The prediction of Churning and windage power losses in High Speed two-stage gearbox via simulation Approach

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Abstract

Speed dependent and load dependent losses are major causes of power loss in gears under certain operating conditions. In a jet lubricated gearbox, the power loss contribution from gears are windage loss as gears are running in an air-oil mist environment inside the gearbox and also power loss in a high speed gearbox due to churning losses at different oil levels were to be running in an oil bath or dipped in oil. This study presents the major findings to predict the speed dependent losses i.e. churning and windage power losses at various oil levels in a high speed two stage gearbox via simulation approach. This will be further used to predict the total efficiency of gearbox and the lubrication requirement to maintain the operating temperature within limit to avoid high temperature distress on the gearbox elements. The speed losses are defined as the sum of churning power losses and windage power losses. The simulation model is applied to a high speed two-stage gearbox to measure the distributions of each individual power loss in the overall no-load losses. The total churning losses are estimated considering the contribution from each of the locations in gear shaft, gear web side faces and the gear tooth. From this analysis concluded that the Windage NASA method is preferable. This analysis concluded that Churning power loss is better to prefer oil level (H/D=0.1) because power loss is increasing with respect to the oil level. The efficiency of this gearbox under pressurized jet lubrication condition is estimated as windage NASA 99.83% and 0.17% of windage losses involved in total gearbox. The efficiency of the gearbox considering the effect of churning with oil level ratio of 0.1 is 99.48% and 0.51% of power loss involved in the gearbox. This shows that there is a major effect on power loss as the oil-dip level rises.

Keywords: **Churning power losses, windage power losses, high speed two stage gearbox and MAT LAB.**

Introduction

Nowadays high speed gearbox applications are demanding especially in aero-engine applications which are used to drive accessories like pumps and generators. The high speed gearboxes Figure-1 are designed to have high power density and more efficient to reduce the lubrication and hence the size of the overall system. A gearbox is a device for transmission of torque and motion. It mainly acts as a torque multiplier or speed reducer. A gearbox assembly comprises critical rotating components such as gears, shafts, bearings and seals, and the static parts gearbox housing which provides interface and support to the rotating parts during operation. The gears in general are integral to the shafts that rotate freely around their axis supported on the bearings assembled to gearbox housing. The major sources of power loss in a high speed gearbox are associated with gears and bearings. The power loss contributions from gears are divided into load-dependent and no-load dependent or speed-dependent parts.**[1]** For the current project work considered speed-dependent or no load dependent power loss in gears for calculating power losses. Speed dependent power losses combination of all losses that exist when a gearbox is rotating, but not transmitting power. Speed dependent power losses derive from seals or from windage losses and churning losses.**[1]**. Considering losses because of gear sliding, rolling, gear windage and ball bearing power loss. Using this analysis they observed each element within the gearbox with helical gearing to the total power loss. **[2].**

Speed dependent power loss combination of all losses that exist when a gearbox is rotating, but not transmitting power. No-load losses derive from seals or from windage and churning.**[3]**The possibility of predicting windage losses on spur gears by using commercial CFD codes is investigated. Two dimensional models are found to be unsatisfactory and lead to unrealistic power loss estimations compared with the measurements on test rigs.**[4].**

The analysis **[5]** showed that the windage losses are highly depends on the rpm speed of the gears and is different for speeds below 1000 rpm. The rolling power loss was found to contribute a less percentage of the total power loss in gearbox system

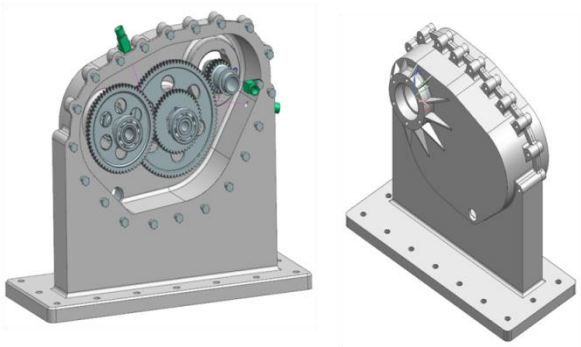


Figure 1:Gearbox Assembly views

Methodology

1)Numerical Analysis

A) Oil Churning Power loss (P_{CL}) :

Churning losses are understood as the movement of the lubrication gear in the gearbox. Mainly because the lubricant is trapped in the gear mesh. This applies more to spur gears than to helical gears**[1].**

Factors affecting the oil churning losses are Viscosity of oil as this resists the motion of gears, Partial velocity, Operating temperature, Module values, Helix angle, Submerged depth of the gears. All rotating components that are in direct contact with the oil-filled lubricant are involved in churning losses; deeper components immersed in water have the most losses. These contradicting expressions of harm have been broken down into three separate sections obtained from.

1) Churning losses for smooth outside diameters (i.e. shaft) given in equation

$$P_{CL1} = \frac{7.37 \times f_g \gamma_o n^3 D^{4.7} L}{Ag.10^{26}} \quad (1)$$

2) Churning losses for smooth sides of gears (gear side faces and both faces) given in equation

$$P_{CL2} = \frac{1.474 \times f_g \gamma_o n^3 D^{5.7}}{Ag.10^{26}} \quad (2)$$

3) Churning losses for tooth surfaces is given by equation

$$P_{CL3} = \frac{7.37 \times f_g \times \gamma \times D^{4.7} \times b_i \times \left(\frac{R_f}{\sqrt{\tan A}} \right)}{Ag \times 10^{26}} \quad (3)$$

Total churning loss is sum of all the losses in the gear P_{CL} ($=P_{CL1}+P_{CL2}+P_{CL3}$)

Where

f_g= Ratio of dipping depth to element outer diameter.
(Ratio of dipping depth to element outer diameter= (H/D)).
= 1 for fully submerged

Oil level (f_g) is the ratio of dipping depth to element outer diameter . in Figure 2, D is the element outer diameter, ‘d’ is the base diameter and H is the oil level .

$$H = D - d$$

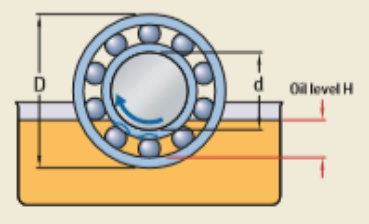


Figure 2: Oil Level

γ= Kinematic viscosity at operating temperature
n= Rotational speed
D= Element diameter
L= Element length
Ag= Arrangement constant = 0.2
R_f= Roughness factor
A=Helix angle

B) Windage Power loss (P_{WL}):

As the gears rotate, centrifugal force flings the lubricant onto the lubricant in the form of oil droplets from the gear teeth. These lubricant droplets create a fine oil dust that hangs in the gearbox / chamber. The effect of oil dust increases the "windage frictional resistance" on the gears and thus increases the power consumption. The combination of these factors as well as losses in the lateral aspects of the gears add to the overall windage losses. factors are the teeth module, the portion of oil dust available on the inner side of the casing and the diameter of the gears. Using gear notation gives the windage power loss for the gear as given by equation (4) can be written from **[2]**.

$$P_{W,g} = 2.82\text{xl}0^{-7}\,\text{x}\left(1+2.3\frac{b}{R_g}\right)\left(\frac{n_p}{m_g}\right)^{2.8} R_g^{4.6}\,\mu_{eq}^{\;0.2} \qquad (4)$$

Where
b= Face width, m
R_g=Pitch circle radius of the gear, m
R_p=Pitch circle radius of the pinion, m
μ= Lubricant absolute viscosity, N sec/m^2
mg =gear ratio
n_p= rotational speed, rpm

The conditions inside the gearbox is that of an air-oil mixture. Thus the viscosity in equation (5) must represent this mixture. The same amount of air-oil mixture density is intended to simulate a typical environment inside a gearbox, an environment same to that in most jet-lubricated gearboxes. For this analysis, viscosity is calculated to represent this mixture. Thus

$$\mu_{eq} = \frac{(1)\mu \times (34.25)\mu_{air}}{35.25} \quad (5)$$

For this analysis, all properties in equation (5) except oil viscosity are assumed constant. Air viscosity at 339 K (34 deg C) are assumed to be
$\mu_{air} = 2x10^{-5}$ N sec/m^2

2) Simulation Procedure

The Churning power loss and windage power loss equations from above equations (1),(2),(3),(4) were inputted into MATLAB software using input as parameters used in the equations. By entering and simulating input values for the equations to get the power losses involved in the high speed two-stage gearbox and also plotting the graphs for power loss values for simple understanding the power losses involved using MATLAB software and those plots and power loss values defined in results and discussions.

Results and Discussion

Churning Power loss

This analysis communicates the variation of power losses of churning power losses at different oil levels (H/D) and shows the gear churning power loss variation with speed for all the four gears for various oil levels. Total churning power losses in gearbox at different oil levels presented in Table-1 which varies with the increasing the oil level ratio due to variation in outside element diameter,smooth sides of gears and tooth surfaces . calculated that low power loss at low oil level by comparing with the other oil levels with the help of the gear data performed at the speeds of 5600 rpm and 29588 rpm for gear-1 ,gear-4, and 7913 rpm for gear-2, gear-3. The speeds of gear-2 and gear-3 are the same because gear-2 and gear-3 are compounded on the same shaft. face width (b) of 10mm for gear-1,2 & face width 20mm for gear-3,4 and the shaft diameter of 30mm. The power loss varies at each Gear in every oil level due to variation in the speed and face width as shown below Table-1. outside element diameter varies with the gear and churning loss performed at different oil levels.

Table-1 :Total churning power loss at different oil levels (H/D)

S.No		Total Churning Power loss (Watts)					
	Oil level	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**
1	**Gear-1**	12.911	25.822	38.733	51.644	64.555	77.466
2	**Gear-2**	5.721	11.442	17.163	22.885	28.606	34.327
3	**Gear-3**	36.528	73.057	109.58	146.11	182.64	219.172
4	**Gear-4**	22.229	44.459	66.689	88.919	111.149	133.379
Power Loss at different levels in Gearbox		**77.389**	**154.78**	**232.165**	**309.55**	**386.941**	**464.34**

Generated MATLAB Plots for churning power loss

Churning power losses at different oil levels presented in below figures. Gear-1 at different oil Levels shown in Figure-3 similarly Gear-4 at different oil levels in Figure-6 and also observed that in every gear power loss is low at lower oil level 0.1 by comparing with other oil levels.

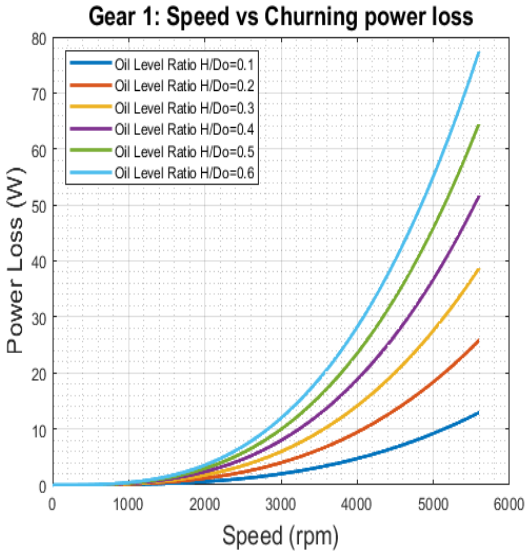


Figure.3

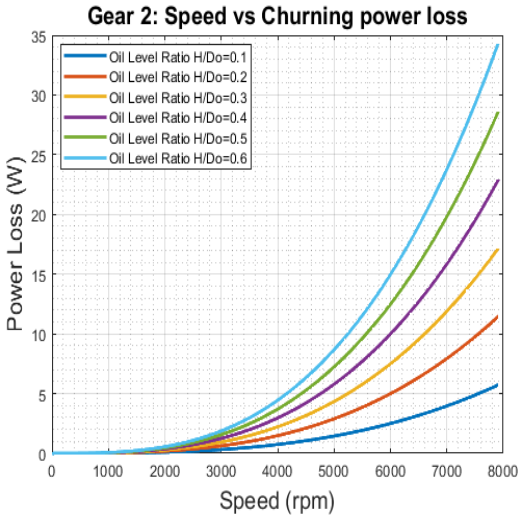


Figure.4

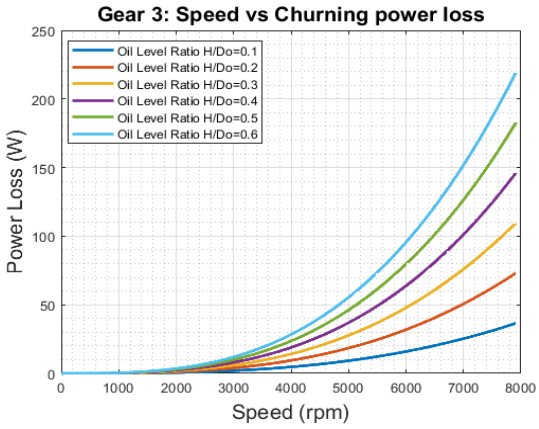


Figure. 5

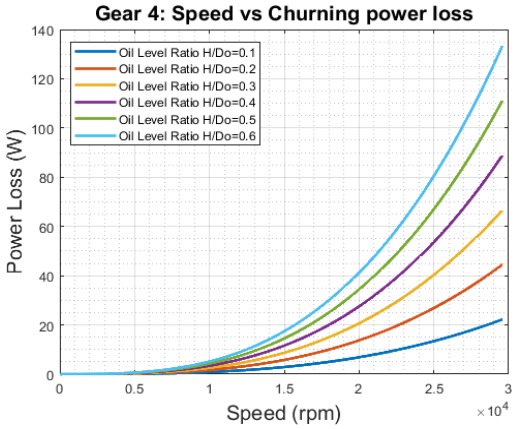


Figure.6

Here calculated that the percentage of power loss in gearbox occurs by the churning losses. Efficiency of churning power loss calculated at power 15000 Watts and churning power loss from above analysis. Churning power loss involved 0.51% of the power loss in gearbox with the churning efficiency of 99.48%.

$$\eta_{Churning}\% = \left(\frac{TotalPower - TotalPowerLoss}{TotalPower} \times 100 \right) = 99.48\%$$

Windage Power loss

The gear windage power losses estimated using NASA Method considering air-oil mixture as medium. The results show that windage power loss using the NASA method **[2]**. Power loss varies due to variation in speed, no. of teeth, root diameter and module (1.6mm) at each gear in Windage method.Windage power loss of the gear performed at the speeds of 5600 rpm and 29588 rpm for gear-1 ,gear-4, and 7913 rpm for gear-2, gear-3. The speeds of gear-2 and gear-3 are the same because gear-2 and gear-3 are compounded on the same shaft. face width (b) of 10mm for gear-1,2 & face width 20mm for gear-3,4. The absolute viscosity of air in the gearbox is $2x10^{-5}$ N sec/m^2 and number of teeth varies with each gear respectively 65,46,86 & 23. Windage power loss at each gear presented in Table-2.

Table 2 :Windage Power loss (Watts)

S.No	Gear	Windage NASA Method (Watts)
1	**Gear-1**	1.812
2	**Gear-2**	1.095
3	**Gear-3**	19.995
4	**Gear-4**	3.906
	Total Power Loss	**26.179**

Generated MATLAB Plots for Windage power loss

Windage power loss estimated in Table-3 is presented graphically in below figures that Windage power loss at gear-1 shown in Figure-7 similarly Gear-4 in Figure-10.

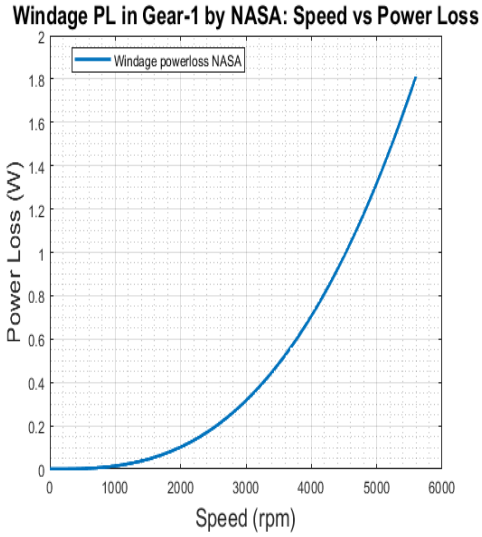


Figure. 7

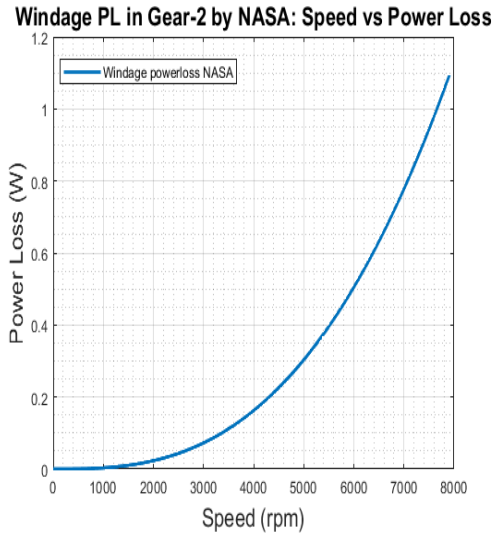
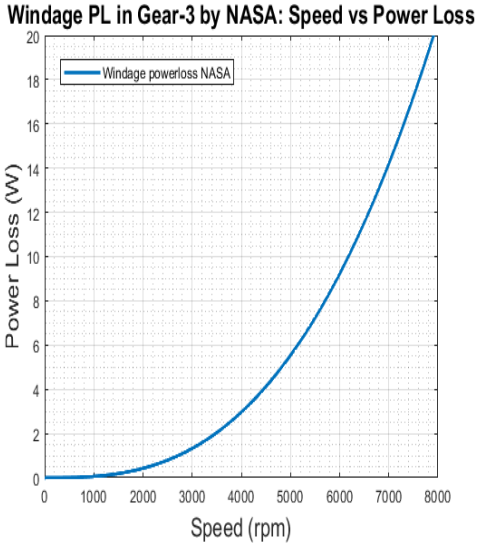


Figure. 8



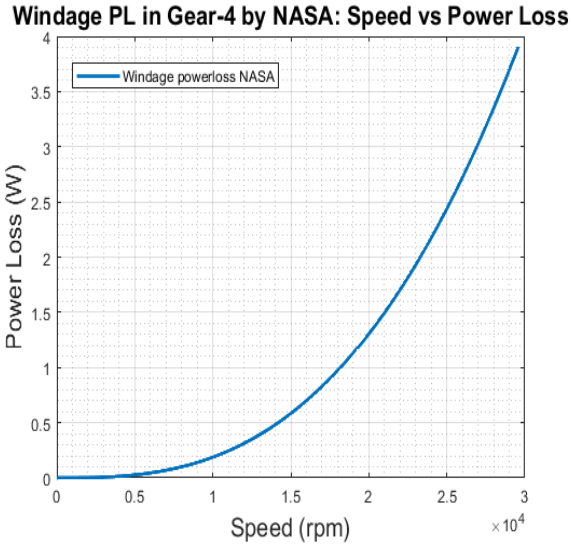


Figure. 9 **Figure. 10**

Here calculated that the percentage of power loss in gearbox occurs by the windage power losses. Efficiency of windage power loss calculated at power 15000 Watts and windage power loss from above analysis. Windage NASApower loss involved 0.17% of the power loss in gearbox with the windage efficiency of 99.83%.

$$\eta_{windage}\% = \left(\frac{TotalPower - TotalPowerLoss}{TotalPower} \times 100 \right) = 99.83\%$$

Efficiency of the gearbox at windage and churning power loss and also percentage of the power loss involved in gearbox by churning and windage losses presented in Table-3.

Table-3 :Efficiency of churning and windage power losses

S.No	Type of power loss	Power loss (Watts)	Percentage in gearbox	Efficiency
1	**Churning power loss**	77.392	0.51	99.48
2	**Windage power loss**	26.179	0.17	99.83

Conclusion

From this analysis concluded that Churning power loss is better to prefer oil level at (H/D=0.1) because power loss is increasing with respect to the higher oil level and also from this analysis estimated the windage power loss using NASA method **[2].** The efficiency of this gearbox under pressurized jet lubrication condition Windage power loss is estimated as windage NASA

(0.17%) with 99.83% of windage efficiency in the gearbox and the efficiency of gearbox considering the effect of churning with oil level ratio of 0.1 is 0.51% with 99.49% efficiency of churning in gearbox. This shows that there is a major effect on power loss as the oil-dip level rises.

Appendix

Basic information data respectively input power, input speed, output speed, number of gears, module and pressure angle shown in Table-4

Table-4 :specifications of Gearbox

Power (Watts)	15000
Input speed (rpm)	5600
Output speed (rpm)	29588
Number of gears	4
Module (mm)	1.6
Pressure angle (Deg)	25

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