Design and Research of Micro Pile Drilling Rig for UHV Transmission Line in Mountainous Area

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Abstract. In order to comply with the local economic development and reduce the project investment, the UHV line projects are mostly along the hilly areas, and the mountainous areas are mostly difficult to construct. At the same time, the mountainous environment is complex, the traffic is inconvenient, and it is difficult for large machinery to transport to the operation site, which makes the construction of UHV line foundation pile less mechanized, and has always relied on manpower and small tools. With the large-scale development of power grid construction, the problems of labor intensity, poor operation safety and low construction efficiency caused by relying on human construction are increasingly apparent. In view of this kind of problem, the micro pile drilling machine realizes the mechanized construction of micro pile foundation in UHV transmission line project through modular design scheme. Micro pile foundation is a new type of light foundation pile foundation (pile diameter is generally 300-400mm) specially designed for mountainous UHV transmission line engineering. It has the advantages of small pile diameter, small working surface, small hole digging torque, high bearing capacity, and small excavation volume, which is conducive to environmental protection. It is a special equipment suitable for the construction of micro pile foundation under complex mountain conditions.

Keywords: UHV Line Engineering, Micro-pile Foundation, Micro-pile drill, Mechanized Construction, Construction technology

1. Preface

1.1. The Purpose and Significance
With the rapid development of economy, corridor resources are becoming increasingly tense. For UHV projects, the average width of the corridor is more than 40m, which leads to a large number of demolition due to conventional wiring, and it is difficult to handle the agreement. In order to comply with the local economic development and reduce the project investment, the UHV line project tends to run along the hilly area.

Due to the restriction of topography and complex geological conditions, the traditional hole forming machine has large volume and heavy weight, so it is difficult to go up the mountain and transfer quickly, and can not realize mechanized construction. At present, artificial drilling is still the main construction method of pile forming in UHV line industry in China. However, the construction efficiency of manual excavation foundation pile is extremely low, and the safety risk of operation under the hole is high. At the same time, the aging degree of China’s population is becoming more and
for more serious, and the shortage of young and middle-aged groups brings great pressure to the recruitment of construction enterprises.

Based on the above analysis, the research on lightweight and modular design of micro pile drilling rig can improve the mechanized hole forming construction technology of micro pile foundation in mountainous areas, avoid the damage of trees and vegetation around the foundation by manual chiseling and blasting operation, improve the efficiency and efficiency of high-voltage transmission line construction in extra mountainous areas, ensure the safety of construction personnel and reduce the labor intensity of construction. It is beneficial to improve the safety quality, efficiency and efficiency of power grid, and is the inevitable requirement for the development of first-class power grid technology. To change the current situation of artificial hole forming as the main construction method in the mountain UHV transmission line industry in China, realize mechanized construction, improve the intrinsic safety of the project, reduce the project cost and reduce the soil erosion. It has good economic and social benefits to promote the use of micro pile drill truck as a special machine for micro pile foundation construction in mountainous areas.

1.2. Current Status
Due to the characteristics of UHV transmission line foundation construction: many points, long line, small amount of single foundation project, poor road conditions, frequent site transfer, etc. At present, the rotary drilling rig widely used in construction, road and bridge industry can not realize modular assembly, and it is difficult to meet the construction needs of digging foundation in mountainous area of transmission line. For a long time, the excavation foundation of UHV transmission lines in mountainous areas in China mostly relies on manual excavation, which lacks efficient and specialized hole forming machinery.

At present, our power transmission line construction will set up a dedicated ropeway transportation line. However, at present, the special cableway erected in China's national grid transmission line construction usually has a bearing capacity of less than 3.5 tons. In view of the problems of mountain access and operation conditions, combined with the load-bearing limit of equipment ropeway transportation and other mountain transportation modes, the transfer transportation of equipment should be solved in the design of micro pile drilling rig.

2. The Method of Rapid Assembly and Lightweight Design of Micro Pile Drill
In order to solve the transportation problem of equipment in the construction process of ultra-high pressure mountain micro pile foundation, the micro pile drill adopts the split modular design, which is divided into eight quick assembly modules, which can be disassembled quickly and transported to the work place by cableway. It is equipped with quick connector and bucket, which can quickly switch the drilling rig to excavator operation and realize diversified operation in mountainous area.

In the design of micro pile drilling machine, through the following technical research, to achieve the purpose of rapid disassembly and rapid assembly.

2.1. Technical Research on Structural Design
(1) In order to reduce the curb weight, without affecting the overall strength, the propulsion system is changed from the original steel propulsion beam to the aluminum alloy dovetail beam, which greatly reduces the weight of the propulsion system [1], as shown in figure 1.

![Figure 1. Aluminum alloy beam.](image-url)
(2) The hydraulic oil tank and diesel tank are arranged at the rear of the rig body, which are used as the counterweight of the whole machine, thus reducing the extra weight structure and greatly reducing the mass of the whole rig;

(3) The rear part of the car body cancels the cover of the equipment warehouse, and directly uses the structural part layout to make the shape, without affecting the appearance, reducing the mass of the whole rig;

(4) In order to achieve the purpose of fast connection, the module taper hole physical positioning technology is used between the modules. The conical mandrel circle limits the other five degrees of freedom of the workpiece except rotating around the axis, as shown in figure 2.

![Figure 2. Conical mandrel and tip.](image1)

When machining shafts or some parts requiring accurate centering, the center hole is specially machined on the workpiece for positioning. The center hole fits with the center pin, that is, the taper hole fits with the taper pin. The two center holes are the positioning base plane, and the positioning datum is the center line determined by the two center holes. As shown in figure 3.

![Figure 3. Installation diagram of quick assembly mode.](image2)

The left central hole is positioned with the axially fixed front apex, which limits three degrees of freedom; the right central hole is positioned by the movable rear center, which together with the left central hole limits two degrees of freedom. The advantages of the center hole positioning are high centering accuracy, uniform positioning datum, and machining all the cylindrical surfaces.

After a brief training, workers can disassemble the rig in 60 minutes and reassemble it in 75 minutes.

2.2. Research on Hydraulic System Technology

Due to the micro pile drilling equipment in mountain area needs to meet the requirements of small volume, light weight, small power and large power conversion ratio. The hydraulic system of micro pile drilling machine in mountain area must be simple, practical, energy-saving and environmental protection, and convenient disassembly between modules should be considered.
The hydraulic circuit of micro pile drilling machine in mountain adopts the control form of plunger pump and electric proportional valve. The control mode of main pump is load sensitive control, which can automatically adjust the flow according to the load size, greatly saving the working energy consumption and reducing the heat generation of the whole rig [2].

Load sensitive control has the following characteristics:

1. Variable pressure and flow;
2. In low-voltage standby mode when no flow is required;
3. Adjust the flow to meet the system needs;
4. When the engine starts, the torque demand is low;
5. A single pump can provide flow and regulating pressure for multiple circuits;
6. Respond to system flow and pressure requirements quickly.

The logic control of the whole rig is completed by the controller programming, which simplifies the complexity of the hydraulic system, reduces the number of pipeline connections and valve groups, reduces the mass of the whole rig, reduces the number of disassembly and assembly pipelines, and greatly reduces the workload of modular disassembly.

At the same time, the proportional valve of pushing and changing the drill is placed on the propulsion beam, so that only one main pressure oil pipe is needed to solve the action of the propulsion beam, which greatly reduces the workload of disassembly and assembly.

We customized the high-pressure quick connector with self-locking function to connect the oil circuit between modules [3], which greatly improved the connection efficiency, as shown in figure 4. The main characteristics are as follows:

1. The material of high alloy steel and galvanized nickel coating not only improves the pressure resistance grade and the stability of the product itself. At the same time, corrosion resistance is considered;
2. The spring installed at the tail can effectively alleviate the vibration caused by the external and prevent the thread from falling off by vibration;
3. The male and female heads are coupled quickly by large pitch threads at both ends of the male and female ends. In the process of coupling, all the key sealing rings at the two end valve cores are gradually pushed into the designed diaphragm inside the valve body to protect all the sealing rings. It can effectively avoid the damage to the sealing ring caused by hydraulic oil surge due to continuous switching of high and low frequency of power output;
4. The thread is equipped with safety lock function, which can prevent accidental disconnection and is safe and reliable;
5. The middle plane connection can achieve zero leakage of plugging and disconnection to prevent hydraulic oil leakage. At the same time, it can avoid foreign matters from entering the hydraulic system;
6. With back pressure release device inside, it allows normal installation under static residual pressure.

Figure 4. Structure diagram of high pressure quick coupling.
3. Design Method of Chassis

Because of the complex working conditions and inconvenient traffic conditions, it often takes a lot of time to transfer the equipment and locate the site. The mass of chassis design is directly related to the overall performance of drilling rig, which is the key design work. Therefore, the walking system requirements of micro pile drilling machine are as follows: high climbing strength, small turning radius, and adaptability to complex terrain in mountainous areas.

The walking mechanism of construction machinery can be divided into wheel type, crawler type, walking type and other modes according to its structure. The following discusses the characteristics of each walking mechanism.

(1) Wheel type walking mechanism
Wheel type walking mechanism has the advantages of stable movement, low energy consumption, fast speed and easy control of moving speed and direction, so it has been widely used, but these advantages can only be brought into play on the flat ground.

(2) Crawler type walking mechanism
The characteristics of crawler type walking mechanism are very prominent. The micro pile drilling machine with this kind of walking mechanism can walk on uneven ground, cross obstacles and climb not too high steps. It has a large contact ratio with the ground and can adapt to different complex terrain.

(3) Walking mechanism
Similar to animals, the use of foot joint mechanism, the use of walking way to achieve the movement of the mechanism, known as walking mechanism. The walking machine with walking mechanism can walk on uneven ground, cross gullies, go up and down steps, so it has wide adaptability. However, it is quite difficult to control, and the structure is complex, so it is not mature enough to fully realize the above requirements.

Considering the advantages and disadvantages of the various traveling mechanisms mentioned above, the crawler type walking mode is selected for the micro pile drill. The double speed traveling reducer is adopted [4], which has the characteristics of small volume, large speed ratio (1:53), strong bearing capacity and reliable performance. The internal balance valve makes the walking smooth and greatly reduces the frustration in the process of walking. The pressure resistance of the reducer is 350 bar, the maximum torque is 23900 Nm, and the maximum traction force of the whole rig is 110 kN.

The crawler walking device is composed of "four wheels and one belt" (driving wheel, support wheel, guide wheel, drug chain wheel and track), tensioning device and walking mechanism, as shown in figure 5. The driving wheel, guide wheel, bearing wheel and carrier wheel are fixed around the track by the tension of the tensioning device to prevent the track from derailing. The track moves forward, reverses or turns through separate hydraulic motors on both sides.

![Figure 5. Track chassis structure.](image)
3.1. Calculation of Traction Force N Of Single Track

\[ N = \left( \frac{mgf}{2} + \frac{\mu mg L_0}{4B} \right) \times 10^3 \]  

\( m \): Drilling rig weight (kg) = 12000;
\( f \): Rolling resistance coefficient, taken as 0.1;
\( \mu \): Rotation resistance coefficient, 0.95;
\( B \): Track gauge (mm) = 2000;
\( L_0 \): Length of track support surface (mm) = 2200;
\( T \): Longitudinal eccentricity between center of gravity of drilling rig and grounding centroid of traveling mechanism.
\( T \leq L_0/6 \) (rounded) mm, t = 367 (mm);
\( N \): Single track traction force (N);
The results show that \( n \approx 35000 \) (N);

3.2. Calculation of Driving Force Torque of Walking System [5]

\[ M = N \times D_k / 2 \times 10^{-3} \]

\( N \): Single track traction force (N);
\( D_k \): Pitch diameter (mm), 522 mm;
\( M \): The driving force torque of walking system is Nm;
The result is: \( M = 9135 \) (Nm).
The driving force torque of the walking motor is 23000 Nm;

3.3. Climbing Ability Test

Table 1 is the result of 7 different angles of roads that we drove the rig. The speed went down while angles of roads were getting higher. Due to the limits of hydraulic components, the rig can climb up 35 degrees at most, which means the climbing ability of the rig is satisfied sufficiently.

| Angle (degree) | Speed (Km/h) | Time (s) | Skidding times | Hydraulic Pressure (bar) |
|---------------|-------------|---------|---------------|--------------------------|
| 0             | 3.5         | 52      | 0             | 50                       |
| 10            | 2.9         | 62      | 0             | 65                       |
| 15            | 2.6         | 69      | 0             | 70                       |
| 20            | 1.8         | 100     | 2             | 110                      |
| 25            | 0.7         | 254     | 3             | 180                      |
| 30            | 0.6         | 300     | 5             | 260                      |
| 35            | 0.5         | 360     | 12            | 280                      |

4. Assembly and Testing

4.1. Drilling Capacity Test
As Figure 6 shows, the construction of micro pile in mountainous area of UHVAC transmission line has high accuracy requirements for the positioning position of pile foundation. Vertical angle of pile foundation and depth of pile foundation, otherwise, the mechanical properties of pile foundation will be affected and waste holes will be easily produced. The design diameter of drilling and punching pile is d. It should be selected according to the construction drilling tools, which should be 0.2m ~ 0.4m, and the design pile length should not exceed 50 times of the pile diameter. Table 2 is the result we got after drilling rig sample drilled 300 holes in open-pit mine.

Table 2. Drilling capacity test result of Class II rock stratum.

| Depth (m) | Diameter (mm) | Time (min) | Total amount | Success amount | Success Ratio |
|-----------|---------------|------------|--------------|----------------|----------------|
| 5         | 200           | 17         | 50           | 50             | 100%           |
| 10        | 200           | 32         | 50           | 50             | 100%           |
| 15        | 200           | 45         | 50           | 49             | 98%            |
| 5         | 300           | 22         | 50           | 50             | 100%           |
| 10        | 300           | 45         | 50           | 49             | 98%            |
| 15        | 300           | 63         | 50           | 47             | 94%            |

5. Conclusion
Through modular design, from the structure, hydraulic, electrical control and other aspects of research, make it adapt to the mountainous complex terrain operation, achieve light equipment, but also meet the rapid disassembly and transportation to the construction site and then rapid assembly. Finally, the mechanized operation and high hole-forming rate of UHV micro pile foundation construction are realized.
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