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◆특집◆ 기어

Study on Bearing Life Calculation for Wind Turbine Gearbox

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풍력터빈 기어박스의 베어링 수명 계산에 관한 연구

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ABSTRACT

Currently, wind power has become a major research field in the area of sustainable development. As one important component of a wind turbine transmission system, most instances of downtime due to a gearbox failure are caused by bearing failures. Gearboxes for wind turbines must have the highest levels of reliability over a period of approximately 20 years, withstanding high dynamic loads. At the same time, a lightweight design and cost minimization efforts are required. These demands can only be met with a well-thought-out design, high-quality materials, a high production quality and proper maintenance. In order to design a reliable and lightweight gearbox, it is necessary to analyze methods pertaining to the bearing rating lifetimes of the standard and of different companies, also including calculation methods for modification factors. This can determine the influence of the bearing lifetime.

Key Words : Bearing simulation(베어링 시뮬레이션), Gearbox(기어박스), Life rating(수명율), Wind turbine(풍력터빈)

1. Introduction

Wind power is suitable and clean energy, and in many countries, wind power has become a major part of their plans for sustainable development. According to the Global Wind Energy 2008 report, it predicts that in 2013, five years from now, the annual growth rates during this period will average 22.4% in terms of total installed capacity, and 15.8% for the annual market, up from 120GW at the end of 2008.[1] And the wind generating system Wind Turbine, which emits no carbon dioxide, has been widely accepted as the clean and environmentally friendly machine.

The technical trend for wind turbines is to increase their reliability and efficiency instead of reducing the large cost of operation. According to the requirements of wind turbine standards, the bearings, which are one of the most important components for wind turbine gearbox, should be designed to optimize

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reliability and economic efficiency[2-4].

2. Bearing reliability

2.1 Bearing life calculation theory

Bearing technology, as well as the bearing industry, began to develop with the invention of the bicycle in the 1850's. And in 1924, A. Palmgren published a paper outlining his approach to bearing life prediction which was the basis for the Lundberg-Palmgren life theory.

Lundberg and Palmgren obtained the following additional relation

$$L_{10} = (\frac{C_r}{P_{eq}})^p \quad (1)$$

where L_{10} is 10% life or operating time exceeded by 90% of a group of bearings, C_r is the basic dynamic load rating, P_{ea} is the equivalent bearing load, p is the load-life exponent, 3 for ball bearings and 10/3 for cylindrical roller bearings.

2.2 Bearing arrangement of wind turbine gearbox

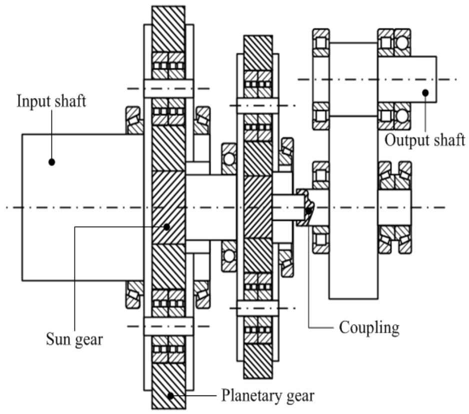
Wind turbine gearbox is equipped with bearings that increase shaft speed of the rotor blades to an output shaft speed to the generator. The speed and acceleration create a varying and difficult set of dynamic condition for the output shaft.

Output shafts are generally parallel shafts equipped with helical gears producing radial and axial loads that must be supported by the bearing system. Except for sun pinions, pinions should be mounted between bearings. Overhung pinions should not be used. Sun pinions should be designed without bearings to achieve load sharing between planet gears.

The type of bearings for gearbox components is shown in Table 1.

2.3 Comparative analysis of bearing life methods

For many years, the use of the basic rating life L10 as a criterion of bearing performance has proved satisfactory. As we all know, the bearing life



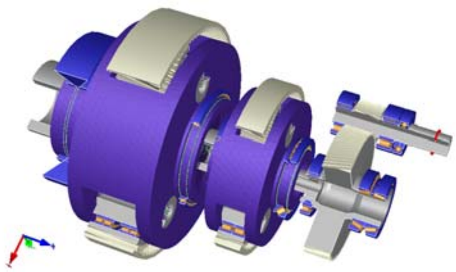


Fig. 1 Schematic of two planetary gear stages, one helical wheel stage.

Table 1 Type of bearings for gearbox components

Arrangement position	Bearing type	
Planet carrier	FCCRB, SRB, TRB	
Plane gear	FCCRB, CRB, SRB	
Low speed shaft	Free	SRB, FCCRB,CRB
	Fixed	FCCRB, TRB, SRB
Intermediate speed shaft	Free	CRB, SRB
	Fixed	TRB, SRB CRB+4PCBB
High speed shaft	Free	CRB, SRB
	Fixed	TRB, SRB, CRB+4PCBB CRB+TRB

computational method from the standard ISO 281 is based on the Lundberg-Palmgren life theory.

And due to the bearing technology and manufacture limit at that time, so the applicability is restricted. However, the quality of bearing used today is improved, and in some cases, the bearing real working life is far beyond its rating life. For many applications it has become desirable to calculate the life for a different level of reliability and the accurate life under specified lubrication and contamination conditions.

From the International Standard, a life modification factor a_{ISO} is introduced, base on a system approach of life calculation as well as the modification factor a_1. These factors are applied in the modified rating life equation:

$$L_{nm} = a_1 a_{ISO} L_{10} \quad (2)$$

$$a_1 = \left(\frac{\ln \frac{100}{R}}{\ln \frac{100}{R}} \right)^{\frac{1}{e}} \quad (3)$$

where a_{ISO} denotes life modification factor which is based on a system approach of life calculation, a_1 is the modification factor for reliability given in the standard, R is reliability, e is Weibull exponent.

ISO 281 has the factor a_{ISO} for bearing modified rating life, in which various reliability, lubrication condition, contaminated lubrication and fatigue load of the bearing are taken into account. But it does not have the detail equation covering the influence of wear, corrosion and electrical erosion on bearing life. So for some accurately calculations, it can not be widely used. SKF, FAG, NSK and Timken etc., besides concerning the life modification factor a_1 for reliability and basic rating life calculation, respectively use modification factors for adjusted rating life calculations. Calculation details are expressed in the general catalogues. For some parameters, technicians can calculate easily by online calculation system in internet. The comparison of bearing life rating methods is shown in Table 2.

Here, the Romax adjusted life accounts for actual operating condition better including the effects of internal clearance, pre-load, misalignment, high-speed centrifugal effects and internally induced loads. And the Romax advanced life method gives a way of comparing life for different detailed bearing designs that is independent of the manufacturer’s published dynamic load rating. It reflects changed in life for those internal parameters that are not covered in the ISO 281 standard, such as raceway conformity and roller profiling.

But the calculating procedure of modification factor from the bearing manufacturer is different, the example of modification factor for SKF is shown in Fig. 2.

According to AGMA 6006, the calculated rating life may not be less than 130,000 hours. When adjusted methods are used, the result should be compared to DIN ISO 281 and the values produced by Table 3. And the contact stress using the Miner’s sum dynamic equivalent bearing load should not exceed the values listed in the standard.

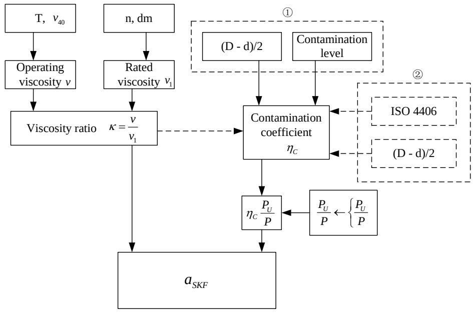


Fig. 2 Flow chart for SKF bearing life modification factor

2.4 Calculation method for several bearings

Besides the calculation of bearing durability depending on the Load Duration distribution (LDD), when several bearings are incorporated in machines as complete units, all the bearings in the unit are considered as a whole when computing bearing life. Fig. 3 is the LDD which was used in the analysis of this Wind Turbine gearbox.

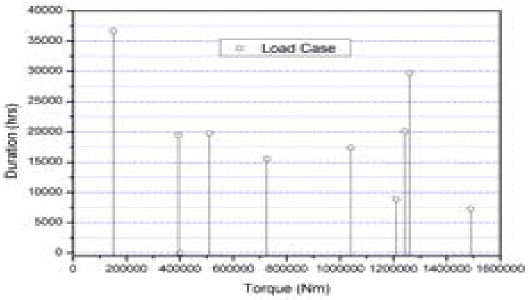


Fig. 3 LDD for the Wind Turbine gearbox

Table 2 Comparison of bearing life rating methods

Methods	Basic Rating Life	Adjusted Rating Life
ISO 281	$L_{10}=(\frac{C}{P})^{\varepsilon}$	$L_{nm}=a_1 a_{ISO} L_{10}$
SKF		$L_{nm}=a_1 \cdot a_{SKF} \cdot L_{10}$
FAG		$L_{hna}=a_1 \cdot a_{23} \cdot L_{10}$
NSK		$L_{nm}=a_1 a_{NSK} L_{10}$
Timken		$L_{nm}=a_1 a_2 a_{3d} a_{3h} a_{3k} a_{3l} a_{3m} a_{3p} L_{10}$
Romax Designer		$L_{10,Adjusted}=f_{lz} \cdot L_{10,ISO}$
	$L_{nm,ADV}=\left(\frac{Q_c}{Q_e}\right)^{\varepsilon}$	

This calculation method is similar in some bearing corporations rating methods. And the calculation equation (NTN calculation method as an example) is:

$$L=\frac{1}{(\frac{1}{L_1^e}+\frac{1}{L_2^e}+\dots\frac{1}{L_n^e})^{1/e}} \tag{4}$$

where L is total basic rating life of entire unit, L_1, L_2 … L_n are basic rating life of individual bearings, e = 10/9 for ball bearings and e = 9/8 for roller bearing.

And when the load conditions vary at regular intervals, the life can be given by the formula:

$$L_m=(\frac{\Phi_1}{L_1}+\frac{\Phi_2}{L_2}+\dots\frac{\Phi_j}{L_j})^{-1} \tag{5}$$

where L_m denotes total life of bearing, Φ_j is frequency of individual load conditions ($\sum\Phi_j=1$), L_j is life under individual conditions.

3. Analysis and simulation

Gearbox failures continue to be a major source in wind turbines. This paper takes account of bearing failures. And from the simulation of gearbox, bearing durability analysis including the effect of system misalignment and advanced contact stress analysis can be conducted.

Table 3 Minimum basic rating life

Bearing position	L_{h10} Required life (hr)
High speed shaft	30,000
High speed intermediate shaft	40,000
Low speed intermediate shaft	80,000
Planet	100,000
Low speed shaft	100,000

For the RomaxDesigner software which has been applied to the wind turbine, a wind turbine gearbox of 2.0 MW can be modeled to reduce the development risks of the full gearbox system. The schematic figure of two planetary gear stages and one helical wheel stage is shown in Fig. 1.

And by using the GH Bladed Software, the wind turbine model of turbulent wind simulations of the complete wind turbine lifetime can be obtained. And a LDD was used to analysis the gearbox. For Romax adjusted life, load zone factor is used to the ISO life for misalignment, clearances and other effects, but for advanced life, the bearing capacity and contact conditions are calculated from detailed bearing geometry.

According to durability analysis of the bearing life prediction in RomaxDesigner, four methods are used to evaluate the bearings life. They are summarized as follows:

① ISO Life: The basic method is based on the ISO 281 standard.

② Adjusted Life: Load zone factor is applied to the ISO Life to account for misalignment, clearances and other effects.

③ Advanced Life: The bearing capacity and contact conditions are calculated from the detailed bearing geometry.

④ DIN ISO 281: It is the new standard with the extended life theory which takes account of lubricant cleanliness and temperature effects.

In this gearbox case, for each load, a predicting life is evaluated based on an ISO life calculation, an adjusted life and an advanced life. The total damage of ISO and Adjusted Life is calculated by summing the ratios of the predicted life and load case duration.

After the simulation, according to ISO 281, all the bearings survive in the duty cycles, expect planet pin 2 left hand bearing, and almost planet pin bearings' adjusted ISO life don't survive (Fig. 4).

When all bearings are adjusted, the total damage of ISO and Adjusted Life is obtained (Fig. 5). Here all bearing rating life is modified, especially planet pin 2 ISO rating life.

Advanced bearing analysis enables the contact conditions and contact stress for each roller element to be calculated. The effect of misalignment on the contact condition of 9th load case which is the strictest load condition can be shown. Two figures (Fig. 6) demonstrate the roller element contact stress for a planet pin 2 left hand bearing of this gearbox. And it means that this bearing has high misalignment

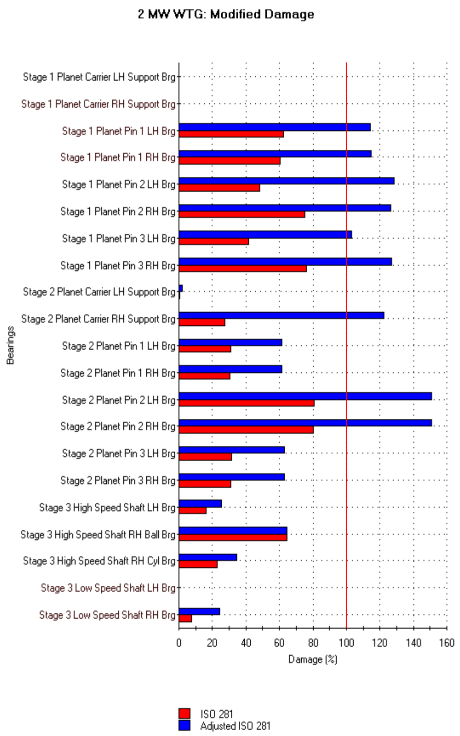


Fig. 4 Percentage damage summary and effect of bearing against cumulative damage duty cycle

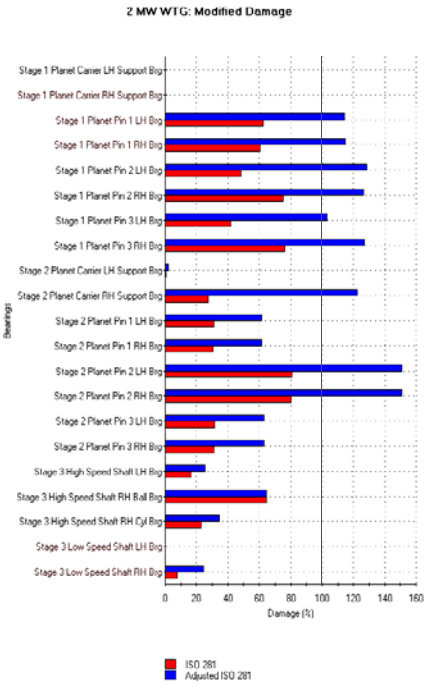
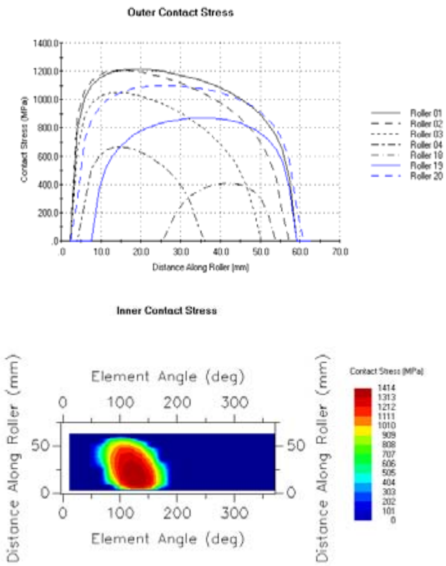
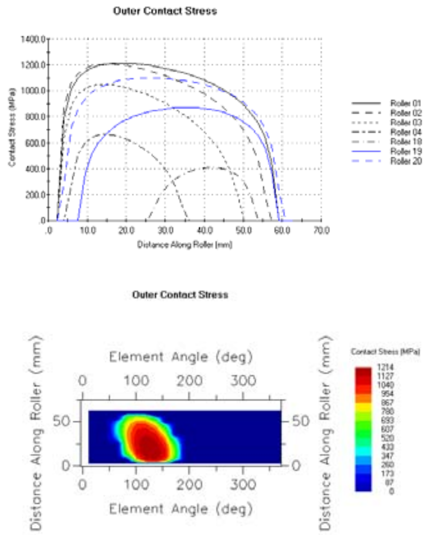


Fig. 5 Percentage damage summary and effect of changed bearing



(a) Inner raceway contact



(b) Outer raceway contact

Fig. 6 Planet pin 2 left hand bearing roller element contact stress for inner and outer raceway contact

4. Conclusions

This paper analyses the bearing rating life methods of the standard and different bearing companies. And by using the Romax software for the modeling and analysis of the gearbox, the planet pin bearing used in this model survives in the load cycles.

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