DIVISION OF DESIGN & MANUFACTURING LABORATORY OF MECHANICHAL TECHNOLOGY

DIPLOMA THESIS: WINDAGE EFFECTS ON BEVEL GEARS DESIGN FOR AERONAUTIC APPLICATIONS

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ABSTRACT

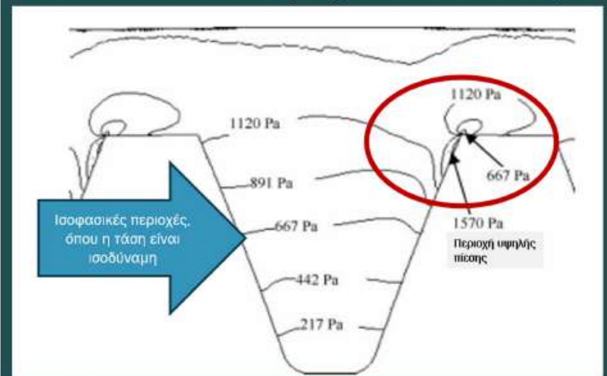
In the following work, an investigation is carried out around the windage power losses (WPL), which occur in gear pairs during meshing in a gearbox of a turbofan aircraft engine. The study around WPL is applied in the aircraft industry in order to improve the design of turbofan engines. The WPL constitute 10% of the total losses with gearbox efficiency reaching 99% and modern engines exceeding 100MW nominal power. The results from this study can save large amounts of fuel, making the engines more environmentally friendly. In this study, the geometric characteristics of the gears are modified to present the least WPL during meshing. Usually, in a gearbox of a turbofan engine the gears used are bevel gears, and the WPL developed inside it can be divided into peripheral windage power losses and windage power losses in the teeth. Our study focuses on the WPL occurring in the teeth of the gears.

Key Words

Windage power losses (WPL), Turbofan engine, Gears, CFD simulation, parametric CAD.

BACKGROUND

Previous experimental research on the WPL of gears has found that the gear cover can have a significant impact on reducing WPL. Dawson conducted a series of experimental studies on frontal and helical gears made of hard material that rotate in air. Diab et al. presented an experimental study of a gear rotating in air without a casing. Dawson and Al-Shibl et al. found that modifying the tooth tip and adding a small chamfer to the leading edge reduced the WPL by 6 %.

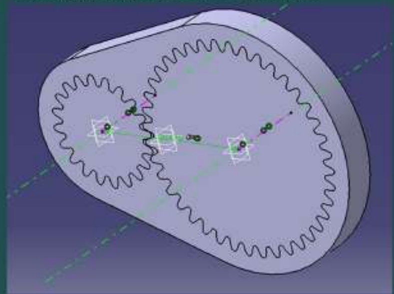


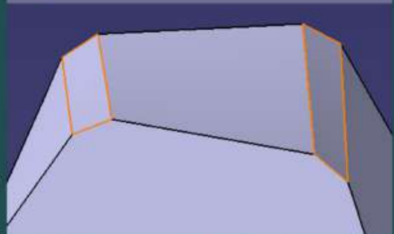
METHODOLOGY

The simulation model used is a pair of spur/ helical gears rotating at high speed in air environment, modifying the chamfer on the gear tip and the pressure angle.

1. Design of the geometry of the gear pair and the surrounding volume in CATIA

- Setting parameters
- Tooth design based on the equations given by gear design theory
- Creation of inclination for helical gears
- Creation of the chamfers and the several teeth
- Gear pair assembly
- Design of gear control volume





2. The calculation and analysis of the basic equations governing the simulation model

- Total WPL $P_T = P_P + P_f$

- Peripheral WPL P_P calculation $dP_P = 4\pi\mu r_0^2\omega^2 db$

- Study of the boundary layer at the periphery of the gear for laminar or turbulent flow and calculate WPL

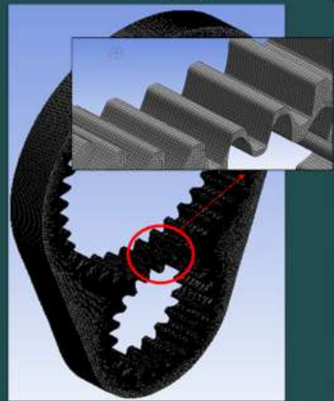
Equations for laminar flow	Equations for turbulent flow
$v_{df}^{(L)} = {U_y}/{\delta^{(L)}}$	$v_{df}^{(T)} = U\left({y}/{\delta^{(T)}}\right)^{1/7}$
$\delta^{(L)} = 3.46\sqrt{{2\mu_k r_0}/{U}}$	$\delta^{(T)} = 0,142(2r_0)^{\frac{6}{7}}\left(\frac{\mu_k}{U}\right)^{\frac{1}{7}}$
$C^{(L)} = 0.578\sqrt{{\mu_k}/{(2r_0U)}}$	$C^{(T)} = 0.02\left[\mu_k/(U\delta^{(T)})\right]^{0,167}$
$F_f^{(L)} = \frac{1}{2}\rho U^2 C^{(L)}(\pi r_0^2)$	$F_f^{(T)} = \frac{1}{2}\rho U^2 C^{(T)}(\pi {r_0}^2)$
$P_f^{(L)} = 0.41\pi\rho\mu_k^{0,5}\omega^{2,5}{r_0}^4$	$P_f^{(T)} = 0.025\pi\rho{\mu_k}^{0,14}\omega^{2,86}{r_0}^{4,72}$

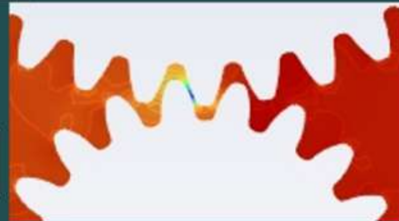
- The calculation of the WPL on the teeth of the gears in the simulation is calculated by relating the static pressure and velocity according to the following equation

$$P_f = F_f\omega r_0,\ p_f C = \frac{F_f}{A},\ P_f = p_f C A\omega r_0$$

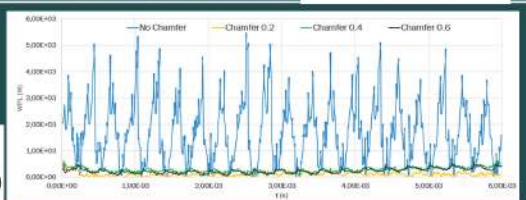
3. The CFD analysis of our model in ANSYS Flow Fluid (Fluent), using dynamic meshing during simulation

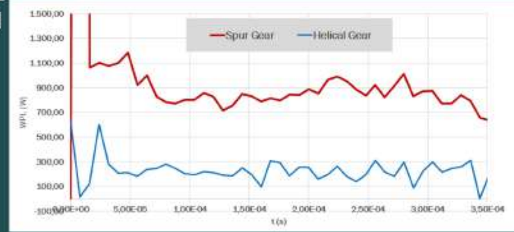
- Import and Modify geometry
- Creating a Computational Static Mesh
- Computational Solving, definition of conditions
- Creating Dynamic Mesh





RESULTS





CONCLUSIONS

- The necessary use of a chamfer to substantially reduce the pressures and the WPL during the engagement
- As the rotational speed increases, the WPL increase, with the increase being greater for higher speeds as we have more turbulence
- Small shifts in pitch or tooth geometry at such speeds greatly affect WPL
- As the contact area with the fluid (air) increases, the pressure and WPL decrease. Increases the surface area distribution of stresses occurring in the isophase regions of a tooth

Ζεύγη οδοντωτών τροχών με ταχύτητα περιστροφής 10000rpm	Αεροδυναμικές απώλειες ισχύος (WPL)
Spur Gears Chamfer 0 mm, φ 20o	837,20 W
Spur Gears Chamfer 0,2 mm, φ 20o	344,35 W
Spur Gears Chamfer 0,4 mm, φ 20o	302,01 W
Helical Gears Chamfer 0,2 mm φ20o	296,95 W
Spur Gears Chamfer 0,4 mm, φ 15o	277,44 W
Spur Gears Chamfer 0,6 mm, φ 20o	259,47 W
Spur Gears Chamfer 0,4 mm, φ 25o	237,25 W
Helical Gears Chamfer 0,4 mm φ20o	207,00 W

FUTURE STUDY

- Use of a control volume containing a two-phase mixture (air - oil)
- Deepening the influence of different chamfers
- Above analysis of the study around the boundary layer
- Study around the oil film surrounding the gear Development of dynamic mesh for helical bevel gears