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◆특집◆ 기어

풍력터빈용 고속단 헬리컬 기어의 치형 최적화에 관한 연구

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A Study on Optimization of Tooth Micro-geometry for Wind Turbine High Speed Stage Helical Gear Pair

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Abstract

The wind industry grew in the first decade of the 21st century at rates consistently above 20% a year. For wind turbine, gearbox failure can be extremely costly in terms of repair costs, replacement parts, and in lost power production due to downtime. In this paper, gear tooth micro-modification for the high speed stage was used to compensate for the deformation of the teeth due to load and to ensure a proper meshing to achieve an optimized tooth contact pattern. The gearbox was firstly modeled in a software, and then the various combined tooth modification were presented, and the prediction of transmission under the loaded torque for the helical gear pair was investigated, the normal load distribution and root stress were also obtained and compared before and after tooth modification under one torque. The simulation results showed that the transmission error and normal load distribution under the load can be minimized by the appropriate tooth modification. It is a good approach where the simulated result is used to improve the design before the prototype is available for the test.

Key Words : Helical Gear(헬리컬기어), Tooth Profile Modification(치형수정), Load Distribution(하중분포), Root Stress(이뿌리응력)

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 report, the wind industry has been expanding at an annual growth rate of 28% over the past ten years.[1] And the wind generating system wind turbine, which emits no carbon dioxide,

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has been widely accepted as the clean and environmentally friendly machine. Since gearboxes are one of the most expensive components of the wind turbine system, the failure rates are very important to the cost of wind energy. In order to help bring the cost of wind energy back to a decreasing trajectory, the technical trend for wind turbines is to increase the gearbox reliability and efficiency instead of reducing the large cost of operation.[2-3] In this paper, the wind turbine gearbox is modeled in a software, and the various combined tooth modifications for a helical gear pair are used to investigate the normal load distribution and root stress under the loaded torque which the helical gear mesh misalignment is considered. The simulation results show that the normal load distribution and gear root stress under the load can be minimized by the appropriate tooth modification after tooth modification.

2. Background

2.1 Load Distribution & KH_β

KH_β is a load distribution factor which is used in the gear rating equation (ISO 6336-1). And this factor accounts for : Elastic deformations, manufacturing tolerances and thermal deformations. They are normalized peak-to-peak strain values. The equations are shown as follows.

$$KH_\beta = \left(\frac{\max[\epsilon]}{mean[\epsilon]}\right)^{\frac{1}{N_f}} \tag{2}$$

$$N_f = \frac{1}{1+\dfrac{h}{b}+\left(\dfrac{h}{b}\right)^2} \tag{3}$$

where h is gear tooth height, and b is gear face width.

2.2 Gear Tooth Modification

Gear tooth micro-modifications are currently implemented. It includes the intentional removal of material from portions of the tooth surface, so that the shape is no longer a perfect involute. Such modifications compensate teeth deflections under load, and the resulting transmission error is also minimized under a specific torque. Micro-modifications can be applied on the involute and lead of gear teeth.

Lead modifications in the form of either lead crowning or end relief compensate for manufactured lead errors, shaft misalignments and deflections. This modification is expected to achieve a unique load along the tooth face width.

In involute modifications, tip relief is applied to minimize tooth corner contact and dynamic excitation (T.E.). Two major parameters are important, the tip relief C_a and the relief length L_{Ca}.[4]

This modification can compensate for the tooth bending and some part of manufacturing errors, as well as the peak-to-peak transmission error (PPTE) which is directly related to the noise level. And for the variation of the length C_a, it is optional and divided into short profile modification and long profile modification. The simplest modification is a linear tip relief on both gears, or linear tip and root relief on one or both gears. Besides these, another modification is a parabolic tip relief which is not used in this paper. Compared to the linear relief, this modification has an advantage in that the pressure angle of the profile does not have an instant change at the start point of the modification. The modification values used in this spur gear pair are based on a procedure recommended from Sigg.[5] The standard tip relief limitation can be chosen as the reference values to calculate the actual profile modification amount.

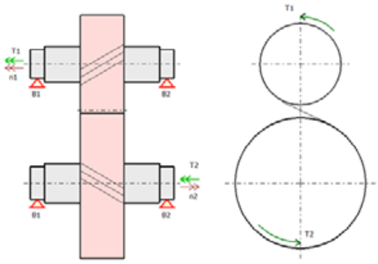
3. Procedure of Analysis and Discussion

In this paper, CAE software has been applied to a wind turbine gearbox, the gearbox of 2.0 MW can be modeled to reduce the development risks of the full gearbox system. The software is only used to analyze the helical gear pair of the third stage in the transmission system. From the rotor blades to the output shaft for the generator, the speed and angular acceleration create a varying and difficult set of dynamic condition for the output shaft. The model of the helical wheel stage's output shafts which equipped with helical gears producing radial and axial loads has been investigated. And the schematic of the helical wheel stage is shown in Fig. 1.

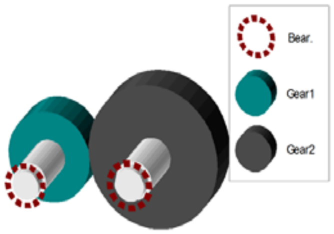
Fig. 2 shows the predicted normal load distribution without gear modification under the torque, and the maximum load intensity is 159.1 N/mm.

Fig. 3 shows the predicted root stress of driving gear without gear modification under the torque, and the maximum root stress is 99.61 MPa.

Fig. 4 shows the predicted root stress of driven gear without gear modification under the torque, and the maximum root stress is 98.83 MPa.



(a) Gear mesh in 2D dimension



(b) Gear mesh in 3D dimension

Fig. 1 Spur gear mesh in 3D dimension

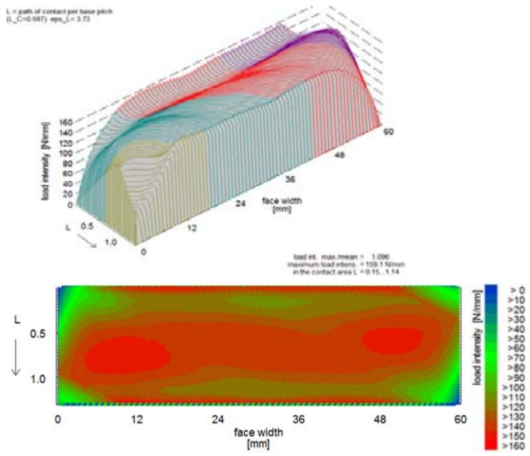


Fig. 2 The normal laod distribution without gear modification under the torque(Maximum load intensity : 159.1 N/mm)

Table 1 Helical gear pair specification

	Driving	Driven
Number of teeth	27	43
Module (mm)	4	
Pressure angle (deg.)	20	
Helix angle (deg.)	30	
Addendum mod. coeff.	0.45	0.4317
Center distance (mm)	165	
Face width (mm)	60	60
Outside diameter (mm)	136.3	210
Root diameter (mm)	117.908	194.608
Profile / face contact ratio	1.292	2.387
Total contact ratio	3.679	
Speed (rpm)	1000	
Torque (Nm)	625.5	

Fig. 5 is the data of profile and lead modification for the helical gear.

After the simulation, the normal load distribution and root stress of gear 1 and gear 2 with profile modification at the load are shown in Fig. 6, Fig. 7 and Fig. 8.

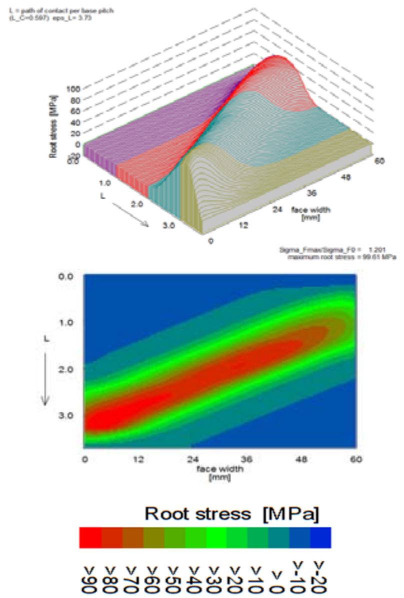


Fig. 3 The root stress of driving gear without gear modification under the torque(Maximum root stress : 99.61 MPa)

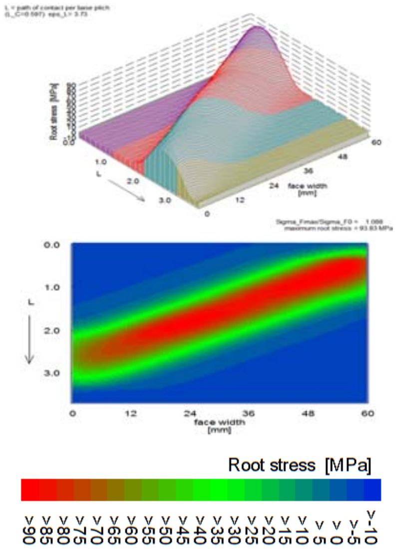
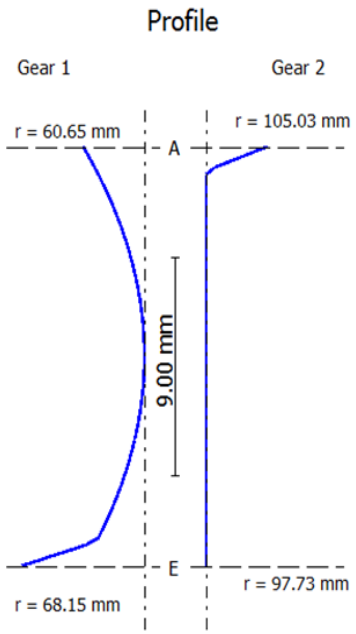
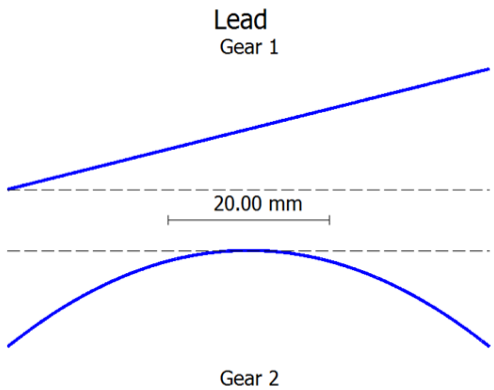


Fig. 4 The root stress of driven gear without gear modification under the torque(Maximum root stress : 98.83 MPa)



(a) Profile modification(gear 1 : La=1 mm, Ca=2 um, crowning Ca=2 um; gear 2 : La=1 mm, Ca=2 um)



(b) Lead modification (gear1 : fhb=-5 um; gear2 : crowning Ca=4 um)

Fig. 5 The data of profile and lead modification for the gear pair

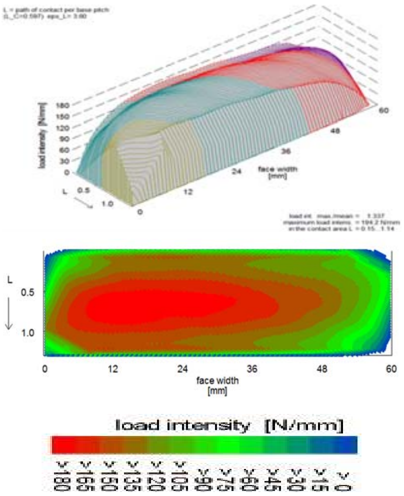


Fig. 6 The normal laod distribution with gear modification under the torque(Maximum load intensity: 194.2 N/mm)

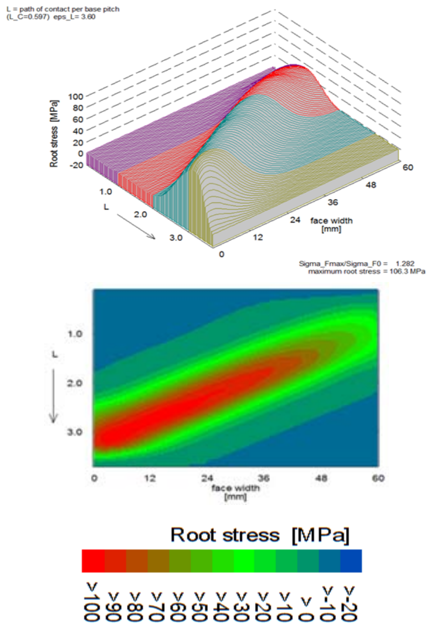


Fig. 7 The root stress of driving gear with gear modification under the torque(Maximum root stress: 106.3 MPa)

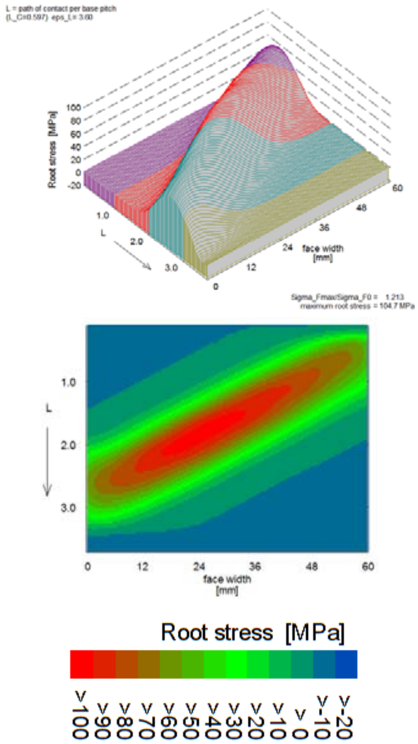


Fig. 8 The root stress of driven gear with gear modification under the torque(Maximum root stress : 104.7 MPa)

By comparing Fig. 2, Fig. 3, Fig. 4, and Fig. 6, Fig. 7, Fig. 8, it is observed that the normal load distribution and the root stress are increased significantly. And the maximum contact region has been shifted to the center of the tooth face.

4. Conclusion

This paper has simply presented an interactive modification procedure to investigate the normal load distribution and root stress of the helical gear pair of a wind turbine gearbox. From the simulation results, the optimal profile and lead crown modification can obtain a good result in gear normal load distribution, root stress for the gear pair of the gearbox. The procedure described above could be a good approach where the simulation is used to check the design before the spur gear pair is available for the test rig by optimizing the gear micro-geometry at the design stage.

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