Development and Application of Lightweight Coring Drilling Rig in Tunnel

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Abstract. This paper introduces ZDY1200G lightweight underground drilling rig. The feeding device was designed with light alloy material and the deformation of the fuselage was measured by 3D DIC speckle deformation measurement. A high-speed gyrator with large through hole for hard rock coring was designed. A hydraulic system based on constant pressure variable displacement pump was developed, which included feed linkage and rotary linkage. The drilling rig has been applied in the Cangyuan lead-zinc mine in Yunnan Province. A rope coring drilling hole with 512.68 m depth and 76 mm diameter has been completed. The reliability and technological advancement of the whole set of equipment have been verified, which provided technical support for the exploration of the Cangyuan lead-zinc mine and also mining areas with similar conditions.

1. Introduction
Tunnel exploration is widely used in mine geological prospecting, especially when the deep cutting of topography results in the influence of surface exploration relocation, the advantage of tunnel exploration is more prominent[1-2]. At the same time, compared with surface exploration, tunnel exploration can not only reduce drilling workload greatly, but also achieve the purpose of drilling along the ore deposit belt[3-4].

Overseas tunnel coring rig products include U4, U6 and U8 from Atlas[5], and also LM35, LM75 and LM90 from Boart longyear[6]. This kind of drilling rig adopts full hydraulic power head split structure, and adopts a large number of new materials and structural forms to meet the application requirements of tunnel exploration. However, the promotion in China was limited because of its high price and long service cycle of spare parts[7-8].

In this case, combined with the advantages of existing tunnel core drilling rigs and surface lightweight core drilling rigs, ZDY1200G fully hydraulic tunnel drilling rig was designed by using light alloy material instead of traditional carbon steel, modular pump station design, step less telescopic lifts and rapid assembly among components.

2. Overall scheme design
In order to solve the problem of relocation of drilling rigs in roadways with poor transportation conditions, light alloy material and modular design idea were adopted. ZDY1200G full hydraulic core drilling rig was developed through field investigation, scheme design, laboratory test, prototype assembly and field industrial test (Figure 1).
Figure 1. ZDY1200G lightweight drilling rig.

The feeding fuselage, base and lifting frame are made of high strength aluminium alloy, which reduce the weight and facilitate the removal. Pumping station is composed of two single pumping stations, which can work independently or in combination. Only one pumping station can be used to save energy for the construction of submersible drilling. The hydraulic system adopts load-sensitive components based on constant pressure variable displacement pump, which has fast linkage response, solved the influence of oil unloading of oil distribution sleeve on drilling rig rotation, and improved the efficiency of rotary circuit. Rotary spindle through hole meets the requirements of three series of rope coring drill pipes B (55), N (71) and Q (89). When encountering complex strata, multi-stage casing drilling can be used to improve the porosity.

Table 1. The technical parameters of ZDY1200G.

| Specification          | Parameter          |
|------------------------|--------------------|
| Rated torque /Nm       | 1200~260           |
| Rated speed /(r/min)   | 290~1000           |
| Drill pipe diameter /mm| 55.5/71/89         |
| Axis inclination /°     | -90~+90            |
| Feed/pull-out force /kN| 85                 |
| Feed/pull-out range /mm| 1000               |
| Rated pressure /MPa     | 26                 |
| Motor power /kW         | 75                 |

3. Executive mechanism design

3.1. Feeding device

Aluminum alloy is used in the feed fuselage, base and lifting frame of the feed device. In this paper, several commonly used high strength aluminium alloy materials were compared. The yield strength of 7005, 2A14 and 6061 in T6 state is higher than that of Q235 material used in traditional drilling rig. However, cracks are easy to occur in different degrees when bending at large angles. Although the strength of 5052 is relatively low, it has good bending property and is easy to form. It is found that 5052-H38 can not only bend at large angles, but also yield strength can reach 210 MPa, and has good machinability after comparison. So 5052-H38 was selected as the material of the feed device.

In order to further verify the feasibility of aluminum alloy as the material of lightweight core drilling rig, the prototype of feeding fuselage was processed and tested (Figure 2). It can be concluded from the test that when the tension pressure reaches 85 kN, the elastic deformation is about 1 mm, the plastic deformation is 0.14 mm, and the plastic deformation disappears after repeated loading of 85 kN tension pressure.
Feeding device is the main bearing part of the pull-out force of the drill. When the drill is pulled out forcefully, the pull-out force is output by the oil cylinder through the trawler. In deep hole drilling, after the gyrorator is removed from the drill pipe, the gripper should directly bear the weight of all drilling tools in the hole[9]. Therefore, the carrying capacity of the clamp support and the gyrorator both need to reach 85 kN.

3.2. Gyrorator

The gyrorator outputs the required speed of drilling through a primary gear drive, with a maximum output speed of 1000 r/min. The hydraulic chuck clamps the drill pipe and rotates with the spindle to provide the required torque for drilling and the maximum output torque is 1200 Nm. The diameter of main shaft through hole is 100 mm, and the drilling tool has strong applicability, which can meet the requirements of different aperture, depth and drilling technology.

Lubrication of high-speed gear shafts and bearings at both ends of spindle are always a difficult problem in gyrorator design[10]. It is difficult to guarantee the lubrication and cooling effect of conventional gear oil throwing method. By lifting the oil surface of the box, the problems of gear oil disturbing heating and noise are serious, and cannot meet the normal drilling requirements, especially for the drilling rigs which need to meet the 360 degree full angle range, its lubrication problem is more prominent.

The drill gyrorator adopts the way of forced lubrication to solve the above problems (Figure3). High-speed gear shaft and bearing at both ends are lubricated and cooled by hydraulic motor unloading oil. Using shuttle valve principle, a steel ball is designed in lubricating passage. Ensure that the high-speed axle bearing with power head in higher position can get more oil-unloading lubrication of motor under any axis inclination.
3.3. Hydraulic control system

The performance of drilling rig is closely related to the hydraulic control system and the selection of hydraulic components. In the design of hydraulic control system, we draw lessons from the experience of development and application of existing drilling rigs. The schematic diagram of the hydraulic control system is shown in Figure 4. It consists of a feed, rotary two basic circuits and an auxiliary function circuit. The rotary circuit mainly provides rotary power for drilling tools. Under the combined action of the feed force provided by the feed circuit, normal drilling can be realized. Rotary circuit mainly provides rotary power for drilling tools and realizes normal drilling with the cooperation of feed circuit[11].

In order to reduce the weight of a single pumping station, the hydraulic control system of the drilling rig adopts three-pump system. Two load-sensitive pumps are connected in parallel as the main pump and one constant pressure variable pump as the auxiliary pump. The load-sensitive system is used for gyrator rotation and rapid feed, which reduces the load of the heat dissipation system of the drilling rig. At the same time, the main pump controls the quick feed and strong pull-out motion to deal with the accidents in the hole. The auxiliary pump controls the decompression drilling, and the constant pressure variable system flow rate can meet the demand of the slow feed and pull-up flow rate.

Figure 3. The structure diagram of gyrator.

Figure 4. The hydraulic system of ZDY1200G type full hydraulic drilling rig.
Rotary circuit is mainly used to overcome the load torque of drilling tools, which requires adjustable speed, high rigidity, and pressure can adapt to the change of rotary load. The rotary circuit is mainly composed of a load-sensitive pump, a load-sensitive valve and a variable motor. Load sensing system has the characteristics of convenient flow regulation and good load adaptability. The combination of load sensing system and variable motor can realize large range regulation of gyror speed. Because ZDY1200G has a wide range of speed regulation and high speed, it should be sensitive to the heating of hydraulic system. There is no throttling loss in the speed regulation process of the load-sensitive system. Therefore, in the speed regulation process of the gytor, the heating of the hydraulic control system is reduced and the efficiency of the drilling rig is improved.

4. Field application

ZDY1200G full hydraulic tunnel drilling rig was applied in Cangyuan County, Yunnan Province (Figure 5). The middle 1730 section of the mine is in the stage of exploration and mineralization at present, and the ore types have certain diversity and complexity[12]. The complex stratum structure and large burial depth in the mining area have brought some difficulties to the mine construction. It is urgent to adopt the method of tunnel exploration to improve the efficiency of ore prospecting and to point out the direction for mine construction and prospecting.

![Figure 5. ZDY1200G field application.](image)

In order to ascertain the spatial occurrence of skarn sulfide ore, a borehole (KZ19-1301) was designed with azimuth angle 210 degree and dip angle -43 degree. Installation of equipment was anchored by mechanical legs and steel cables. Drilling procedure started after calibration by geological technicians.

76 mm diamond dual-tube coring bits generally select the pressure of 6-10 kN according to the formation conditions. When drilling in soft rock strata, smaller bit pressure should be selected, and larger bit pressure should be selected when the formation is complete and hard. The amount of flushing fluid is affected by drilling inclination, formation lithology, drilling diameter and other factors. Selecting the appropriate amount of flushing fluid is conducive to drilling straight.

After 23 days of field application, one coring hole with 76 mm diameter and 512.68 m depth was completed. The maximum mechanical efficiency of drilling was 6 m/h and the footage of the fastest shift (12 hours) in the construction process reached 35 m. Compared with the conventional coring process, the efficiency was greatly improved. The cumulative length of core was 496.32 m, the core recovery rate was 96.8%, and the core structure was complete and clear. Through field observation and core identification, the geological characteristics of the middle 1730 section have been preliminarily grasped to achieve the purpose of exploration.
5. Conclusions
ZDY1200G lightweight tunnel drilling rig is mainly used to meet the requirements of metal mine tunnel drilling construction. It fully embodied the requirements of high speed, light weight of main components under harsh relocation conditions. Drilling efficiency has been greatly improved by drilling the drilling rig and matching technology. The coring rate of boreholes was 96.8% in field application of drilling rig in Cangyuan County, Yunnan Province. The more detailed geological data of Dongyi roadway have been obtained, and the exploration purpose has been achieved, which provided a technical reference for the rope coring drilling construction in similar mining areas.

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