Design of Drilling Turbine Generator under Coalmine Well

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Abstract: Aiming at solving the problem of low endurance of detection instruments under coalmine well, a turbine generator, which relied on water drive to generate electricity in drilling, was designed based on the explosion-proof requirements of coal mine equipment. The generator structure, turbine structure, overall structure and circuit design of the turbine generator were discussed in detail. By setting up the test platform, the speed of the prototype and the driving performance of the water flow were tested. The test data shows that the prototype accords with the design goal and it can meet the requirements of underground drilling detection instrument in coal mine.

1. Background
With the continuous progress of intelligent information in coal mine area, more and more data, parameters and conditions need detecting in underground drilling. The requirements of the measuring instruments and the supply of electric energy in underground boreholes in coal mines are higher. Presently, the form of cable power supply is limited by the coal security since the provided limited voltage and current one could not meet the normal working requirements of the instrument in the hole. When installing the phones, the battery capacity is also limited. Therefore, the continuous working ability of the instrument in drilling is limited and the detection efficiency is difficult to be improved.

At present, the field of oil drilling generally relies on turbine generators to solve this problem. However, the use of turbine generators is limited for a variety of reasons in the field of coal. First, compared with oil drilling, the drilling fluid displacement in coal field is small, which cannot drive the rotor of turbine generator while drilling to reach a stable speed. Therefore, the turbine generators could not provide stable electric energy. Second, the size of the existing turbine generator can not meet the requirements of underground size in coal mine. Third, there is no mandatory explosion-proof requirement for turbine generators in petroleum holes and the safety of generator output power cannot meet the requirements of underground explosion protection in coal mines.

2. Principle
The working principle block diagram of the turbine generator is shown in Figure 1. When the mud pump injects the mud into the hole, the high-speed flow of mud flows through the guide wheel vane channel and enters the turbine vane passage. The mud impinges the blade to produce rotating torque, which drives the turbine and turbine shaft to rotate at a high speed. The permanent magnet rotor of the generator is fixed to the spindle. Therefore, when the turbine shaft rotates, it drives the permanent magnet rotor to rotate, which is running at a high speed reference to its stator coil. The whole process is equivalent to cutting the magnetic inductance line in the coil to produce induction EMF. After rectifying, filtering and stabilizing, the electric energy is stored in the battery pack, which supplies power to the drilling detector after double protection circuit.
3. Structure design

To adapt to the size of drill hole and in-hole detector in coal mine, it is necessary to redesign the structure of turbine generator.

3.1. Design of motor structure

The motor structure adopts the magnetic coupling connection mode, whose structure and parameters of electric machine are shown in Figure 2 and Table 1 respectively. When the mud drives the turbine to rotate, the external magnetic steel of the magnetic coupling rotates with the turbine synchronously. Based on the principle of same-sex repulsive and heterosexual absorption of magnetic materials, the magnetic steel and solid rotating shaft and rotor assembly rotate together in magnetic couplers. The rotor assembly rotates and cuts the magnetic inductance line in the stator coil to generate electric energy.

![Figure 2. Motor Structure.](image)

| Motor Type      | Rated Speed | No-load Speed | Rated output Voltage | Rated Power | Resistance | Electrokinetic Constant |
|-----------------|-------------|---------------|----------------------|-------------|------------|-------------------------|
| Three-phase AC motor | 5500r/min   | 8700r/min     | 24V                  | 60W         | 1.47 Ω     | 4.35V/1000r             |

3.2. Design of turbine structure

The form of turbine structure is shown in Figure 3. The guide wheel and turbine were added in the design. When drilling, the high-speed mud flowing into the drill pipe first flows through the fixed guide wheel, and then hits the turbine blade after passing through the guide wheel to drive the turbine to rotate. Guide wheel can improve the working efficiency of downhole turbines, and its function mainly includes two aspects: ① regulating working condition; ② the high speed mud flowing through the guide wheel forms a stable flow trend and improves the conversion efficiency of the turbine to the kinetic energy of the mud.
3.3. Design of overall structure

The overall structure adopts the form of flameproof and intrinsic safety. The instrument is put in an explosion-proof cavity and one output port is set as the intrinsically safe output. The overall structure is shown in Figure 4.

In Figure 4, 1 is motor assembly; 2 is axial buffer; 3 is rectifier movement; 4 is energy storage battery; 5 is outer barrel; 6 is adapter; 7 is connecting cylinder; 8 is generator connecting line; 9 is protective cap.

4. Design of circuit

Most of the detection parameters in coal mine are measured when drilling is stopped. Therefore, a battery pack is placed as energy storage component in the power generation device. When drilling is normal, the generator charges the battery pack. When drilling is stopped, the battery pack supplies power to the supporting instruments. The circuit part of the power generation device includes rectifier, voltage stabilizer, detection, charging voltage and current limit, battery pack charge and discharge protection, two-stage voltage and current limit circuit discharge. Rectifier, voltage stabilizer, detection and primary charging voltage limit and current limiting circuits are arranged on a circuit board, which is called rectifier circuit board. The battery pack charge and discharge protection circuit are arranged on a separate circuit board, which is called battery protection board. The two-stage voltage and current-limit discharge circuit is a single circuit board, which is called intrinsic safety protection board. The block diagram of the partial connection of the circuit is shown in Figure 5.

The circuit of rectifier circuit board mainly rectifies the three-phase alternating current emitted by the motor, voltage conversion, primary charging over-current and over-voltage protection and data communication. To prevent the power generation voltage from affecting the performance of the circuit and the instrument, a voltage stabilizer diode is designed to prevent the output voltage from being too high.
According to the explosion-proof requirements of mine battery and the working conditions in drilling, the battery protection board circuit needs to have under-voltage, over-current, over-voltage and battery pack information monitoring functions.

To meet the power output requirements of mine intrinsically safe equipment, the intrinsic safety board circuit needs to have double over-voltage and over-current protection functions.

5. Testing
To verify the design effect of turbine generator, the power generation performance test under different rotating speed of generator was carried out after the prototype was assembled. The photo of the generator speed performance test is shown in Figure 1. The turbine generator is driven and rotated by an external motor and the output voltage of the speed test can be adjusted. The speed test data are shown in Table 2.

![Figure 6. Generator Generating Test-bed at Different Speed.](image)

| Speed (r/min) | Load (Ω) | Load Terminal Voltage (V) |
|---------------|-----------|---------------------------|
| 1000          | 10        | 2.15                      |
| 1500          | 10        | 4.25                      |
| 2000          | 10        | 7.37                      |
| 2500          | 10        | 10.35                     |
| 3000          | 10        | 12.28                     |
| 3500          | 10        | 13.8                      |
| 4000          | 10        | 14.19                     |

After directly adjusting the turbine speed, the internal performance of the prototype was tested. Then the overall performance test of the prototype driven by external mud pump was carried out. The physical photos of the test are shown in Figure 7. The generator is loaded into the outer pipe and placed on the test bed. It is connected with water stool, and the turbine is driven by mud pump to drive the generator to work with different mud flow rate. The water required for the mud pump is provided by the water tank and placed in the tank for recycling. The test data is shown in Table 3.
Table 3. Measurement Value of 10Ω External Load Under Different Flow Rate.

| Flow (L/min) | Load (Ω) | Voltage (V) | Electric current (A) | Power (W) | Temperature (°C) |
|--------------|----------|-------------|----------------------|-----------|------------------|
| 96           | 10       | 2.2         | 0.261                | 0.5742    | 18.9             |
| 130          | 10       | 3.2         | 0.365                | 1.168     | 18.9             |
| 160          | 10       | 4.2         | 0.48                 | 2.016     | 18.9             |
| 185          | 10       | 6.7         | 0.8                  | 5.36      | 19               |
| 222          | 10       | 8.2         | 0.95                 | 7.79      | 19               |
| 270          | 10       | 10.2        | 1.1                  | 11.22     | 19.1             |
| 290          | 10       | 9           | 1                    | 9         | 19.3             |
| 340          | 10       | 8.3         | 1.2                  | 9.96      | 19.7             |
| 360          | 10       | 10.7        | 1.3                  | 13.91     | 20.5             |

The turbine speeds at about 1000 r/min at 100L flow rate and its instantaneous power generation is about 0.6 W; the turbine speeds at about 1500 r/min at 160L flow rate and instantaneous power generation is about 2 W; the turbine speeds at about 2000 r/min at 200L flow rate and instantaneous power generation is about 6 W; the turbine speeds at about 2500 r/min at 270L flow rate and instantaneous power generation is about 11 W.

When the rotating speed is more than 2500 r/min, the data voltage and power continue to increase steadily. When the flow rate is greater than 270L, the output voltage and power decrease. The data is obviously out of sync because the prototype is not installed inside the rectifier circuit behind the voltage regulator diode when measuring the speed. Under the influence of voltage stabilizing diode, when the flow rate increases and the flow rate is more than 270V, the voltage stabilizing diode at the back end of the rectifier circuit is started, the electromagnetic torque is increased and the rotating speed is reduced when the load becomes larger. At the same time, the voltage stabilizer diode also consumes some of the energy generated by the generator.

6. Conclusions
The underground drilling turbine generator designed in this paper meets the explosion-proof requirements and actual working conditions of mine equipment. The instantaneous power generation capacity of the generator can be basically maintained within the range of 11~13W. The battery capacity of the generator can be selected flexibly according to the power consumption characteristics of the matching instrument, which basically meets the requirements of the conventional drilling instrument for continuous power supply.
Funded Projects
[1] Development of Explosion-proof Turbine Generator for Underground Wireless While Drilling Measurement (2018XAYMS01).
[2] Major National Science and Technology Special Tasks in the 13th Five-Year Plan(2016ZX05045-003-001).
[3] Special Fund for Scientific and Technological Innovation and Entrepreneurship of CCTEG (2018MS007).

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