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Structure Analysis of the Turbine Generator for Automatic Vertical Drilling Tool

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Abstract: Generating electricity by downhole turbine generator is one of the main methods to provide power supply for the downhole measuring and controlling in the drilling process of oil and gas production. This study has analyzed three kinds of structure of the existing turbine generators, including the common unsealed structure, the axial magnetic drive structure and cylindrical magnetic drive structure. By combining the dynamic seal compensating protection technology and the magnetic drive technology, the supporting high-speed bearing of the rotating turbine and the dynamic seal components has been sealed with compensating protector and high speed rotating of the turbine has been transmitted to the rotor of the generator without contact by the magnetic drive which can isolate the generator from the power mud fluid completely, improve the working condition of the turbine generator and increase the service life and reliability of the moving parts of turbine generator. The study also discusses the material selection of the key parts.

Key words: Turbine generator, structure, vertical drilling, tool, analysis

INTRODUCTION

At present, there are three ways to supply power to downhole measuring and controlling function in the drilling process of oil and gas production: Utilizing a wire to supply power from ground, supplying power from downhole battery packs and downhole independent generator, the corresponding technologies and equipments are intelligent drill pipe with built-in wires, downhole lithium ion battery packs and downhole mud turbine generator. As the development of measure while drilling, rotary steering drilling, geometry steerable drilling, automatic vertical drilling technologies, etc., the demand on power in downhole measuring, storing and controlling has increased, the requirement of power has reached to 300~1000 W. It is an ideal way that power for downhole measuring and controlling system is supplied from the ground by built-in wire in the intelligent drill pipe, there is no limit on transmission power, the mass commercial production has not been realized because of the high cost. It was a common way that supply power to downhole measuring and controlling system by lithium battery packs short section in the past, due to the high temperature environment, long time power supply, power capacity and environment protection requirement, the cost of this type of downhole lithium battery packs will increase dramatically and cannot adapt to the requirement. The power of mud generator can be achieved by circulating mud, it will be a trend in the future because of

its wide power range, no new pollution problems and lower cost. Downhole mud turbine generator is indispensable power to rotary steering drilling system and automatic vertical drilling system, it provides power for these systems to measure, storage and transmit information, as well as the system control. Because of the requirement of control, mud turbine generator is often configured in pairs with the upper and the lower turbine generator, the structure of these two parts is also quite different. Turbine generator works in the drilling mud including solid phase grain and high-speed rotating will quicken abrasion and erosion of the moving parts such as bearings and seals which have a short service life and are the vulnerable parts of the system. It is no doubt that these will increase the engineering

application cost of the rotary steering drilling system and the automatic vertical drilling system. The structure principle of common ordinary turbine generator is shown in Fig. 1 (Tang and Ma, 2003).

The structure of turbine generator is discussed emphatically in the paper. By combining the dynamic seal compensating protection technology and the magnetic drive technology, the supporting high-speed bearing of the rotating turbine and the dynamic seal components has been sealed with compensating protector and high speed rotating of the turbine has been transmitted to the rotor of the generator without contact by the magnetic drive which can isolate the generator from the power mud fluid completely, improve the working condition of the

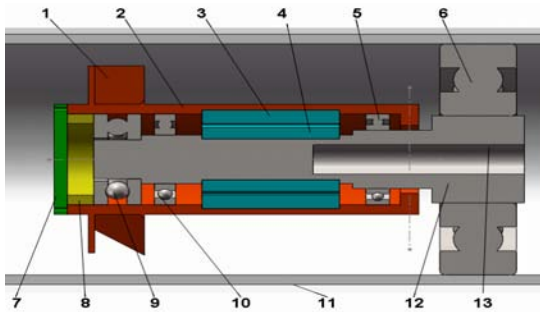


Fig. 1: Structure principle of turbine generator, 1: Turbine, 2: Shell, 3: Rotor magnetic steel, 4: Stator and stator coil, 5: High-speed alignment bearing, 6: Low-speed main bearing, 7: gland, 8: Compression ring, 9: High-speed thrust bearing, 10: High speed ball bearing, 11: Tool shell, 12: Electronic housing shaft, 13: Through wire hole

turbine generator, increase the service life and reliability of the moving parts of turbine generator and reduce the cost of automatic vertical drilling system.

STRUCTURE AND PRINCIPLE OF TURBINE GENERATOR

Focusing on downhole turbine generator, the researchers have developed relative work (Yan *et al.*, 2005; Zhang *et al.*, 2006; 2009; Shen *et al.*, 2008; Sheng *et al.*, 2008; Li *et al.*, 2008; Liang, *et al.*, 2010; Jian *et al.*, 2008) and have made the substantial progress on turbine vane, magnetic drive and performance test, etc. In terms of the turbine generator structure, one type belongs to the ordinary mud structure, mud flows through the gap between the generator stator and rotor, as well as the high-speed rotating bearings, another type belongs to magnetic drive structure isolated from mud structure, the turbine generator is completely sealed in the generator shell by magnetic drive technology, this kind of sealed turbine generator has the high efficiency and reliability in which the stator coil and the rotor magnets steel are isolated from mud, so that becomes the basic form of turbine generator. Axial and cylinder type of magnetic drive are two common structure forms, therefore, there are two types of generator: Axial generator and cylinder magnetic drive generator, but such types of generator still exist the problem that reliability of high-speed bearing dynamic seal is not high, still due to the short service life, the application of rotary steering drilling system and automatic vertical drilling system have been restricted to some extent.

Structure principle is shown in Fig. 1. Its principle is that mud drives the turbine 1 rotating which drives motor shell 2 and generator rotator magnetic steel 3 rotating, the relative rotation between the rotator 3 and stator coils 4 will cut the magnetic lines of force to generate current. The basic principle is similar to hydraulic generator, just because of the restriction on the size of borehole and high temperature and high pressure mud working environment, it has the special structure problem that need to be solved. The mud displacement is $15\sim 50\text{ L sec}^{-1}$, the environment temperature can reach to 150°C , the highest rotational speed of turbine can reach to $1500\sim 2000\text{ r min}^{-1}$. Due to the high-speed bearing of turbine generator working in the mud and mud flowing the gap of motor, it may cause the shorten service life of high speed bearing, unreliability of dynamic seal, the low efficiency of motor, the mud erosion of rotor magnet steel and stator coil.

The structure of axial magnetic drive mud generator is shown in Fig. 2. Its principle is that mud drives turbine 1 rotating, as well as control shaft 2, the inner magnetic rotor 6 is driven to rotate through transmission 5, the outside magnetic rotor 8 is also rotated with inner rotors synchronously, this can make the generator rotor rotate, in this way, electric power can be got. This structure is more complex than structure 1, but it adds the dynamic seal 4 and oil chamber 13 filled with lube oil which can seal high-speed turbine bearing in the oil cavity body and adds the axial magnetic drive at the same time, seals the rotor and the stator of the motor in air chamber 11 which is formed by magnetic drive distance sleeve 7. In addition, it utilizes the slip effect produced by the magnetic drive inner and outside magnetic rotors to enlarge the range of mud displacement and to protect the generator from exceeding the limit speed caused by large mud displacement. This structure solves problems such as the short service life of high speed bearing, the low efficiency of motor, the easily mud erosion of rotor magnet steel and stator coil. But the problem is still not solved that the reliability of high-speed dynamic seal is not high enough and it should not be used for lower turbine generator.

The structure of cylinder magnetic drive mud generator is shown in Fig. 3.

Its principle is that mud drives the vane 2 rotating, then turbine 3 and buffer wall jacket 4, outside magnetic rotor 7 are driven. outside magnetic rotor 7 and inner magnetic rotor 11 form the cylinder type magnetic drive, thus inner magnetic rotor 11 is rotating synchronously with outside magnetic rotor 7, while the levitated shaft 10 connected to the inner magnetic rotor is also rotating which drives the rotor shaft of generator, in this way, the electric power can be generated.

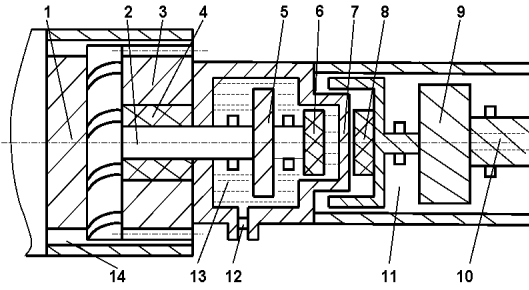


Fig. 2: Structure of axial magnetic drive mud generator, 1: Turbine, 2: Control shaft, 3: Liquid allocator, 4: Dynamic seal structure, 5: Transmission, 6: Inner magnetic rotor, 7: Distance sleeve, 8: Outside magnetic rotor, 9: Motor, 10: Through wire line, 11: Air chamber, 12: Hydraulic balance system, 13: Oil chamber and 14: Mud flow channel

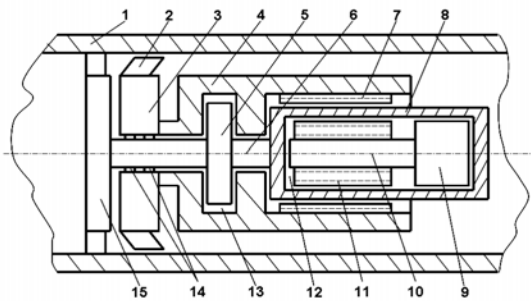


Fig. 3: Functional structure of cylinder magnetic drive mud generator: 1: Tool shell, 2: Vane, 3: Turbine, 4: Buffer wall jacket, 5: Bumper plug, 6: Plug rod, 7: Outside magnetic rotor, 8: Distance sleeve, 9: Motor, 10: Levitated shaft, 11: Inner magnetic rotor, 12: Air chamber, 13: Through mud chamber, 14: High-speed bearing and 15: Support

Its structure is more complex than the structure 1, bumper plug 5 is located in the middle of inner wall of buffer wall jacket 4, one of buffer wall jacket 4 and bumper plug 5 is magnet and there is a buffer gap between them which forms a magnetic snubber assembly and can reduce the outside magnetic rotor 7 hydraulic impact from turbine 3. Its cylindrical magnetic drive distance sleeve is connected with motor seal shield, isolate the whole generator in the air chamber from mud completely. This structure utilizes the slip effect produced by the magnetic drive inner and outside magnetic rotors to enlarge the range of mud displacement and to protect the generator from exceeding the limit speed caused by large mud displacement.

STRUCTURE OF COMPENSATING DYNAMIC SEAL TURBINE GENERATOR

In the automatic vertical drilling system, there are two turbine generators, upper and lower generator, the structure is shown in Fig. 4. Because of different location, the structure of them are not identical, the new design structure of the upper and lower turbine generator are shown in Fig. 5 and 6.

From the view of function, the upper turbine generator just transmits power to the electronic housing at bottom, the lower turbine generator not only transmits power to the electronic housing at top but also provides torque to control shaft and upper disc valve at the bottom of it, therefore, the structure of lower turbine generator is relatively complex.

The structure of upper turbine generator: The structure of Upper turbine generator is shown in Fig. 5. Its principle is that mud drives turbine 1 rotating, magnetic drive shell 2 and rotating permanent magnet 3 which are integrated with the turbine, are also driven, as magnetic drive consists of outside magnetic rotor 3 and inner magnetic rotor 4, inner magnetic rotor 4 follows with outside magnetic rotor 3 rotating synchronously, the generator rotating shaft which is connected with inner magnetic rotor 4 rotates as well, then the power can be generated.

The structure of the new design upper turbine generator is more complex than what is shown in Fig. 1. As all high-speed bearing 5, 6, 18, 20, 22 are sealed in the magnetic drive shell 2 which is full filled with high temperature resistant capacitor oil 24 by piston ring 7, kalsi high-speed dynamic seal components 8 and compensated spring 9, all of these form a compensating high-speed dynamic seal, this seal can make high-speed bearing isolated from mud and keep good lubrication condition, at the same time, compensating spring can keep pressure of the lubricating oil higher than the mud outside, make sure the mud not intrude into the seal chamber through dynamic seal. Introducing thick oil film kalsi seal which utilizes the unique fluid dynamic structure, has better kinetic pressure structure for unidirectional flow fluid, adds the thickness of oil film, reduces friction, has good cooling and enhances the ability of abrasive and erosion resistance. The whole generator is isolated completely from mud by magnetic drive distance sleeve. With using the magnetic drive slip effect, the displacement range of generator is enlarged and the generator has been protected from exceeding the limit speed.

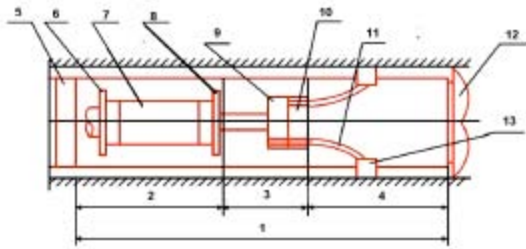


Fig. 4: Functional structure of automatic vertical drilling system: 1: Automatic vertical drilling system, 2: Stabilized platform, 3: Flow distribution unit, 4: Steering executing mechanism, 5: MWD, 6: Upper turbine generator, 7: Electronic housing, 8: Lower turbine generator, 9: Upper disc valve and controlling shaft, 10: Lower disc valve, 11: Mud channel, 12: Drilling bit and 13: Plunger and pad.

Structure of lower turbine generator: The structure of Lower turbine generator is shown in Fig. 6. The principle is that mud drive turbine 5 rotating, magnetic drive shell 12 and rotating outside permanent magnet 8 which is integrated with turbine, are also driven, as magnetic drive consists of outside magnetic rotor 8 and inner magnetic rotor 9, inner magnetic rotor 9 follows with outside magnetic rotors 8 rotating synchronously, the motor enclosure 25 which is connected with inner magnetic rotor 9 and generator permanent magnet 28 rotate as well, the power can be generated.

The structure of new design upper turbine generator is more complex than what is shown in Fig. 1. As all high-speed bearing 4,10,14 are sealed in the shell 12 of magnetic drive which is full filled with high temperature resistant capacitor oil 7 by piston ring 2, kalsi high-speed dynamic seal component 3 and compensating spring 1, piston ring 15, kalsi high-speed dynamic seal component 16 and compensating spring 17 forming two pairs of compensating high-speed dynamic seal, this seal can make high-speed bearing isolate from mud and keep good lubrication condition. At the same time, compensating spring 1, 17 can keep pressure of the lubricating oil higher than the mud outside, make sure the mud not intrude into the seal chamber through dynamic seal. The whole generator is isolated completely from mud by magnetic drive distance sleeve 6. As same as the upper turbine generator, it also can protect the generator from exceeding the limit speed.

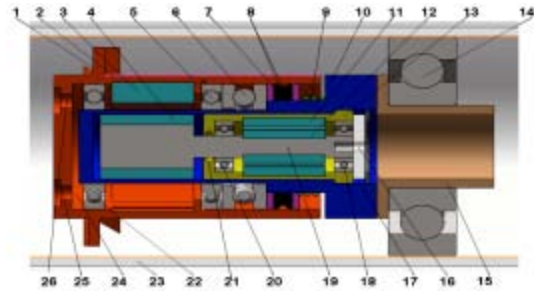


Fig. 5: Structure of upper generator diagram, (1) Turbine, (2) Shell, 3: Outside magnetic rotor, 4: Inner magnetic rotor, 5: High-speed bearing, 6: High-speed thrust bearing, 7: Piston ring, 8: High-speed dynamic seal sets, 9-spring, 10: Distance sleeve, 11: Rotor coil, 12: Permanent magnet, 13: Motor shell, 14: Electronic housing low-speed main bearing, 15: Electronic housing, 16: Through wire hole, 17: Set ring, 18: High-speed bearing, 19: Motor shaft, 20: High-speed bearing, 21: Dynamic seal, 22: High-speed alignment bearing, 23: Tool shell, 24: High temperature resistant capacitor oil, 25: Oil-in cock hole and 26: Oil drain cock hole

CHARACTERISTICS OF COMPENSATING DYNAMIC SEAL

This structure of turbine generator has three significant characteristics: isolation between motor and mud, improvement of high-speed bearing lubrication, kalsi high-speed dynamic seal automatic compensation.

Isolation between motor and drilling mud: The high-speed rotating of turbine can be transmitted to rotors of generator without contact by using the cylinder magnetic drive, the inner magnets and generator are sealed in the electronic housing completely by distance sleeve which can realize the complete isolation between generator and mud, avoid mud which contains solid particles to wear magnets of rotor and stator coil through the generator air-gap, simplify the design of generator, improve the mud generator working environment, increase the service life, efficiency and reliability of dynamic seal of generator, enhance the stability of performance parameters of generator as well.

High-speed bearing lubrication condition improvement: Bearing rotating at high speed with turbine

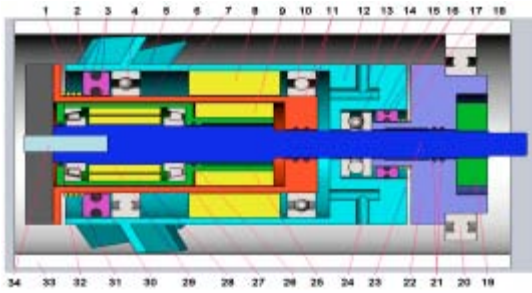


Fig. 6: Structure of lower turbine generator, 1: Spring, 2: Piston ring, 3: High-speed dynamic seal components, 4: High-speed alignment bearing, 5: Turbine, 6: Distance sleeve, 7: High temperature resistant capacitor oil, 8: Outside magnetic rotor, 9: Inner magnetic rotor, 10: High-speed ball bearing, 11: Distance sleeve static seal, 12: Shell, 13: Oil in cock hole, 14: High-speed thrust bearing, 15: Piston ring, 16: High-speed dynamic seal sets, 17: Compensating spring, 18: Main bearing pedestal, 19: back nut, 20: Low-speed main bearing, 21: Bearing ring static seal, 22: Bearing ring, 23: Output shaft, 24: Oil drain cock hole, 25: Enclosure, 26: Dynamic seal, 27: High-speed bearing, 28: Permanent magnet, 29: Stator coil, 30: High-speed bearing, 31: dynamic seal, 32: Motor transparent cover, 33: Tool shell, 34: Through-wire hole

and its seal components are sealed by compensating protector seal and the pressure compensating rotating kalsi dynamic seal has been adopted to keep three groups high-speed rotating bearing of turbine working in the insulating lube oil in seal capsule and the bearing lubrication and cooling have been realized by high temperature resistant insulating oil instead of from mud, this dynamic seal improves the lubrication condition and enlarges the service life of high-speed bearing.

High-speed dynamic seal automatic compensation: Pressure compensating rotating dynamic seal not only plays a role in rotating seal, its compensating spring also balances the inner and outside pressure of seal capsule, it can keep the inside pressure of capsule higher than the outside, it also can prevent mud invade the capsule; when the insulating lube oil in the capsule occurs leakage, the pressure in the capsule will reduce, with the joint effect of spring thrust and capsule external pressure, the dynamic seal ring set moves inward so that the pressure automatic compensation in the capsule will be realized. The

reliability of dynamic seal is improved greatly. In addition, the application of thick oil film kalsi seal can strengthen the effect of abrasive and erosion resistant.

KEY COMPONENTS MATERIALS SELECTION

Turbine generator distance sleeve, compensating spring and high-temperature resistant permanent magnet are key parts, the materials selection of these parts has great influence on the performance of turbine generator.

Material of distance sleeve: Distance sleeve is installed between inner and outside magnetic rotors, whether inner or outside magnetic rotors has a relative rotative speed to sleeve, the distance sleeve will be in approximate sinusoidal alternating magnetic field, therefore, the material of sleeve should not only endure the differential pressure of inner and outside, but also have the lower eddy current losses, if using a metal conductive material, it will produce the eddy current and heat itself, reduces the transmission power, so the material of it should select no magnetic permeability material with high strength, large resistivity and corrosion resistance, because of the high pressure downhole, after optimization, Titanium alloy (TC4) is selected, this kind of material not only has the high resistivity, but also can meet the strength requirement, the resistivity is $1.62 \Omega \text{ mm}^2 \text{ m}^{-1}$, the tensile strength is up to 895 Mpa.

Compensating Spring Material: Compensating spring is used for forming the pressure compensating dynamic seal, that is required to have more accuracy and stable elasticity, as it is exposed in the mud, endures the high temperature and high pressure corrosion environment, so metal material with the stable temperature performance and corrosion resistance should be chosen, after optimization, alloy with constant elasticity (3J21) is used, this kind of material has stable high temperature elastic properties and corrosion resistance.

Permanent magnet and others material: All the magnetic drive of turbine generator and itself need to use the high temperature resistant permanent magnets, samarium cobalt permanent magnet material ($\text{Sm}2\text{Co}17$) has been developed in recent years, its working temperature can reach to 300, rate of decline of magnetic remanence falling is 3% which can meet the need. In addition, the material of bearing choose 9Cr18Mo, its wear resistance performance is good, bearing capacity is strong, it is an ideal anti-corrosion bearing manufacturing material of downhole tools.

CONCLUSION

The combination of dynamic seal compensating protect technology and kalsi seal has been applied to turbine generator of automatic vertical drilling tool which can make the high-speed bearing and dynamic seal components be protected by compensating protector seal and improve the reliability of high-speed bearing dynamic seal and service life.

Applying magnetic drive technology to turbine generator of automatic vertical drilling tool can transmit the rotation from turbine to motor rotor in no contact condition which realizes the absolute isolation between generator and mud power fluid and improves the mud environment which turbine generator works in.

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