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Transmission Scheme Design of Gearbox for 15MW Offshore Semi-direct-driven Wind Turbine

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Abstract: In order to further improve the reliability of wind turbine operation, reduce manufacturing, installation and maintenance costs, and make the size of the gearbox further reduced, in this paper, the gear box design of 15MW offshore semi-direct-driven wind turbine is studied. First, analyze the development trend and demand, draw up the basic transmission plan, then, carry on the gear structure design, use the software modeling, the motion analysis and carry on the check, the life analysis, finally, the design of sealing mode, design box, end cover structure, determine the fastener, connection, design of dust-proof program and design of lubrication. This reduces the weight and volume of the main engine of the medium-speed transmission mechanism of the wind turbine. The obvious benefits are lower overall load, lower difficulty in manufacturing, transportation and installation, lower cost and controllable technology, the market prospects are broad and competitive.

Keywords: Offshore wind turbines, Gearbox, Semi-direct drive, Medium speed transmission.

1. Introduction

With the development of science and technology and the progress of the times, energy and environment are the urgent problems for human survival and development. The electric power industry is the basic pillar industry which concerns the national economy and People's livelihood, and is closely related to the development of the national economy. At present, the world's main forms of power generation are thermal power, hydropower, wind power, nuclear power and solar power generation. Thermal power generation not only consumes a large amount of primary fossil fuels and is non-renewable in the short term, but also causes serious air pollution. Hydropower and nuclear power generation are inevitable to water resources and the environment have a certain impact. Therefore, the development and utilization of renewable energy, especially the development and utilization of wind energy, has been highly valued in our country and other countries in the world, and wind power has become the main form of wind energy utilization [1] . In recent years, the global wind power industry has been developing rapidly. As one of the fastest-growing renewable energy sources, the proportion of wind power in the global power production structure is increasing year by year, which has broad prospects for development, especially in recent years, the technology of wind turbine develops rapidly. With the emergence of smart wind turbine and smart wind farm, the wind turbine is developing towards diversification.

China's offshore wind energy potential is huge, resources are stable, the power of the unit is large, easy to absorb, but the start is late, the development of offshore wind power, there are three aspects of significance: first, to help optimize China's energy structure, second, it can relieve the pressure on the power consumption and environment in big coastal cities, and solve the problem of electricity consumption far away from land and islands Third, because the lack of technology is typical of the industry, technology and market advantages are very prominent, so it can become a breakthrough in our high-end equipment technology innovation, promote our industrial technology innovation as a whole. The 14th five-year plan describes how to build a modern energy system: scale up wind and solar power, and develop offshore wind power in an orderly manner. To develop high-quality offshore wind power industry and speed up the development of offshore wind power in the deep sea, promoting large-scale, intensive and sustainable development of offshore wind power is an important support for accelerating China's energy restructuring and achieving its 2060 carbon neutrality target [2] . The capacity factor of offshore wind power is generally over 40% , and even up to 60% , which is much higher than that of PV and onshore wind power. In 2020, capital spending on offshore wind surpassed offshore oil and gas for the first time, according to Clarkson Research, and capital is shifting from offshore oil and gas to offshore wind and related industry chains. Of these, 50% of the world's offshore wind projects are in China. From the perspective of the future development trend, the proportion of offshore wind power will continue to expand and gradually gain a leading position.

2. Transmission Scheme Design

2.1. Wind turbines

Common classification of wind turbine units: according to the spatial physical position of the transmission shaft, there are horizontal axis and vertical axis. At present, all the mainstream wind turbine units in the wind power industry are horizontal axis, they include direct-drive permanent magnet electric generator, semi-direct-drive electric generator, and doubly-fed asynchronous generators

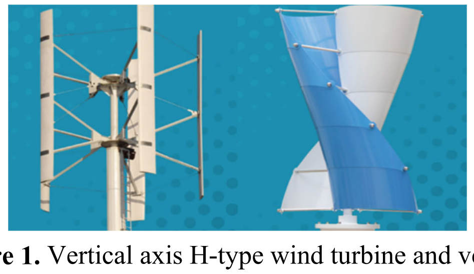

Figure 1. Vertical axis H-type wind turbine and vertical axis S-type wind turbine

Wind turbine is generally composed of wind turbine, transmission, generator, variable pitch device, tower, Battery Controller, inverter, unloader, grid-connected controller, brake device and energy storage device.

2.2. Comparison of common wind turbine schemes

The common three main transmission routes are double-fed, direct-driven, semi-direct-driven, direct-driven wind turbine directly connected with the wind turbine, increasing the stability of the system, at the same time, the volume of the motor and the difficulty of design, manufacture and control are increased. The utility model does not need an electric excitation device, and has the advantages of light weight, high efficiency and good reliability [4] . In direct-driven wind power generation system, the direct coupling between the wind turbine and the generator, because there is no gearbox and its accessories, the transmission mechanism is greatly simplified [5] , reducing the number of parts of the unit, thus reducing the failure rate, the reliability is greatly improved, and the danger of oil leaking into the sea water is reduced, the maintenance work of the generator is reduced, and the noise is reduced, which is friendly to the electric network [6] . In addition, the short board of Direct Drive technology also includes the heat dissipation of the generator, the head load is too big, etc. , will cause the engine room and the wheel hub joint serious wear [7] . When the capacity of a single unit exceeds 2 MW, the volume and weight will increase rapidly if the power generation is to be increased, and the demagnetization hazard exists in the permanent magnet motor, which limits the development of the permanent magnet direct-driven synchronous generator [8] . The doubly fed induction generator (DFIG) uses the impeller to convert the wind energy into mechanical torque. The speed of the DFIG is increased through the gearbox through the main shaft transmission chain. The DFIG stator windings are connected to the power grid, the stator energy of the generator is incorporated into the power grid by the excitation converter[9]. The DFIG rotor is connected with the wind turbine through a coupling, and the wind turbine can convert the wind energy into mechanical energy for the whole system through the optimal tip speed ratio [10] . The DFIG rotor windings are connected with the rotor-side converter and the grid-side converter, which can transfer the generated power to the grid in two directions [11] . The concept of semi-direct drive comes into being in the process of direct-drive and doubly-fed wind turbine development. The mechanical transmission part is similar to the double feed, but the transmission ratio is lower, and the gearbox structure is simpler, which makes it more advantageous in size and volume, The transmission chain is supported by four points, and the gearbox only bears the torque transmitted by the wind wheel. The state of stress is stable, and the safety and reliability are high, it also has higher efficiency at low speed, so it can output more power than the same power dfig at the same input power. Moreover, the low-voltage traversal ability is strong, the failure rate is lower, the daily maintenance is more convenient; the electric drive part is similar to the direct drive, but the rotational speed is higher, the weight is lighter, the system integration degree is high, has solved the generator manufacture and the transportation question, the size of the whole generator is greatly reduced, the weight is reduced (by more than 20%) , and the application range of the fan is increased [12] . This characteristic determines that semi-direct drive can improve the reliability and service life of the gearbox on the one hand, and at the same time, can take into account the corresponding generator design compared to the direct drive generator, improve the design and manufacturing conditions of high-power direct-drive generators [13] . Semi-direct-drive permanent magnet synchronous motor is smaller than direct-drive permanent magnet synchronous motor, so the use of raw materials less than direct-drive generators, making the dependence on raw materials greatly reduced rare earth. Based on the environment of offshore wind power, current technology, cost and other situations, semi-direct drive has been the preferred route of offshore wind power [14] . Wind turbine gearbox is the main transmission component in the wind turbine transmission system. Its failure rate is the highest in the transmission chain and even in the whole wind turbine system, the research and development of wind power gearbox is the core of the development of wind power technology, the research and development of high-power and high-reliability wind power gearbox is an important subject for developing wind power technology. However, the semi-direct drive gearbox is not without its shortcomings. As a low-speed gearbox, the semi-direct drive gearbox is easy to break down due to many parts, so it needs a large amount of operation and maintenance costs, and even needs to be replaced when necessary, and the stability is insufficient, the layout space is big, the front and rear chassis is big, the transmission chain is long, to the connection component request is high. Wind turbine transmission system including bearing support, spindle, gearbox, high-speed shaft brake, generator, coupling and so on [15] . The drive system of wind turbine can be divided into semi-direct drive system, double-fed system and semi-direct drive system according to the drive mode, ming-yang, Vestas and so on have adopted the semi-direct drive route, the data shows that ming-yang intelligent adopts 4.5% of the semi-direct drive route. XMW model, the host weight is only 96 tons, lighter than some models by more than 30% , its gearbox output shaft speed per minute about 300 rpm, speed less than high transmission ratio gearbox output shaft 1/5. According to the introduction, Mingyang Intelligence's original 3MW and 6MW semi-direct drive models, known as SCD ultra-compact wind turbines, are less integrated than other semi-direct drive technology solutions, in theory closer to the design of the extreme . With the increase of unit capacity, the volume and weight difference between the medium speed transmission unit and the traditional unit is larger and larger. When the capacity reaches 15 MW, the difference between the medium speed unit and the traditional unit may be more than 100 tons , medium speed transmission mechanism host light weight, small size, the obvious benefit is to reduce the overall load, reduce the difficulty of manufacturing, transportation, installation, low cost, technology controllable, more competitive . In the middle-speed transmission technology line camp itself, according to the main shaft, gearbox and generator integration and combination relationship, can also be divided into a variety of forms of technical solutions . First of all, there are three middle-speed transmission units connected with the middle shaft, transmission system integration is lower, relatively closer to the doubly-fed unit layout. This can be counted as the first form, but there are now only a handful of models in this form . As technology developed, the intermediate shaft between the gearbox and the generator was gradually removed by the design engineer, but the two remained relatively independent, connected together by couplings, achieving a moderate integration of the drive system . On this basis, an international gearbox manufacturer recently stated publicly that it further integrates the generator and the gearbox, “The generator rotor through the hollow shaft and bearing directly hanging on the gearbox output sun shaft, the stator can be directly installed on the gearbox.”. This can be classified as the second form of medium-speed transmission form . The ultra-compact type, which integrates the main shaft system, the gear box and the generator, can be classified as the third type of medium-speed transmission type, at present, it is the medium-speed transmission form with the largest installed capacity and the largest single-machine capacity of the prototype in our country .

2.3. The mainstream way to increase torque density

With the increasing capacity of single machine, there are two main ways to improve the torque density: one is to increase the number of planetary wheels, the other is power shunting technology . The more planetary gears in the gearbox, the greater the total power that can be shared, and the lighter the gearbox at the same power. Power shunting is another way of sharing torque, in short, the first stage of the output power is divided into two inputs . In fact, the international gearbox manufacturers have set a clear target of increasing the torque density of the gearbox to above 200 nm/KG. At present, the torque density of our traditional gearbox is still far from . At present, our country's wind turbine technology has not formed its own intellectual property rights, basically by licensing the introduction of foreign professional wind turbine design company's technology , the introduction of wind turbine technology at the same time did not put the gearbox design, manufacturing technology synchronous introduction. Domestic wind power gearbox design also does not have its own intellectual property rights, usually from Romax, Obita12 and other foreign professional design companies imported, and foreign professional design companies do not have rich manufacturing technology in manufacturing technology, so the domestic enterprises are usually in accordance with the requirements of the fan factory parameters on the structure and size of the gearbox analogy design, then combined with the domestic technology level to achieve large-scale production of wind power gearbox, but did not master the Advanced Design and manufacturing technology abroad . Although the localization of wind power gearboxes in our country has made great progress in recent years, however, there are still many problems that restrict the development of the wind power industry : 1) there is a serious lack of basic research and data accumulation, and there are some limitations in absorbing and absorbing foreign technologies, and there is no independent innovation capability . 2) due to the late start of the domestic wind power industry, the background is too low, the understanding of high-precision heavy-duty gear design and manufacturing technology is not deep, high-tech level of human resources are scarce . 3) at present, it is only in the stage of analogical design and structural design in our country. In fact, there are a lot of hidden troubles and quality problems in the increasing large-scale production. 4) the high-power gearbox experimental equipment and testing means are deficient . 5) domestic gearbox manufacturers lock their doors and keep secrets strictly, and do not form a benign competition mechanism of resource sharing and information exchange . With the increasing of the single-machine capacity in the global wind power market, the development of high-power gearbox is becoming more and more rapid, and the wind power gearbox manufacturers such as GE, Winergy, Renk, Bosch etc. , design verification of the design proposal using simulation test and bench test . The design reliability of wind power gearbox is studied systematically, and rich experience and original design data are accumulated . The structure of wind power gearbox has been extended from the conventional structure of one-level planetary two-level and two-level planetary one-level parallel to a variety of composite structures, power shunting structures, and so on . The common form of structure can be seen roughly in Figure 6, the traditional cylindrical gear line can not be applied to the high-power gearbox, do not repeat here. The traditional technology route, One planetary gear stage + Two spur wheel stages/Two planetary gear stages + One spur wheel stage , is the most productive and widely used project in China at present, because of the limitation of the maximum capacity of the transmission line, it can not meet the requirements of the increasing wind turbine capacity in the future. Most of these technologies are applied to 1.5 MW-2 MW wind turbines . Flexible shaft technology route, this technology originates from the patented technology many years ago, in recent years flexible shaft technology in the wind power gearbox industry rapidly heating up, many foreign companies have been in the domestic technology transfer or project cooperation, in essence, the problem of even load of planetary gear train is solved by adjusting the adaptability of Planetary Gear Train . According to the relevant data, if the technology is used properly, the average load coefficient of planetary gear trains can reach about 1.04, which has been greatly improved compared with the experimental value of AGMA standard . However, the technology requires strict precision for machining and assembly. Whether the expected design effect can be achieved has a close relationship with the production capacity of the manufacturer. In addition, the larger the floating amount, the better, this may result in the transfer of the problem, such as causing minor wear between the meshing gear pairs or the rest of the components in the planetary gear train . Power shunting, such as Planetary gear stage-Fixed planet in Figure 6, is the ultimate goal of all gearbox designs, and power shunting technology provides a convenient way to achieve this goal, in the wind turbine gearbox industry, the most representative designs that adopt the concept of power shunting are Maag and Bosch , namely the Planetary coupled gearbox and Differential gearbox in Figure 6.

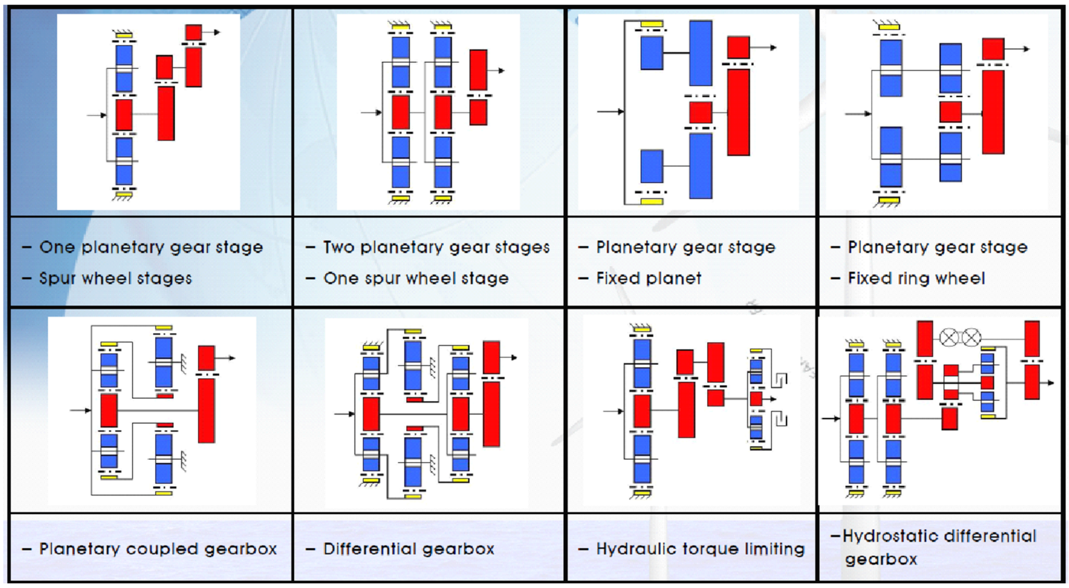

Figure 2. Common wind power gearbox structure

Methods to improve the power density of gearbox

1. Reduce gear load

1.1 load reduction by power shunting

1.2 the load distribution uniformity between the meshing pairs is improved by the load sharing technique

1.3 the load distribution uniformity is improved by gear modification

1.4 by increasing the tooth width to reduce the tooth unit line load

2. Increase the ultimate stress of gear

2.1 through the tooth surface modification (heat treatment methods and materials, etc.) to improve the gear limit stress

2.2 the load-carrying capacity of the gear can be improved by means of modification of the tooth surface (such as shot peening)

2.3 the load-carrying capacity of the gear is improved by the modification of the tooth surface (such as the optimization of the profile of the excessive curve of the gear, etc.)

2.4 through the tooth surface modification (ultra-precision machining, etc.) to improve the bearing capacity of the gear

2.5Increase the required limit stress by reducing the minimum required Factor of safety

3.Lightweight technology for other components

In order to increase the transmission ratio and ensure that the overall size of the gearbox of the common wind turbine is not too large, the transmission line is usually a composite gear train, which contains several inner gear rings and planetary gears, however, the size of the inner gear ring is usually very large, which brings great inconvenience to the manufacture and installation, and the failure rate is very high . The use of planetary gear and Planetary Rack, the need for high manufacturing accuracy, but also increased the overall complexity, the corresponding will make fault frequency. These factors also directly lead to the life of most wind turbines to meet the 20-year target. So we want to find a more sophisticated way, try to avoid the use of inner ring gear and planetary gear, make the overall as simple as possible, increase operational reliability.

3. The Transmission Mechanism Is Realized

Combining the advantages and disadvantages of manufacturing cost and dimension, the transmission scheme of two-stage fixed shaft gear train is proposed:

1. Determine the transmission ratio;

2. Design and check of relevant parameters of gear styles;

3. Axial and circumferential positioning design, circumferential positioning to adopt the end cover, shaft shoulder, retaining ring, etc. , circumferential positioning to adopt spline positioning mode;

4. End Cap Design;

5. Fastener selection such as bolts, nuts, etc.

6. Bearing selection, to use double row roller bearings, and the use of double bearings;

7. All levels of box design, it shall be capable of withstanding the forces required for operation, meeting the requirements of installation, fixing functions, observation holes and sensor positions, centralized lubricant collection functions, pipeline fixing, lightweight and other requirements.

8 The design of connection mode between boxes;

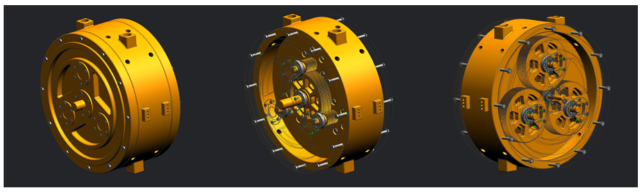

Figure 3. Three-dimensional model of gear box

4. Lubrication, Cooling and Other System Design

4.1. The cooling system

The cooling system is connected with the shell through hoses; the high-speed shaft is connected with the coupling; the hollow pipe is connected with the slip ring; a brake is installed on the trunk; strong and weak electricity are connected with the main control. The cooling system has air cooling and water cooling. Air cooling system: simple structure, easy installation, low price, heat dissipation performance is not water cooling. Mounted on top of the gearbox. Water cooling system: good heat dissipation performance, installation more trouble, to use a separate pump station water supply, water and cooling, the price is more expensive. The 6.25 MW semi-direct drive gearbox oil-water heat exchanger is installed on the independent oil tank. The spline sleeve is connected with the generator rotor by flange, the back case is connected with the generator stator by flange, the cooling system is connected with the water cooling system, the independent oil tank is connected with the back frame, and the strong or weak electricity is connected with the main control.

4.2. Gearbox heater

Gearbox heaters are generally located at the bottom of the gearbox. Some types of oil pumps also have a heater under them. When the fan starts at low temperature, the viscosity of the oil in the oil pool is very high and the oil is almost solid. In this case, the gearbox lubrication system can not work. The function of the heater is to heat the lubricating oil of the gearbox oil pool.

4.3. Gearbox air filter

The gearbox air filter air filter consists of a filter element and a shell. It is blue in normal condition and needs to be replaced with a new air filter when the color of the desiccant changes to red. The purpose of the air filter is to remove particulate matter and moisture from the air and prevent them from entering the gearbox and causing the gearbox to fail. The gearbox filter is the role of filtering oil particles, the two have essential differences.

4.4. Sealed Way

Sealing mode if the bearing sealing performance is poor, it will lead to dust moisture and debris into the bearing, and lead to the loss of lubricant. Therefore, the wear of the parts and components is produced, and the environmental pollution and product pollution are caused by the leakage of lubricant.

4.5. Contact Seal

As its name implies, is the seal cover and its relative movement of the bearing parts contact and no gap seal cover. Due to the direct contact between the seal and the fitting, the friction and heat are produced in the rotation, the problem of lubrication is easy to occur, and the contact surface is easy to wear, thus causing the seal effect of the bearing to decline, the quality of the bearing is not up to the required standard. Therefore, the contact seal bearing is only suitable for medium and low speed working environment, and the surface hardness of the shaft contact with the seal element is required to be more than 40 HRC, Surface roughness RA & Lt. The contact seal has the following sealing methods:

4.5.1. Felt ring seal

The felt ring seals a trapezoidal groove on the bearing cover, places the fine felt with the rectangular face in the trapezoidal groove in contact with the shaft, or compresses axially with the pressure cover, so that the felt ring is compressed and produces radial pressure to hold onto the shaft, to achieve sealing purposes. The sealing structure is simple, the cost is low, but the sealing effect is poor, once can not be adjusted, wear is more serious, mainly used for journal circumference speed V & LT; 4-5m/s, working temperature & LT; 90 ° C grease lubrication occasions.

4.5.2. The Leather Bowl is sealed

In the bearing cover to place a sealed leather bowl (leather bowl is made of oil pull rubber and other materials) directly on the shaft. In order to enhance the sealing effect, an annular spiral spring is used to press the inner ring of the leather bowl and the shaft, so that the inner ring of the leather bowl and the shaft have a close cooperation, and the sealing effect is better than that of the felt ring 6 ~ 7M/s grease or lubricant lubrication, the disadvantage is that the rubber bowl easy to harden and easy to wear. When using must pay attention to the direction of the cup seal flange, if in order to prevent oil leakage, then the wrist flange should face the bearing, if to prevent impurities invasion, then the cup flange should back bearing, high requirements can be used in pairs.

4.5.3. Seal ring seal

The sealing ring is usually made of leather, plastic or oil-resistant rubber, and can be made into different section forms according to needs. 0-shaped seal ring section for the circular, depending on its own elastic pressure on the shaft, simple structure, easy assembly and disassembly. Also in common use are the/-and U-shaped sections of the seals, which have a lip-shaped structure. The direction of the sealing lip should be towards the sealing part, which is similar to the direction of the flange in the sealing of the leather bowl. When the temperature is high, high speed, it is best to seal the lip also back to the bearing installed outward. Sealing ring sealing effect is better than felt ring, can be used for grease and oil embellish bone seal. In order to improve the sealing effect, the contact between the journal and the seal drawing should be hardened (HRC & GT. 40) and polished or polished to enhance the wear resistance.

4.5.4. Skeleton Seal

We often say the skeleton seal, that is, the improvement of the Leather Bowl SEAL, in order to improve the overall strength of the leather bowl seal, oil-resistant rubber inside the installation of cross-section for l-shaped, the overall ring-shaped metal village, so that the leather bowl seal is not easy to deformation, this kind of seal is easy to install and has good performance. It is generally suitable for the occasion of the circumferential speed V & Lt. 7M/s of the journal.

4.5.5. Seal ring seal

This is a notched ring seal, it is placed in the sleeve of the ring groove, sleeve and shaft rotation together, seal ring notch after being pressed with the flexibility of the bore wall in the static parts, can play a sealing role, the sealing more complex.

4.6. Contact Seal

Non-contact seal is the seal and the seal relative movement of the bearing parts do not contact, there are appropriate gaps in the middle of the seal. This form of seal, almost no friction in the rotation of the bearing heat, seal cover no wear, this form is suitable for high-speed and high-temperature working environment. The smaller the gap of non-contact seal, the better. There are three types of non-contact seals:

4.6.1. Clearance Seal

Clearance Seal is in the shaft and bearing cover through-hole clothes leave a small annular gap, the radius of the gap is 0.1-0.3 mm, the longer the gap is smaller, the better the seal effect. In order to improve the sealing effect, a plurality of parallel annular grooves can be opened in the bearing cover hole, and the grooves are filled with lubricating grease. If used for oil seal, can be in the bearing cover hole wall out of the screw groove, to leak out of the oil because of the role of spiral transmission and be sent back to the bearing, screw groove according to the rotation of the shaft to determine.

4.6.2. Oil flick ring seal

When the oil is lubricated, the leaking oil can be thrown into the groove of the bearing cover through the centrifugal force of the oil flick ring on the shaft, and flow back into the bearing or oil pool through the oil return hole, journal circumferential speed should not be less than 5 -6 m/s, oil flick ring is also commonly used to isolate the grease in the bearing and the lubricating oil in the box.

4.6.3. Labyrinth seal

The basic principle of this kind of sealing is to form a section of flow channel with great flow resistance at the sealing place. From the structure of the static and rotating parts to form a small zigzag gap between the formation of a"Maze.". If the maze is radial, the axial dimension is compact, but the radial dimension is larger. If the"Labyrinth" is axial, then the radial size is compact, but the bearing cover to split, once the axial clearance to be larger, so as not to get stuck because of the thermal deformation of the shaft. The labyrinth seal is reliable for both lubricating oil and lubricating grease, and the higher the speed, the better the effect.

5. Summary

In summary, this paper focuses on the study of 15 MW offshore wind turbine gearbox transmission system, it includes the design of gear, connection, fastener, positioning parts, lubrication system and cooling system, which lays a foundation for the design of wind turbine based on transmission system. To a certain extent, it reduces the cost of manufacturing, operation and maintenance of wind turbines. Through the corresponding design and analysis, the following important conclusions are obtained:

1. Considering the huge cost pressure and fierce competition in the current wind turbine market, the high cost of direct-driven wind turbine, the poor low-voltage traversal ability of doubly-fed wind turbine, the relatively complex structure, the high failure rate and the high maintenance cost, therefore, the proposed use of semi-direct-driven wind turbine.

2. The planetary gear train is widely used in wind turbine. The disadvantages of the planetary gear train lie in its complex structure, high failure rate and high cost of manufacture and maintenance.

3. The box adopts split type box, water cooling and air cooling combined cooling mode, forced lubrication and pressure lubrication combined lubrication mode.

In general, these conclusions are helpful to improve the stability of large MW offshore wind turbines, reduce costs and enhance market competitiveness.

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