from 115 Pa to 815 Pa when going from the root diameter to the outside diameter of the gear. This difference in pressure induces the creation of aerodynamic drag forces, i.e. the moments of drag due to the effect of pressure and viscosity. This resistive torque to the movement of the gear causes the windage power losses which tend to increase with the gear rotational speeds.

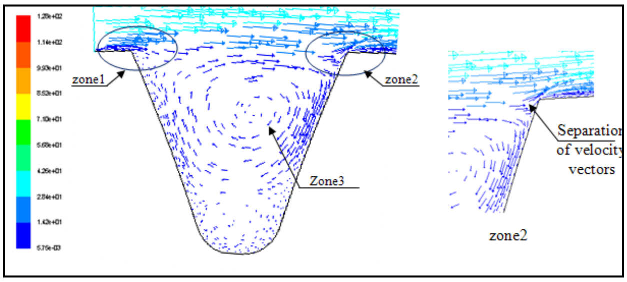

Fig.10 Relative velocity cartographies for the mesh type 2 with a rotational speed of 20000 rpm

Figure 10 shows the relative velocity cartographies for the mesh type 2 when the rotational speed is 20000 rpm. Three significant zones can be distinguished in the velocity profiles:
-Zone 1: in this tooth edge the velocity vectors remain tangent to the teeth outer diameter. The same direction is observed in the free space between teeth and gearbox.
-Zone 2: concerns the opposite edge in which a separation of the velocity vectors is observed. In this zone was also observed a high pressure gradient as show in figure 8
-Zone 3: situated in the inter teeth space. The velocity vectors present a vortex shape.

3.2 Influence of the number of the teeth

In order to observe the influence of the number of the teeth on the evolution of the windage power loss, we carried out two simulations. The first one with a gear n°1 (120 teeth) and the second one with gear n°4 (25 teeth). Figure 11 shows the total windage power loss for the two gears.
We noticed that the power losses for the gear n°4 are very weak for all the rotational speed compared with those of the gear n°1. This fact is explained by the increase of the active surfaces being opposed to the air flow and consequently amplification of the power loss.
For a rotational speed of 20000 rpm, the static pressure cartographies for the two types of gears are given in figure 12.

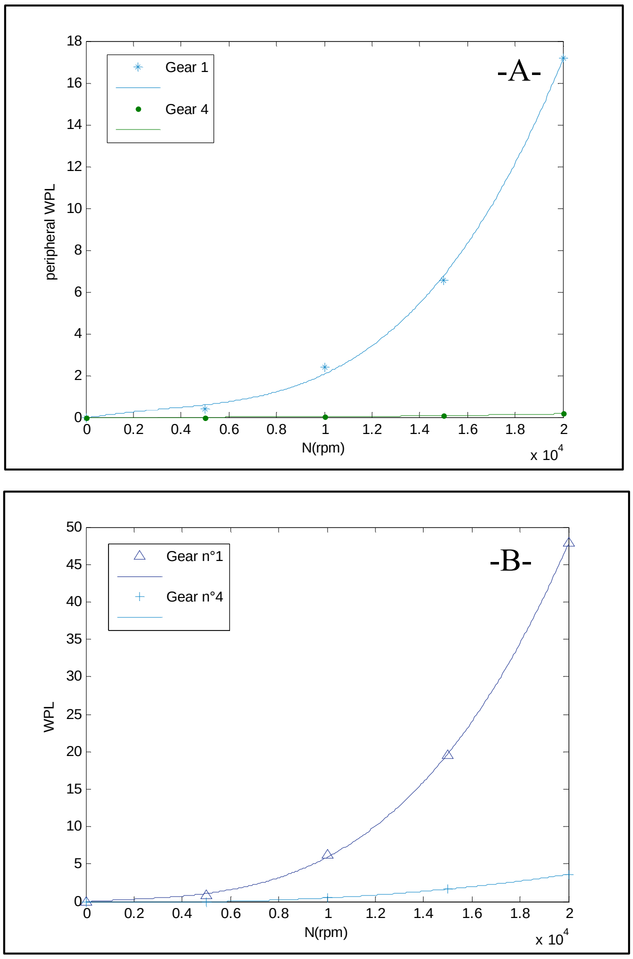

Fig.11 Peripheral (A) and total windage power loss (B) for the gear n°1 and n°4

Increasing the number of the teeth causes a significant change of the pressure starting from the root diameter of the gear to the outside diameter. This variation is as follows:
-For the gear n°1 (120 teeth): 115 Pa to 815 Pa,
-For the gear n°4 (25 teeth): 18.9 Pa to 174 Pa,
This increase induces a significant variation of pressure gradients at the tip of the tooth gear.

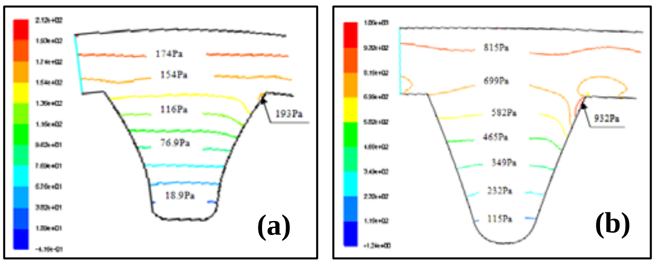

Fig.12 Comparison between the static pressure cartographies for two types of gear: Z=25 teeth (a) and Z=120 teeth (b)

3.3 Influence of the module change

To implement the influence of the gear module on static pressure cartographies and on the WPL, two simulations are performed with gear n°4 (m=1mm) and gear n°2 (m=8 mm).

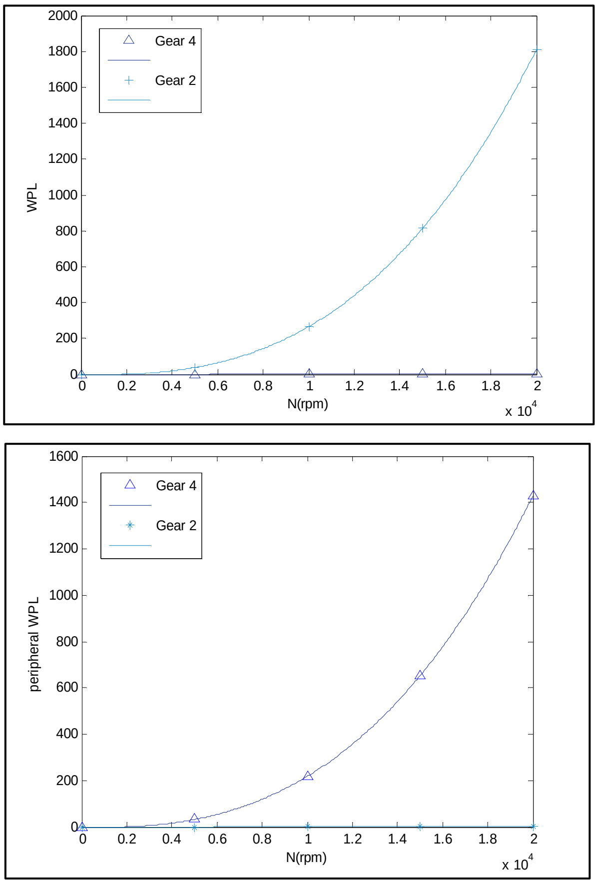

Fig.13 The total windage power losses for the gears n°4 and n°2

Changing the gear module from 2 mm to 8 mm results in a substantial increase of the total power loss (figure 13). This change is induced by the extension of the height of teeth (the distance between the root diameter of the gear and its outside diameter), that explains why the peripheral losses are rather enormous compared to those on the side losses.

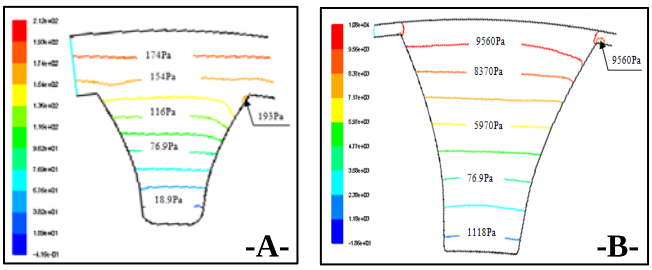

Fig.14 Comparison between the static pressure cartographies for two types of gear : m=1 mm(a) and m=8 mm(b)

Figure 14 shows the static pressure cartographies for the two module cases

The increase of the inter-teeth free space due to module increase induces a significant variation of the pressure. This variation passes:

-For the gear n°4: from 150 Pa to 629 Pa,

-For the gear n°2: from 1180 Pa to 9560 Pa,

3.4 Influence of the lubrication in the gearbox

In the gearbox of gear transmission, the fluid around the gear can be a mixture of air and vapor of oil made up of droplets of various sizes, its density will depend on the voluminal oil concentration in the air. An equivalent density of the oil-air mixture can be expressed as function of the density of each fluid. For a 3% ratio air-oil, the equivalent density and viscosity can be determined by (Neil et al., 1980):

$$\begin{cases} \rho_{equi} = \dfrac{(1)\rho + (34.25)\rho_{air}}{35.25} \\ \mu_{equi} = \dfrac{(1)\mu + (34.25)\mu_{air}}{35.25} \end{cases} \quad (14)$$

Figure 15 shows an important increase of the power loss when air is changed to air-oil mixture for the gear n°1. As an example, for a rotating speed of 20000 rpm, the losses grow from 50 to 700W. This rise in the power loss is explained by the existence of a strong pressure gradient (figure 16) between the gear teeth which is about 15300 Pa for the air-oil mixture, while it does not exceed 699 Pa in the case of the gear rotating in the air.

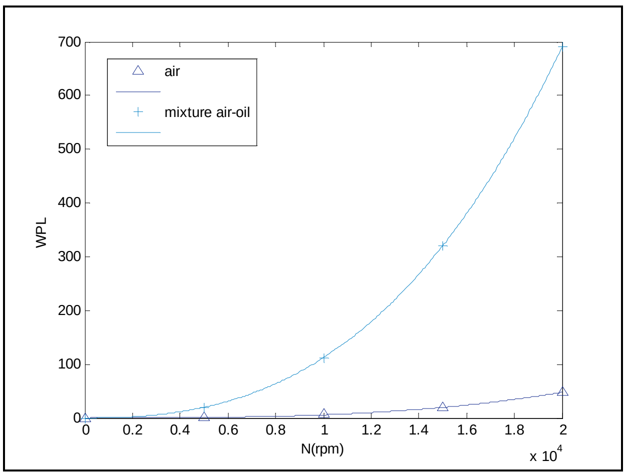

Fig.15 The windage power losses of the gear teeth

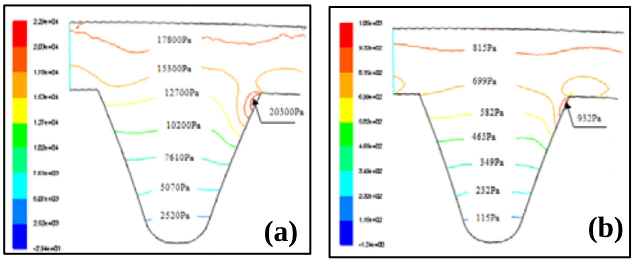

Fig.16 Comparison between the static pressure cartographies of simulation on the gear for two types of lubrication: (a) mixture air-oil and (b) air

3.5 Influence of the addendum modification on the gear teeth

In this section the influence of an addendum modification on the power losses is scrutinized. Figure 17 shows the change of the addendum factor from 0 to 0.5 when using gears n°2 and n°3.

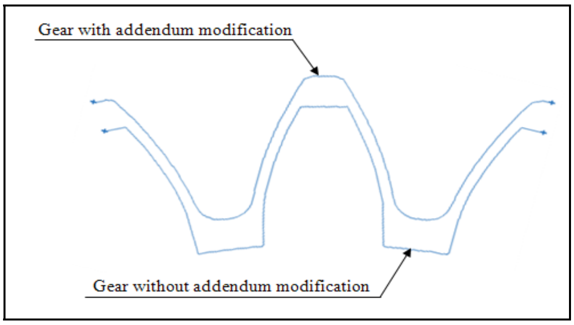

Fig.17 Comparison of the geometry of the gear teeth with and without addendum modification

The change of the addendum modification presents three principal interests (Fedala, 2007):
-The increase of the bending resistance by increasing the section of embedding,
-The optimization of the specific slips to decrease erosion on the small gear of the gears transmission
-Ensuring a fixed distance between centres,

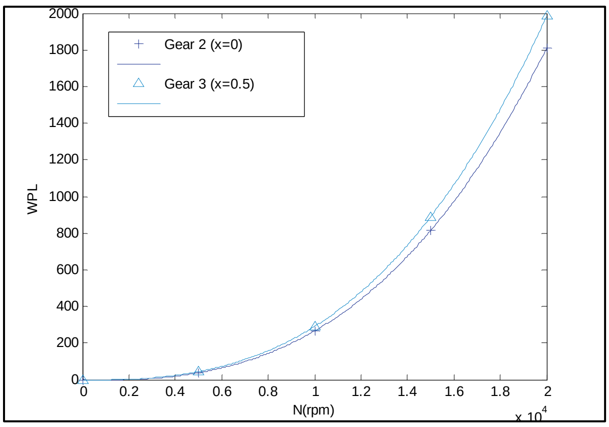

Figure 18. Windage power losses of the gear teeth for both cases of addendum modification

The addendum modification of gear teeth induces a light increase in the total power loss at high speed. This increase is due primarily to a variation of the pressure gradients between the outside diameter of the teeth and the gear box when making an addendum modification of 0.5, as shown in figure 18. For a rotational speed of 20000 rpm, the static pressure cartographies for the two types of gears are given in figure 19. It noticed higher gradients of pressure around the teeth outer diameter.

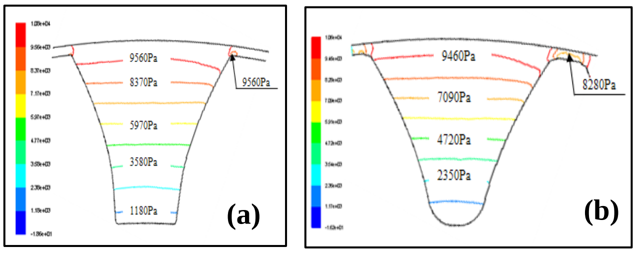

Figure 19. Comparison between of static pressure cartographies simulated on a gear for both cases of addendum modification: x=0 (a) and x=0.5(b) (2000rpm)

4 Conclusion

The windage power loss due to the effect of aerodynamic trail of the teeth in the air-lubricant mixture is a very complex phenomenon which involves several aspects (rotational speed, the shape of tooth, lubrication, the number of tooth, the module). In order to study the influence of each parameter on the amount of power loss, we proceeded to the resolution of the equilibrium equations of the assessment associated with the studied system. As the analytical solution is almost impossible especially in the turbulent case, where the equations are nonlinear, we adopted a numerical resolution. To this effect, the finite volume method was used with a two-dimensional model of a spur gear. The computations were carried out using the computation fluid dynamics code Fluent "6.3.26 ".
As results the viscous moment used to compute the windage power loss. It is also possible to plot the cartographies of pressure and velocity field. The main remarks can be summarized as flows:
-Increasing the rotational speed of the gear has a prevalent influence on the growth of moment and consequently on the power loss. This power lost induced a reduction in the efficiency of the gears.
-The presence of the teeth is the principal source of the increase of the pressure gradients especially on the inter-teeth space. This rise induces the increase of the effect of the aerodynamic trail which

amplifies the resistance of the surrounding fluid against the rotation of the gear.
-Gear lubrication type has an important influence on the windage power loss.
Future work will focus on a three dimensional model of the gear set. The objective will be the shape optimization of the gear body in order to minimize the windage power loss.

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