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CFD Study on the Windage Power Loss of High Speed Gear

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Abstract. The windage power loss is main factor of the power loss in a high speed gearbox. CFD simulation method has been developed for a detailed understanding of the physical mechanism of windage power loss. Comparisons are made with experimental data from the open literature. The CFD results are in good agreement with experiment. The study focuses on the influence of the shroud on the windage power loss for rotating speed ranging from 5000rpm to 7000rpm. It is critical to capture the energy efficiency prize by shrouding the gear. Smooth shroud and grooved shroud have been selected to reduce the windage power loss. It is observed that the better performance occurs with shroud, whereas it is found that the grooved shroud provides a considerable increase in energy efficiency at about 10% over the smooth shroud.

1. Introduction

Gearbox is the key part of high speed train, it mainly responsible for the transmission of motor power to the wheel. With the improvement of train speed, the power loss has become the key problem in the high speed gearbox. The power loss directly affects the equilibrium temperature of the gearbox, which is directly related to the working conditions of the lubricating oil, the sealing system and the bearing lubrication. As a result, it greatly affects the reliability and life of the gearbox [1].

The splash lubrication is generally adopted in high speed gearbox. It is commonly overheated by the windage power loss. The windage power loss is strongly related to the rotating speed. With the increasing of rotating speed, the windage power loss increases significantly and it becomes an indispensable part in the power losses of high speed gearbox. The equilibrium temperature of the gearbox is very high at high rotating speed. The equilibrium temperature can be reduced by decreasing of windage power loss.

The numerical simulation of windage power loss of high speed gear has been focused in this work. According to previous studies, some works were done to exam the efficiency losses of the gearing systems. Massini did numerical and experimental investigations to study windage power losses resulting by a single spur gear rotating in a free oil environment [2]. The numerical results were compared with experimental data in terms of resistant torque as well as PIV measurements, achieving a good agreement for all of the rotating speeds. Two different theoretical approaches were developed to predict windage losses in high speed gear by Diab [3]. It is found that both theoretical approaches give good results in comparison with the experimental evidences. A numerical approach was investigated and validated to develop physical understanding of the aerodynamics of windage power loss by Matthew [4]. Absolute and relative frame CFD simulation, overset gridding, multiphase flow analysis, and sub-layer resolved turbulence modeling were brought to bear in developing the numerical method. Sylvain applied a CFD code to three-dimensional simulations of windage power loss generated by spur gears rotating in air [5]. Emphasis was placed on the simplification which can be made in the numerical approach in order to gain cost and time needed for reaching a converged solution when using both fine mesh and important angular velocity. Although there were several previous studies on the windage power loss, the control methods of windage power loss had been seldom studied. The windage power loss causes general efficiency losses of gearing systems. It is thus important to control the windage power loss.

The purpose of the present study has been to explore the effects of smooth and grooved shrouds on windage power loss. Numerical models have been established to replicate the flow field surrounding a single spur gear. The gear geometry in present study has been built based on the existing experiment [6]. The effects of smooth and grooved shrouds on the windage power loss have been indicated in terms of the resistant torque.

2. Validation of numerical model

The existing experiment of high speed gear has been conducted by Marchese for measuring windage power loss [6]. A frequency converter has been used to adjust the rotating speed. Windage power loss has been found to increase with increasing the rotating speed. In this study, numerical model has been applied to replicate the existing experiment. Geometry of the high speed gear as well as operating conditions of the numerical model has been made based on the existing experiment. The gear is characterized by a module of 5mm, a pressure angle of 20degree, a pitch diameter of 150mm and a face width of 24mm. A schematic of the numerical model without control is shown in figure 1.

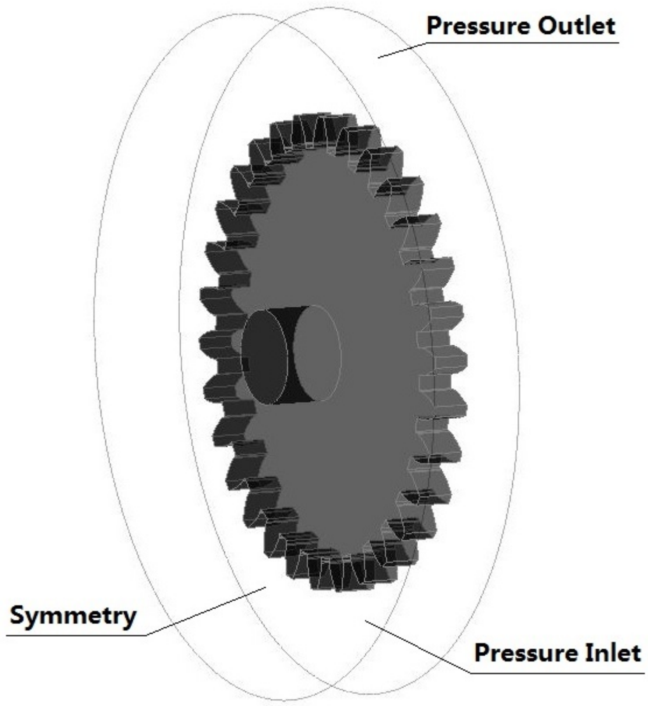


Figure 1. Geometry and boundary conditions of numerical model without control.

The air flow around high speed gear without control has been replicated by using the commercial software Altair HyperWorks AcuSolve. Pressure inlet and pressure outlet have been applied to the inlet and exit of the computational domains. The symmetry boundary condition has been applied to simulate the half computational domain. Unstructured mesh has been used in all regions. The grid number in computational domain is approximately 4 million. The air properties are characterized at the room temperature and atmosphere pressure. As the equations are solved in rotating frame, appropriate boundary conditions have been applied. The rotating velocity of the gear in the rotating frame is set as zero. The rotating velocity of the shrouds in the rest frame is set as zero. The windage power losses at different rotational speeds ranging from 5,000rpm to 7,000rpm have been investigated numerically. Numerical results have been validated by the existing experimental results. The windage power losses at different rotating speeds are shown in figure 2. The numerical results are in excellent agreement with the experimental data.

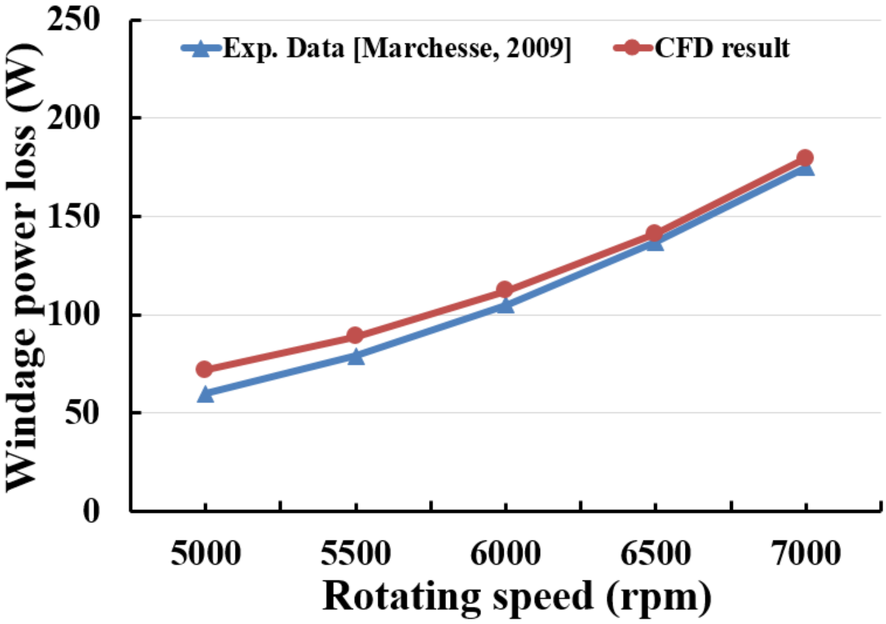
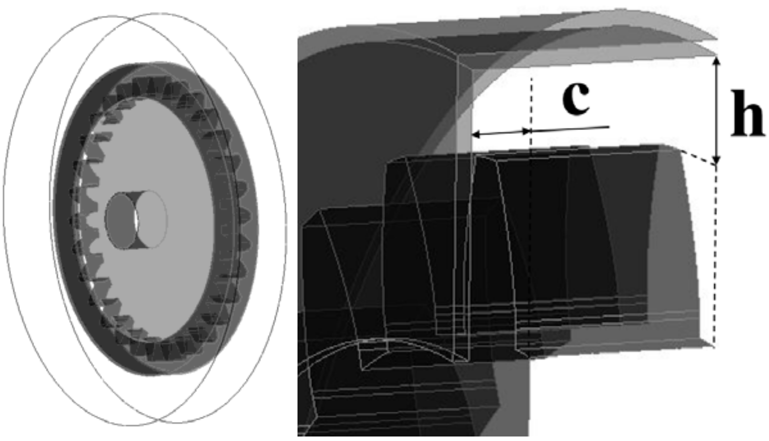


Figure 2. Comparison between numerical model and existing experiment.

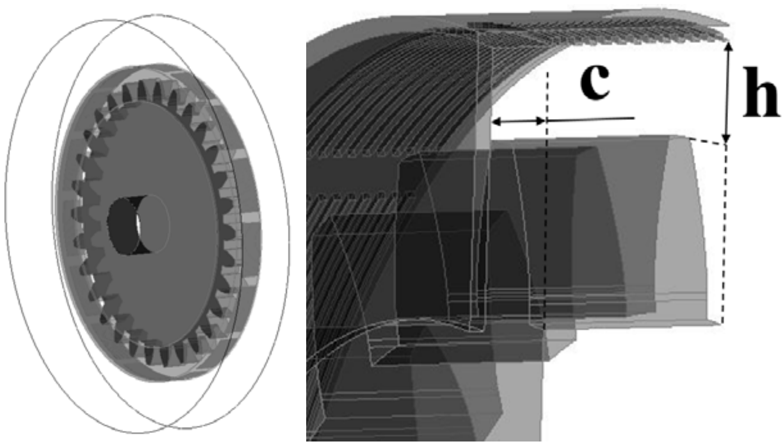
3. High speed gear with different shrouds

As we know, the windage power loss of high speed gear is directly proportional to tooth width, pitch diameter and dynamic viscosity of working medium. The windage power loss can be effectively reduced by reducing the above parameters. However, these parameters are determined by the lubrication requirement and difficult to be adjusted.

The windage power loss is also greatly affected by the volumetric flow rate around high speed gear. The power loss can be reduced by decreasing the volumetric flow rate. It is necessary to install the shroud for decreasing the volumetric flow rate around the gear. This study focuses on the influences of smooth and grooved shrouds on windage power loss for rotating speed ranging from 5,000rpm to 7,000rpm. The schematics of the high speed gears with smooth shroud and grooved shroud are shown in figure 3. The terms of c and h are respectively axial and radial distances between shroud and gear. The term c keeps constant at 4mm in this study. The grooved shroud is different than smooth shroud in that grooved shroud has grooves along the circumference. The cross-section of the groove is 0.5mm in width and 0.5mm in height.



a. smooth shroud



b. grooved shroud

Figure 3. Geometry of computational domains with two kinds of shrouds.

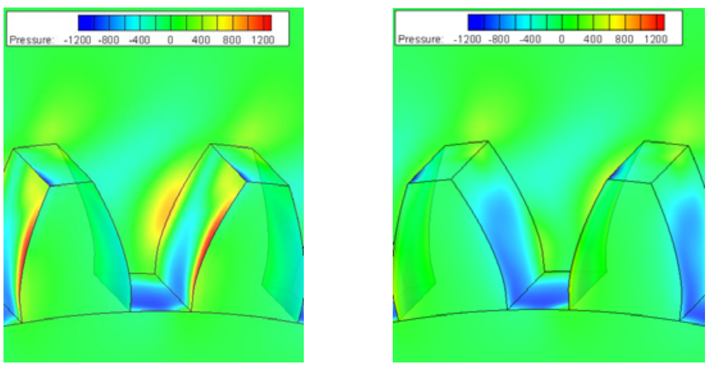
4. Results and discussion

4.1. Effect of smooth shroud on windage power loss

Air flow around the gear teeth has been investigated numerically. The pressure distributions on the tooth surface have been indicated to understand the mechanism of the windage power loss. The air is sucked into the gap between two teeth from both sides of the gear. Then it is thrown out of the gap along the radial direction.

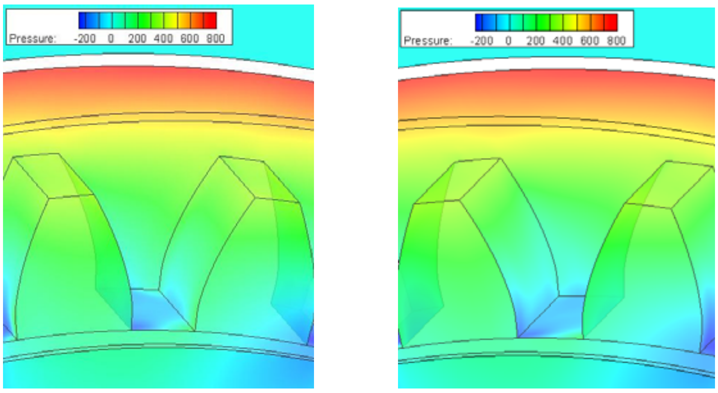
The pressure contours at gear and symmetry surfaces without control are shown in figure 4. It is shown that adjacent tooth surfaces have different pressures. The pressure difference induces the rotating resistance torque of high speed gear. To keep constant rotating speed, the corresponding power has been taken to overcome the resistance torque.

A smooth shroud is applied for enclosing the high speed gear and restricting the pumping action by the gear teeth. The volumetric flow rate around the gear is reduced by enclosing the gear. The pressure difference is much lower with the smooth shroud, as shown in figure 5. Figure 6 indicates the effects of smooth shroud on windage power loss at different rotating speeds. The windage power loss increases with the increase of rotating speed. The smooth shroud is able to reduce the windage power loss by approximately 75% compared to the configuration without control. Shrouding the gear is effective to reduce the windage power loss.



a. pressure surface b. suction surface

Figure 4. Pressure contours without control (ω=7000rpm).



a. pressure surface b. suction surface

Figure 5. Pressure contours with smooth shroud (h=7mm, c=4mm, ω=7000rpm).

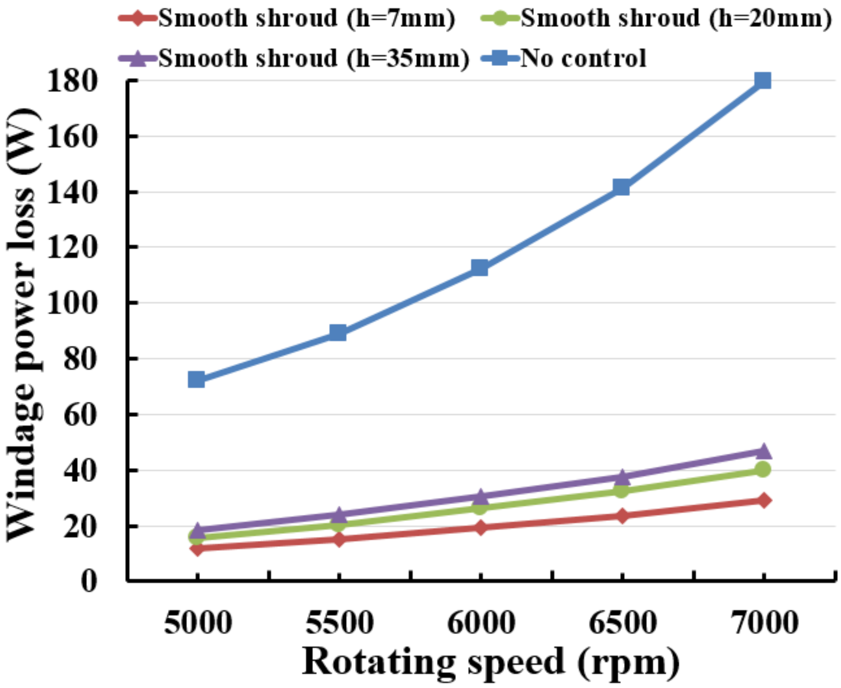
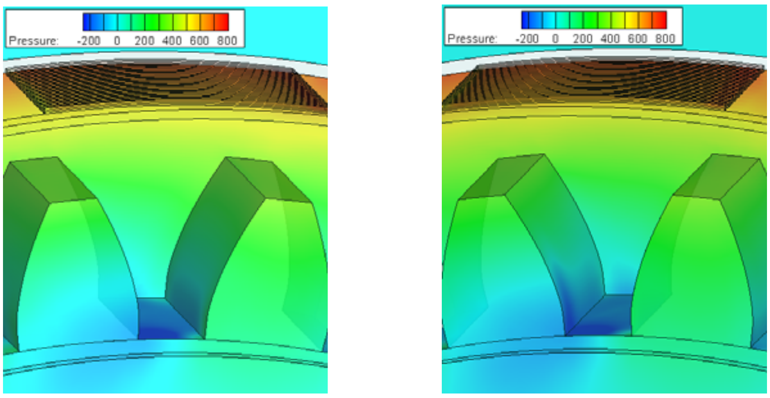


Figure 6. Windage power losses at different rotating speeds.

4.2. Effect of grooved shroud on windage power loss

Due to the space limitation, the size of shroud is sometimes difficult to be adjusted. It is necessary to add the grooved surface on the shroud if higher energy efficiency is needed. Grooved surface is able to further reduce the windage power loss when the space between shroud and gear is fixed. Figure 7 indicates the pressure contours at gear and symmetry surfaces with grooved shroud. It is shown that pressure difference between pressure surface and suction surface is much lower than the condition without control. The grooved shroud is able to restrict the pumping action as well.

In addition, the grooved shroud is able to further reduce the windage power loss by reducing the wall shear stress. The velocity gradient along the radial direction from bottom of the groove is shown in figure 8. The velocity gradient in grooved shroud is much lower than smooth shroud. The surface friction in grooved shroud decreases as the velocity gradient decreases. Windage power losses with smooth and grooved shrouds have been shown in figure 9. It is observed that the grooved shroud provides a considerable increase in energy efficiency at about 10% over the smooth shroud.



a. pressure surface b. suction surface

Figure 7. Pressure contours with grooved shroud (h=7mm, c=4mm, ω=7000rpm).

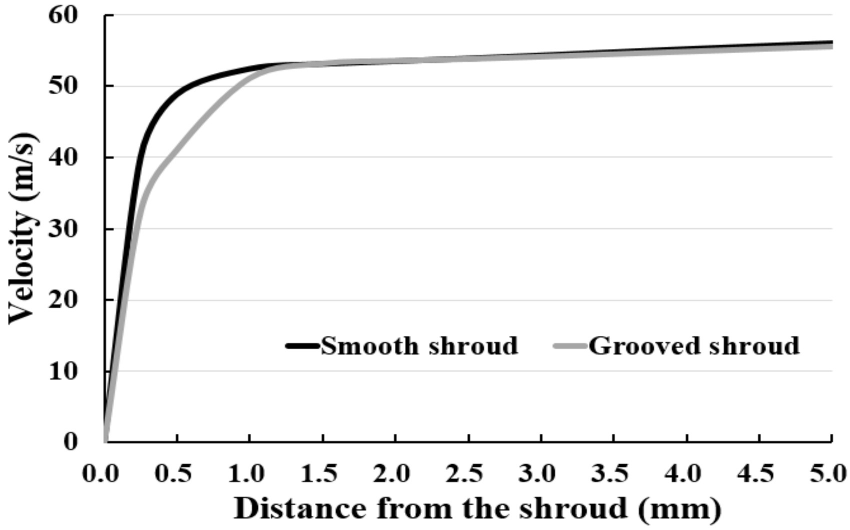


Figure 8. Velocity gradients along the radial direction (h=7mm, c=4mm, ω=7000rpm).

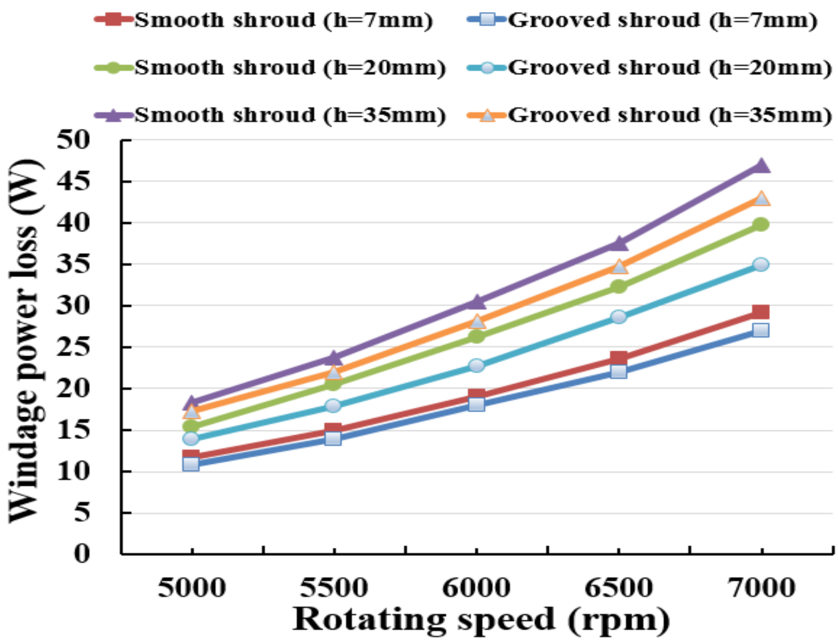


Figure 9. Windage power losses at different rotating speeds.

5. Conclusions

Numerical approach has been taken to understand the physical mechanism of windage power loss. Numerical result has been validated with the existing experiment. It is in good agreement with the experimental result. The effects of smooth and grooved shrouds on windage power loss have been focused in this study. Smooth and grooved shrouds have been applied for enclosing the high speed gear and restricting the pumping action by the gear teeth. The windage power loss has been reduced by shrouding the high speed gear. The comparison between smooth shroud and grooved shroud has been indicated. It is found that the grooved shroud provides a considerable increase in energy efficiency at about 10% over the smooth shroud.

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