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***ARTICLE***

# RESEARCH ON MICRO-PITTING OF GEAR FLANKS TO WIND TURBINE

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**ABSTRACT**

The analysis of factors that affect the micro-pitting of wind turbine gears was conducted. In general, to avoid micro pitting, not only lubricating factors should be paid more attention but also the manufacturing and design factors shouldn't be omitted. It was suggested that some improving measurements which can increase the micro pitting resistance of gear flanks should be used in wind turbine gearboxes.

**KEYWORDS**

Micro-Pitting, Factors, Wind Turbine

## 1. INTRODUCTION

In recent years, with the rapid development of wind power, shipbuilding, aerospace, and other industries, the demand for long-life and high-reliability gearboxes has also increased rapidly. This has also led to the need for low-speed and heavy-duty gear transmissions. Phenomenal attention and in-depth systematic research. In fact, for low-speed heavy-duty gears, compared with the bending strength and contact strength of gears, micro pitting of gears has become a more important factor affecting its life and operational reliability. Therefore, in recent years, the American Gear Manufacturers Association (AGMA), British Gear Association (BGA), and American Renewable Energy Laboratory (NREL) have successively carried out a series of related special studies and have made some progress. In China, this issue has not attracted enough attention, so it is necessary to conduct a comprehensive and systematic analysis and research and formulate corresponding control plans and countermeasures.

## 2. THE GENERATION AND HARM OF GEAR MICRO PITTING

The Micro pitting phenomenon, also known as the gray spot phenomenon, refers to a characteristic phenomenon of graying on the tooth surface during the working process of gears. Its essence is the appearance of tiny cracks on the tooth surface with a small amount of material transfer, that is, a comprehensive process of forming tiny cracks on a tooth surface and cold glue. This phenomenon generally occurs on the meshing tooth surfaces of low-speed heavy-duty gears, such as the low-speed transmission tooth surfaces of wind power gearboxes and marine gearboxes.

The mechanism of micro pitting is generally considered to be due to the mixed or boundary lubrication between the meshing tooth surfaces of the low-speed heavy-duty gears. During the gear meshing process, due to the direct contact between the wave peaks of the microstructure of the two tooth surfaces, and under the action of more contact and shear stress and relative friction, the local temperature of the tooth surface increases, and the oil film or chemical reaction film rupture, resulting in complex elastic-plastic deformation. Microcracks and material transfer on the gear surface are also produced in the process.

The micro pitting cracks on the tooth surface are all located on the surface and are relatively small, generally with a depth of 10-20 μm and an inclination angle of less than 45° to the surface. Micro-pitting mostly occurs in the running-in stage of the gearbox. The most prone to micro-pitting on the tooth surface is the area where the sliding and rolling speeds are in opposite directions. Because it is generally located below the pitch circle of the gear for the driving or driven gear. position, which has been confirmed by more experiments or observations.

Depending on the load and application conditions, and with the improvement of the tooth surface lubrication conditions, some of the tooth surfaces will not continue to be worn after micro-pitting corrosion occurs. However, with the increase of operating time, the wear of some tooth surfaces is further intensified, the tooth profile accuracy decreases, and the dynamic load between the meshing tooth surfaces increases and leads to further expansion of micro-cracks. To a certain extent, it will cause macroscopic pitting and peeling of the tooth surface, and eventually lead to deterioration and loss of the performance of the transmission device.

Due to the prevalence of micro pitting in low-speed and heavy-duty gear transmission, and its serious impact on the operating life and reliability of high-end transmissions, foreign research on this related topic has been very active in recent years. Many achievements have been made from the systematic research on various influencing factors of micro pitting to the design and manufacture of gears against micro pitting. At present, FZG/FVA has also specially formulated the micro-pitting corrosion test specification for lubricating oil and gear pairs. Generally speaking, the factors that affect the micro pitting corrosion of tooth surface mainly include the following categories:

(1) Lubricating medium factors, such as the type of oil, viscosity, oiliness,

and types of additives;

(2) Material type, heat treatment state, and organization;

(3) Design parameters and manufacturing process methods. The following part will analyze several main influencing factors to determine reasonable design, manufacture, and use methods.

## 3. INFLUENCE OF LUBRICATING OIL ON MICRO PITTING CORROSION

Numerous tests and applications have shown that synthetic oil has better comprehensive lubricating performance than mineral oil. Therefore, the current high-end gearboxes, such as wind power speed increase boxes, all use various synthetic lubricating oils as their lubricating media. The general advantages of synthetic lubricants are high viscosity-temperature index, strong oxidation resistance, good low-temperature fluidity, anti-wear, low friction power consumption, low volatility, long oil change interval, and strong resistance to micro pitting.

There are three main types of synthetic oils in common use today:

(1) Poly-α-olefin lubricating oil, also known as PAO oil, is a kind of long-chain alkane obtained by the polymerization of α-olefin under the action of a catalyst, followed by distillation and hydrogenation. It is currently the most commonly used type of synthetic oil. Representative brands or manufacturers such as EXXONMOBIL, TOTAL, BP, ANDEROL, and KLUBER all provide such oils.

(2) Polyester lubricating oil referred to as PAG oil. Numerous tests have shown that PAG oil is superior to PAO oil in terms of viscosity-temperature index, anti-wear, anti-micro pitting corrosion, ability to dissolve water, lubricity, and cleanliness. Only slightly inferior to PAO oil in low-temperature stability, material compatibility, and base oil compatibility. Due to the above advantages, PAG oil has gradually been widely used in wind power gearboxes. Its representative brands and manufacturers mainly include COGNIS, STEPAN, FUCHS, SHELL, and KLUBER.

(3) Ester lubricating oils, in addition to the basic advantages of synthetic oils, are characterized by fast biodegradation, little impact on the environment, and little tendency to generate sludge residues. At present, the research and development of this type of product are very active abroad. With the further improvement of its performance and the improvement of long-term work stability, its application will gradually be popularized and expanded. At present, one of the main uses of ester oil is as a mixture of PAO oil to improve the lubricity of oil and reduce the friction coefficient of the tooth surface.

On the whole, PAG oil has better comprehensive performance than PAO oil, especially in the anti-micro pitting ability. In addition, in areas with large changes in ambient humidity and relatively humid environments, PAG oil is more suitable because of its excellent viscosity-temperature and water solubility. However, in regions with lower temperatures, PAO oil has certain advantages. When the water content of PAO oil is high, hydrolysis and oxidation are easy to occur, the emulsification phenomenon is aggravated, the acid value increases and the resistance to micro pitting corrosion is decreased. Therefore, when using PAO oil, its water content should be strictly monitored, and once it exceeds its allowable content or the oil performance deteriorates, it should be replaced as soon as possible.

It should be noted that PAG oil has a certain solubility for general paint. Therefore, epoxy-resistant paint should be used in the interior of the lubricating gearbox or simply not painted to prevent the dissolution of the paint from affecting the performance of the lubricating oil and the lubrication system. In addition, the mutual solubility of PAG oil and other different kinds of oils is poor, so it is easy to form a gel-like substance when mixed together. Therefore, before filling the gearbox with oil, the inside of the box should be thoroughly cleaned as required, and it should not be mixed with different types of oil during use.

Experiments have shown that the effect of extreme pressure additives in gear lubricants on the micro pitting resistance of the oil is complex. Extreme pressure additives can greatly improve the resistance to gluing of gear pairs. However, in many cases, some types of extreme pressure additives and tooth surface chemical corrosion, result in stress corrosion cracks, and adverse effects on the resistance to micro pitting of tooth surface. Therefore, we need to conduct further systematic tests and application research on the types and proportions of additives to make the use of extreme pressure additives more scientific and reasonable.

Another important factor that affects the micro pitting resistance of oil is the cleanliness of oil. This is because if the oil is mixed with too large and hard abrasive particles, it will often destroy the oil film or boundary film between the two contacting tooth surfaces of the gear or in the bearing, and thus lead to various types of damage. Therefore, micro-spots are more likely to occur. eclipse. Therefore, it is very important to maintain the cleanliness of the oil or limit the number of tiny particles. At present, many existing technical specifications have specific regulations on the cleanliness of the new oil for wind turbine gearboxes, including the oil in operation (see Table 1). These should be strictly controlled during the product implementation process. According to the FZG/FVA test specification, the synthetic oil currently used in wind turbine gearboxes is generally required to have a high level of micro pitting corrosion resistance under the test conditions of lubricating oil temperature of 60°C and 90°C or expressed as SKS≥10 class. All brands of lubricant suppliers should provide this parameter in their product performance tables.

**Table 1:** Cleanliness required for micro pitting resistance of lubricants

| Oil sample source | Cleanliness class (ISO4406:1999) |
|---|---|
| New oil before adding gearbox | 16/14/11 |
| Oil in gearbox after factory test | 17/15/12 |
| Oil in gearboxes in operation | 18/16/13 |

## 4. INFLUENCE OF HEAT TREATMENT AND PROCESSING TECHNOLOGY FACTORS

Micro-pitting corrosion may occur in quenched and tempered gears, carburized and quenched gears, or nitriding gears. At present, low-speed and heavy-duty gear transmissions basically use carburized and quenched gears or nitriding gears. Therefore, relevant research on gear materials and heat treatment conditions Basically, it is carried out for the above two types of gears. For example, the existing research involves the influence of heat treatment structure type and uniformity, retained austenite content, carbide morphology and distribution, hardness and gradient distribution, surface coating type and structure on micro pitting corrosion, etc.

According to the existing research and knowledge of gear micro-pitting corrosion, the tendency of micro-pitting corrosion of gas nitriding gears (HV>850) is greater than that of carburizing and quenching gears, and the tendency of micro-pitting corrosion of quenched and tempered and induction or flame quenched gears be smaller. Consistent with the requirement to improve the bending and contact strength of gears, the use of gears containing elements such as nickel and molybdenum has significantly stronger resistance to micro pitting. Based on the generation mechanism of micro pitting corrosion The hardness, microstructure, sliding friction characteristics, and load characteristics of the gear contact tooth surface have a great influence on the generation of micro pitting corrosion. Positive progress has also been made in the research of forming tooth surface coating through PVD technology to improve tooth surface hardness and reduce the friction coefficient of the tooth surface to improve the micro-pitting corrosion resistance of the tooth surface. For example, when the coating materials used are WC/C and B4C, the thickness is 1 to 4 μm, and the hardness is 800 to 3000 HV, the experiments show that the resistance to micro pitting is significantly improved [1-2]. The micro pitting phenomenon occurs and the tooth profile accuracy is not degraded. With the in-depth research on the bearing load, surface roughness, friction characteristics, and quality control related to surface coating technology and the application of this technology, the use of additives to improve the friction characteristics of tooth surfaces in oil products will be less, and less. This will have a positive effect on improving the performance of the transmission pair and protecting the environment. At present, surface coating technology has begun to be used in wind power bearings. FAG and TIMKEN have launched coated bearings designed to improve bearing performance and service life and have begun to use them. The long-term use effect remains to be tracked and observed. Its prospects are worth looking forward to.

The use of the conventional shot peening process is very obvious to improve the bending strength of the gear teeth, but it has an adverse effect on the contact strength of the tooth surface and the resistance to micro pitting. This is because the shot peening after grinding the tooth surface will increase the tooth surface. surface roughness. The ultrasonic shot peening technology developed in France can effectively overcome this shortcoming. Laboratory simulation tests have been carried out, showing the positive effect of this process on improving the contact strength of the tooth flank and the resistance to micro pitting. Through further and more systematic research and development, it is possible to provide a technical method to effectively improve the micro pitting resistance of gear tooth surfaces. Another approach used by a UK company is to combine shot peening with the superfinishing process described below, after two shots of different particle sizes and strengths, and finally superfinishing. This not only effectively retains the residual stress on the tooth surface formed by shot peening, but also greatly reduces the tooth surface roughness.

It has been proved that the most effective means to improve the micro pitting resistance of the gear tooth surface in the gear machining process is to use the superfinishing process to reduce the roughness of the gear tooth surface [3]. According to the theory of electrohydrodynamic lubrication, the reduction of tooth surface roughness is more conducive to the generation and maintenance of lubricating oil film between tooth surfaces, thereby reducing the local contact stress and wear on the surface, and correspondingly, the risk of micro-pitting corrosion can also be greatly reduced. At the same time, the fatigue strength of the gears treated by the super-finishing process will also be improved, the operating temperature and noise will be reduced, and the wear and tear will be greatly reduced.

The equipment and process technology for tooth surface ultra-finishing in foreign countries have been relatively mature. It is to place the workpiece in non-abrasive high-density ceramic abrasive particles with a diameter of 3 to 5 mm. At the same time, high-frequency vibration is applied to the particles and gears. During the multiple reciprocating motions, the tiny wave crests on the tooth surface can be further smoothed. In the above-mentioned grinding process, it can continuously add a special oxidation layer liquid, this chemical oxygen-assisted grinding layer agent, to the surface of the abrasive particles. The broken parts are ground and regenerated continuously, which can speed up the running-in of the tooth surface. It can be seen that superfinishing is a fine grinding process with strong craftsmanship. Its final effect depends not only on the control of various relevant process parameters but also after superfinishing and processing of tooth surface technology. The tooth surface is generally rough and rough. The requirement is Ra<3μm. The use of super-finishing has been adopted by the foreign wind power gearbox manufacturing industry as the normal processing technology for the finishing of low-speed gears. Winergy, Renk, Hansen, Rexroth, and other companies all use this process for finishing related gear tooth surfaces. At present, the application of this process in my country is not widespread. This phenomenon should be paid attention to and changed as soon as possible. Otherwise, it will inevitably have an adverse impact on the product quality, life, and operational reliability of wind power gearboxes in my country.

## 5. DESIGN EVALUATION OF TOOTH SURFACE RESISTANCE TO MICRO PITTING CORROSION

Based on the above analysis of the relevant factors affecting the micro-pitting corrosion of the tooth surface, it can be considered that the lower the roughness of the meshing tooth surface, the thicker the lubricating oil film thickness between the meshing tooth surfaces, and the possibility of micro-pitting corrosion on the meshing tooth surface. smaller. As the research on the generation mechanism, influencing factors, preventive measures, and design evaluation of gear surface micro pitting corrosion is still in progress, there is no standard method for the design, calculation, and evaluation of gear micro pitting corrosion resistance in the world. However, at this stage, it is a feasible way to use the film thickness ratio between the meshing tooth surfaces to evaluate the micro pitting resistance of gears, and a preliminary opinion has been formed. The calculation formula for the film thickness ratio is:

$$\lambda = \frac{h_{\min}}{\sqrt{(R_{a1}^2 + R_{a2}^2)}} \rightarrow$$

where: $h_{min}$ represents the minimum oil film thickness μm between the meshing tooth surfaces;

$R_{a1}$ and $R_{a2}$ represent the arithmetic square difference μm of the roughness of the meshing two tooth surfaces.

Obviously, the larger the λ, the smaller the direct contact part of the micro-wave crests between the meshing tooth surfaces, and the smaller the probability of micro-pitting corrosion. When λ is greater than a certain critical value $\lambda_{min}$, the occurrence of micro-pitting corrosion can be completely avoided. Or the micro pitting corrosion is very slight, that is, the judgment condition is

$$\lambda \geq \lambda_{\min}$$

There are many factors affecting the thickness of the lubricating oil film between the meshing tooth surfaces, such as the viscosity of the lubricating oil, the speed of the gear, and various parameters of the gear. Moreover, the transmission types used in the low-speed stage of the wind power gearbox include NGW, NW, and other types [4]. At the same time, wind power gears often use various modification processes, which make the calculation of the film thickness between the meshing tooth surfaces of the transmission pair. The analysis of influencing factors is very complicated. 5 Conclusions The generation mechanism and influencing factors of micro-pitting corrosion between the meshing tooth surfaces of low-speed and heavy-duty gears are analyzed and discussed. Several measures to improve the micro-pitting corrosion resistance of tooth surfaces are summarized.

(1) Synthetic oil with an anti-micro pitting ability of grade 10 or above is used. According to the specific application environment and load conditions, PAO oil or PAG oil can be selected.

(2) Appropriate oil viscosity and additives should be selected.

(3) Various performance indicators of the oil should be checked regularly, and the oil should be replaced in time when the performance of the oil deteriorates.

(4) The cleanliness of the oil and the gearbox should be kept.

(5) The superfinishing process is used to reduce the roughness of the tooth surface.

(6) Use appropriate surface coating treatment and shot peening technology.

(7) In the design stage, the anti-micro-pitting criteria should be used to evaluate the suitability of the design parameters for the anti-micro-pitting corrosion.

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