the accident treatment time, the complexity of the accident and the construction cost.

2.2. Top-driving drilling rig design requirements

According to the conditions and characteristics of deep drilling, and analyzed the existing problems of drilling rigs, puts forward higher requirements on the rig and the new design idea:

- In the event of hole shrinkage, blocking or sticking accidents, for strata reason, existing drilling rigs cannot ream and back ream, Especially in deep hole directional drilling or horizontal drilling, hole accidents occurred more so that affect the efficiency of dealing with accidents. Therefore in the process of drilling rig design, the drilling rig does not require the kelly and its power unit can ream or back ream at any height of the stroke. Especially in the directional drilling, it can improve the drilling efficiency.
- The stroke of existing drill rig is too short, that cannot drill with drill-pipe stand. The stroke of full hydraulic motor head drive drilling rig is less than 6m, spindle-type drilling rig has short stroke and needs to recheck. Both of the rigs have low drilling efficiency and long drilling auxiliary time, which lead to rising drilling cost. In geo-drilling process, for strata reason and drilling technology, when blocking or sticking accidents happened, frequent replacement of bit and extracting core are required. To solve the above problems, a top-drive drilling system with more than 20 m stroke need to be developed, to avoid happening hole collapsing shrinkage and breaking, etc. When sticking in the trip, with the back tongs, top-driving can quickly connect drilling tools, ream and back ream with drill stand, within 20 m stroke, saving more than 50% on makeup and breakout of the auxiliary time, can save 20% of drilling time.

- At present, some of vertical shaft drill and hydraulic power head drill need the kelly, in the deep drilling, each time run in hole and pull out of hole, easily induced hole collapsing, shrinkage and breaking, etc. Bit repeatedly broken rock, which is unfavorable for coring. In the design process, the ability of makeup and breakout must be strengthened so the labor intensity of driller can be reduced, improve the speed of the makeup and breakout, drilling auxiliary time can be reduced.
- In the deep drilling, the brake band winch failure rate is high, the chuck can't effectively stuck drill pipe, the pipe loss is big, can't accurately control the drilling speed and bit pressure. New equipment design requires a good operating performance, centralized display the parameters of the drilling and circulating fluid, control and record the parameters in the process of drilling, have good economic performance, safe and reliable, easy maintenance, etc.
- The deep of geological core drilling is defined by 55.5 mm and 71 mm pipe, because of the complexity of the deep drilling, the need of multilayer casing, drilling structure requires its drilling diameter is bigger than in the shallow hole drilling, can't completely drill with the defined pipe, can only use a bigger diameter drill pipe, torque and the hoisting capacity of the current rig will become inadequate, when handling the accident of the output torque, pulling force of the drilling rig, is not enough, the ability of dealing with borehole accidents is insufficient.^[1] So to strengthen drilling torque and hoisting capacity, improve the speed of deep borehole construction lifting drilling tools is necessary. Especially in geological system, because of its many coring drilling technology, in complex stratum hole, the trip time and the blocking or sticking accidents are more, so it is particularly necessary to enhance the hoisting capacity of drilling rig.
- The efficiency of fully hydraulic drilling rig is low (less than 50%), but its energy consumption is large, the hydraulic oil should be replaced periodically, high use cost, prone to failure, and it is not easy to find out and deal with. So design high efficiency and power factor of the permanent magnet motor direct top-driving rig can effectively improve the efficiency of energy conversion.

3. The Design of Permanent Magnet Motor Direct-drive Top-driving Drilling Rig

3.1. Designing of the whole machine

The top-driving drilling system can directly drive the pipe from the derrick top, drill along the drill track, complete the drill pipe rotary drilling, stand drilling with circulating mud, mechanical makeup and breakout, ream or back ream with drilling fluids, etc. Permanent magnet direct drive top-driving drilling rig has not been applied both at home and abroad; it is the first time deep borehole permanent-magnet motor direct drive top-driving drilling rig has been developed.

The rig includes: derrick, drill track, permanent magnet motor direct drive device, draw works, mud pump and control system, etc. (Fig. 1)

3.2. The design of permanent magnet motor direct drive top-driving device

Permanent magnet motor direct drive the top-driving device to work, no gear transmission in the device, circulating fluid through the hollow shaft motor rotor, hollow shaft at both ends is combined with the water swivel and drill pipe, drill pipe transmits torque, so it can avoid damage of the drill pipe.

In complex strata, when drilling tools are jammed, top-driving device can rapidly connect drill string with back-up wrench, ream and back ream with pump circulation within 20 m stroke, it can reduce the probability of jamming or blocking accidents

To improve the automation level of drilling rig, reduce drilling auxiliary time, top-driving device can realize makeup and breakout with back-up wrench. The balance device, at the top of the top-driving device, is designed to protect the drill pipe thread while makeup and breakout.

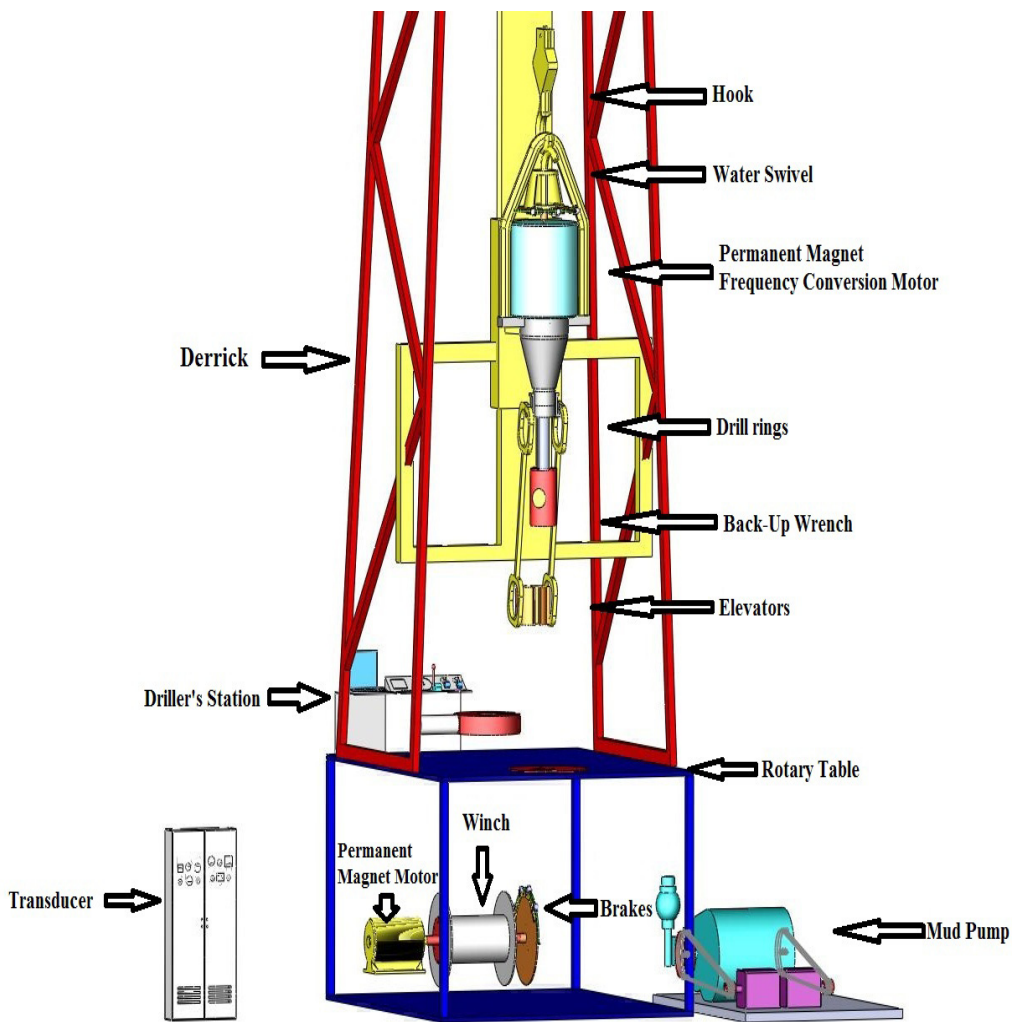


Fig.1 General Assembly Drawing of Drilling Rig

3.3. The design of winch

The permanent magnet motor directly drive the winch, no gear transmission, for the first time in geo-drilling rig adopts double broken line winch, during run in hole and pull of hole, stepless speed regulation can be realized. During run in hole, energy consumption braking can be used by permanent magnet motor. In an emergency, safety clamp brakes also can be used. It fundamentally solves the common drill in gear drive, parking, sealing and lubrication problems, and improves the reliability of the site operation. (Fig. 2)

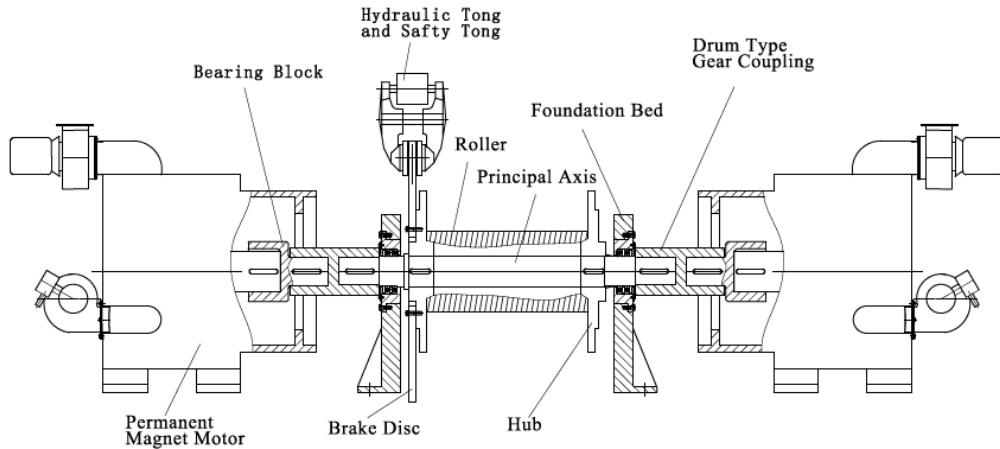


Fig.2 Permanent Magnet Motor Driven Winch

3.4. Control system design

The frequency conversion control system and drilling parameter gathering feedback control system control the drilling speed and bit pressure, can realize automatic drill, frequency conversion stepless speed regulation, no friction brake, drill hover, and other functions.

With the low speed and high torque permanent magnet motor drive and control system, top drive drilling rig uses the current international advanced full digital vector control of ac frequency conversion technology and automation, intelligent control technology, computer control technology, field bus communication and process control technology, operators in the driller station centralized control by PLC, and a variety of control program of drilling rig telex, detection system, hydraulic system, electric control system of the operation of each part of the mechanical system, to implement the intelligent of the drilling rig, automatic control. (Fig. 3)

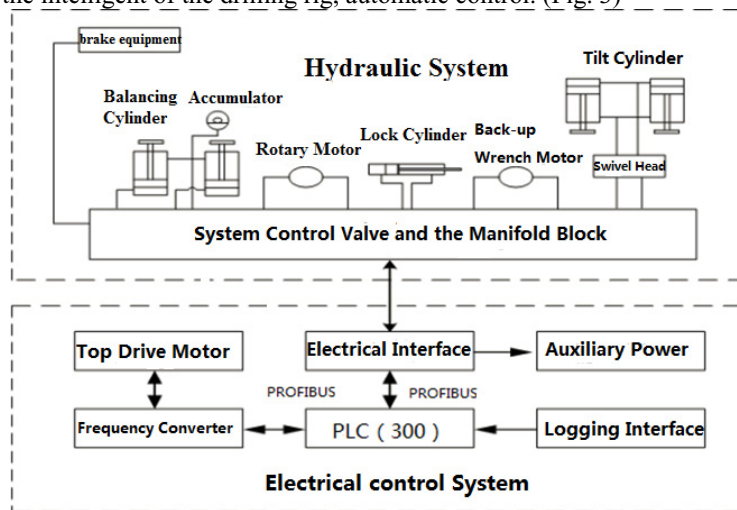


Fig.3 The control system of drilling rig

4. Performance Parameters and Characteristics of the Drilling Rig

4.1. The performance parameters of the drilling rig

The performance parameters of the drilling rig are as following:

- Drive mode: Permanent magnet frequency conversion motor direct drive drill pipe and winch;
- Top-drive motor parameters: Power (260 kW), rated frequency 55 Hz;
- Maximum final hole diameter: 150 mm;
- Rated torque: 15 kN.m;
- Maximum torque: 30 kN.m;
- Rated speed: 165 r/min;
- Speed range: stepless speed regulation from 0 to 360 r/min;
- Winch power: 520 kW;
- Fast line pull: 135 kN, fast line speed of not less than 10 m/s;
- Derrick height: 33 m;
- Hook load: 1350 kN (10 lines);
- Water swivel diameter: 65 mm;
- Stroke: 26m.

The top-driving drilling system can directly drive the pipe from the derrick top, drill along the 26 m drill track, complete the drill pipe rotary drilling, stand drilling with circulating mud, mechanical makeup and breakout, ream or back ream with drilling fluids, etc drilling technology. Blocking or sticking accidents caused by various reasons can be timely and effectively solved by top drive drilling rig; at the same time, the rig can drill with drill stand, which would greatly improve the drilling speed.

4.2. The characteristics of the drilling rig

When sticking accident happened during run in hole and pull of hole, top-driving rig can realize the long stroke (more than 20 m) drill, reaming and back reaming with mud circulating, which reduce the probability of the accidents, the time of dealing with accidents. The top drive has elevators, rings, water swivel and back-up wrench, it can directly connect drill pipe at any height in the stroke, ream or back ream with drilling fluids,

Efficiency and power factor of asynchronous motor is very low, the efficiency of hydraulic drilling rig is less than 50%, oil has pollution to the environment, and the permanent magnet motor efficiency and power factor can reach more than 90% under the condition of low load rate.^[2] Top drive device and winch both use the permanent magnet motor as their engine, energy saving can reach more than 20%, which can realize the goal of energy conservation and emissions reduction (Fig. 4).

Permanent magnet motor directly drive drill pipe and winch, not through the gear transmission, with the characteristics of high transmission efficiency, convenient maintenance, and low failure rate.

The top drive drilling rig can realize characteristic of drilling process as follows: Reaming and back reaming with drilling fluids during the process of run in hole and pull of hole, drill stand drilling, single drill pipe drilling. This can effectively solve the complex problems encountered in the process of deep-drilling.

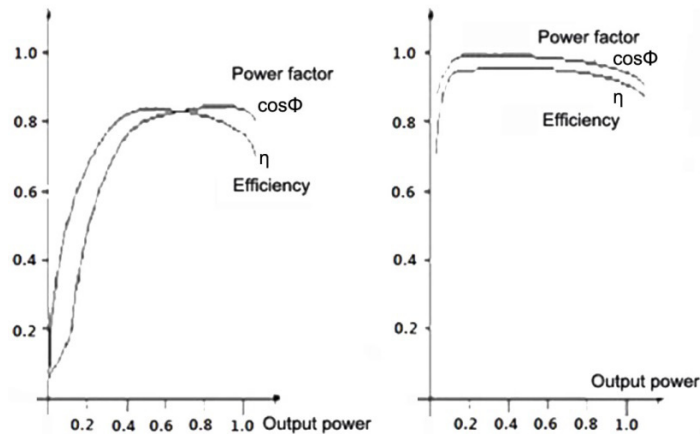


Fig.4 Asynchronous Motor, Permanent Magnet Synchronous Motor Efficiency and Power Factor, and the Curve of Load Factor

5. Conclusions

Top drive device is one of the three new technologies of modern drilling equipment, which can realize stand drilling, connect drilling tools in the derrick on any height with mud circulating, and ream and back ream during the process of run in hole and pull of hole, reduce the accident rate, drilling time and save drilling cost in deep-drilling.^[5] Now almost all of offshore oil drilling platform has been equipped with the top drive device. In the design of a new type of drilling rig of the land, top drive device also has been considered. In international market, the construction team equipped with top drive device is essential condition to participate in bidding. Thus equipped with top drive drilling rig has become a trend in the development of contemporary drilling technology.

In the next years, the number of deep geological exploration and scientific drilling holes, directional drilling holes, shale gas exploration, hot dry rock exploration bore, oil and gas exploration holes whose depth is more than 2000 m are no less than 10000 each year (excluding oil drilling, exploration engineering magazine statistical data in 2011). So highly efficient drilling rig is required in the complex stratum, the new generation of permanent magnet direct-drive top drive multi-purpose geological drilling rig can meet this requirement, and fill the blank of the domestic industry and solve the problem of lack of proper drilling rig in drilling of deep hole, horizontal hole and directional hole. The development of deep hole permanent magnet motor direct drive top-driving drilling rig accord with the requirements of drilling technology development and innovation concept, is the development direction of the deep hole core drill, will promote the development of geological drilling technology.

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