

# Churning losses of spiral-bevel gears at high rotational speed

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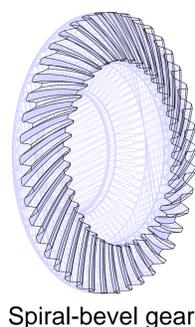
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## Context: Improving the efficiency of helicopter gearboxes

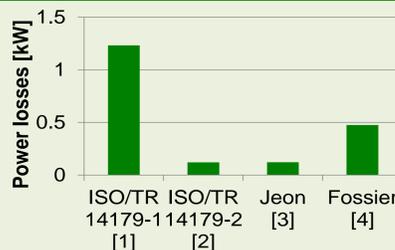
In the general context of the reduction of energy consumption, gearbox efficiency has become a major issue in aeronautic applications. The power losses in gear units can be divided into two parts: i) the load-dependent power losses and ii) the load independent (or no-load) power losses. As far as splash lubricated gears are concerned, churning losses are an important part of no-load losses and an accurate evaluation of this dissipation source is required.



Spiral-bevel gear

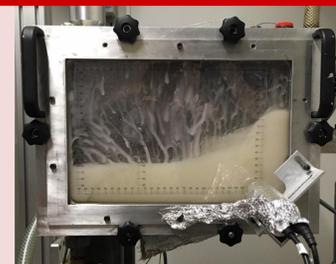
### Literature

Churning losses models for spiral-bevel gears predict very different power losses in the case of helicopter tail gearbox application<sup>†</sup>.



### Churning test rig at LabECAM

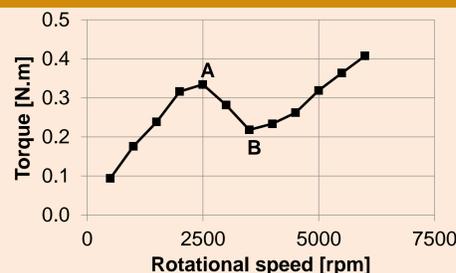
- Losses are measured with a torque meter (accuracy of 0.1% F.S);
- Oil temperature is regulated;
- Housing dimensions : 400x275x85 mm



### Experimental data

Measurements<sup>‡</sup> show the same evolution with speed whatever the bevel wheel dimensions, its immersion depth or oil type.

There is a uncommon behavior of the drag torque: the torque increases with the rotational speed until a local maximum is reached (point A); then the torque decreases and a local minimum is noticed (point B); for higher rotational speed the torque increases.



### Literature

None of the literature models [1,2,3,4] predict this evolution of torque with speed.

**Creation of a new model**

### New no-load losses model for splash lubricated spiral-bevel gears

At higher rotational speeds windage effects become not negligible and tend to displace the free surface of the oil bath resulting in a decrease of gear immersion depth.

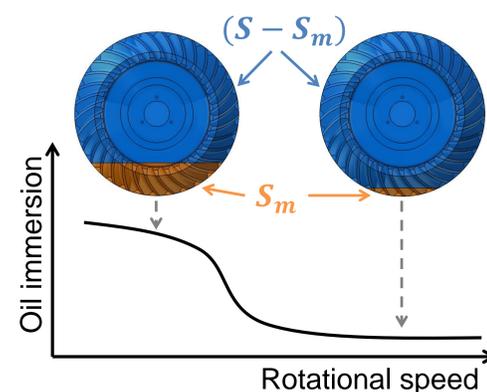
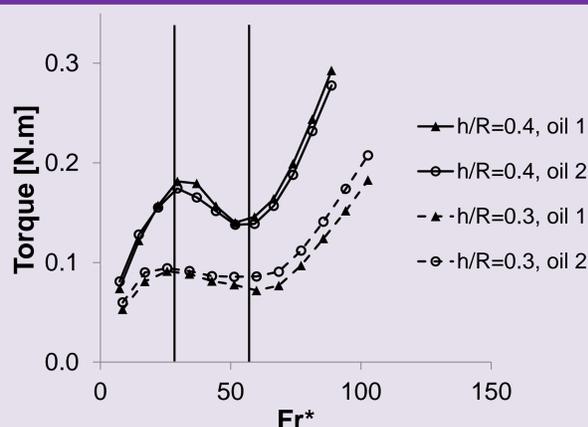
This decrease of oil immersion can be characterized by a Froude number:

$$Fr^* = \frac{\omega R_0}{\sqrt{gh}}$$

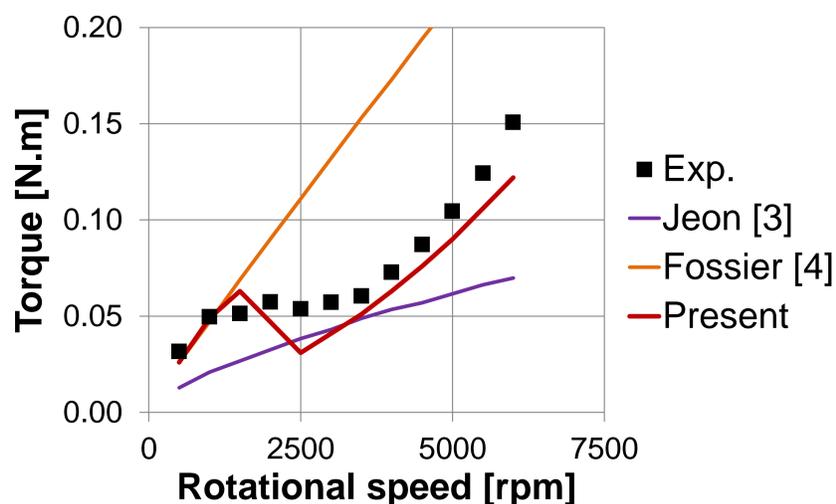
where  $\omega$  is the rotational speed,  $R_0$  the external radius of the gear,  $g$  the gravity acceleration and  $h$  the oil immersion depth. The same evolution of torque with  $Fr^*$  is reproduced with spiral-bevel gears of several size, with different oils and at different immersions.

From this data a **simple model of gear local immersion depth** in the oil sump can be established and therefore be used for the estimation of the torque:

$$T = \underbrace{\frac{1}{2} \rho_{oil} S_m R_0^3 \omega^2 C_{m,churning}}_{\text{Churning part}} + \underbrace{\frac{1}{2} \rho_{air} (S - S_m) R_0^3 \omega^2 C_{m,windage}}_{\text{Windage part}}$$



Gear<sup>†</sup> with 810 kg/m<sup>3</sup> and 18cSt oil at h/R=0.2



### References

- [1] "ISO/TR 14179-1," tech. rep., 2001.
- [2] "ISO/TR 14179-2," tech. rep., 2001.
- [3] S. Jeon, "Improving Efficiency in Drive Lines : an Experimental Study on Churning Losses in Hypoid Axle," PhD thesis, Imperial College London, 2010.
- [4] C. Fossier, "Investigations on the efficiency of truck axles and their hypoid gear set : A thermo-mechanical model", PhD thesis, Université de Lyon (INSA Lyon), 2018.

<sup>†</sup>Spiral bevel wheel of 205 mm outside diameter, 30 mm width and 40 teeth rotating at 3000 rpm in an 850 kg/m<sup>3</sup> and 18 cSt oil at h/R=0.5.

<sup>‡</sup>Spiral bevel wheel of 157 mm outside diameter, 22 mm width and 41 teeth.

