Churning losses of spiral-bevel gears at high rotational speed

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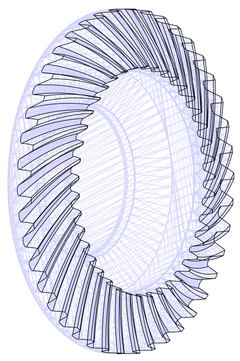
Context: Improving the efficiency of helicopter gearboxes

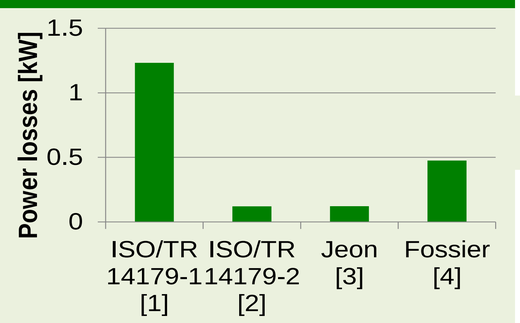
In the general context of the reduction of energy consumption, gearbox efficiency has become a major issue in aeronautic applications. The power losses in gear units can be divided into two parts: i) the load-dependent power losses and ii) the load independent (or no-load) power losses. As far as splash 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

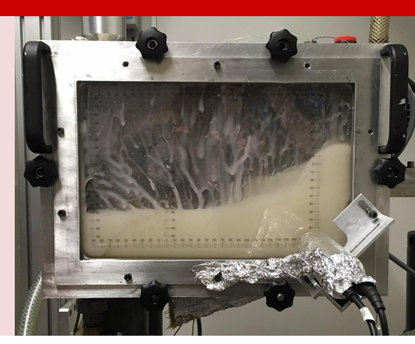
Literature

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



Churning test rig at LabECAM

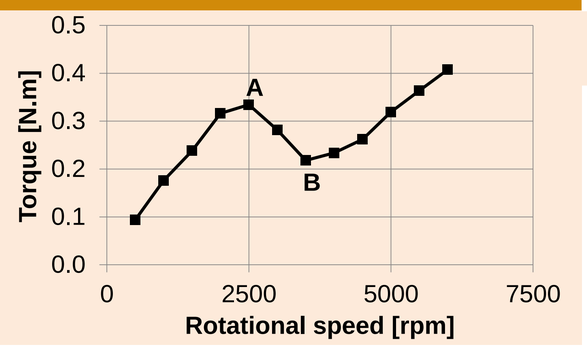
- Losses are measured with a torque meter (accuracy of 0.1% F.S);
- Oil temperature is regulated;
- Housing dimensions : 400x275x85 mm



Experimental data

Measurements‡ 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

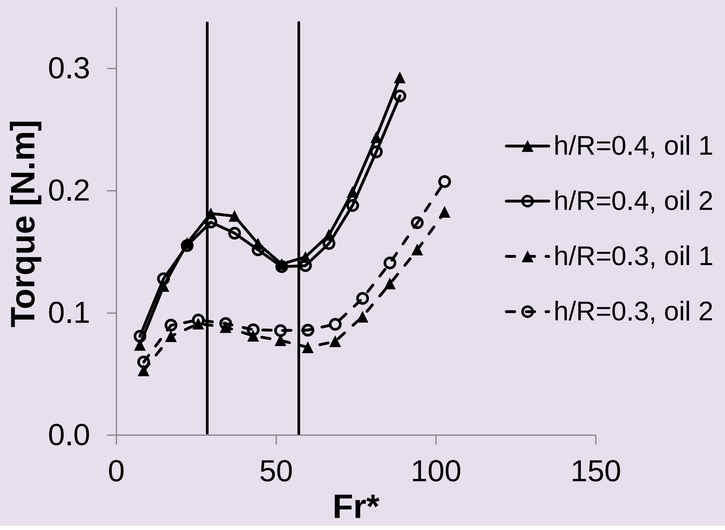
New no-load losses model for splash lubricated spiral-bevel gears

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:

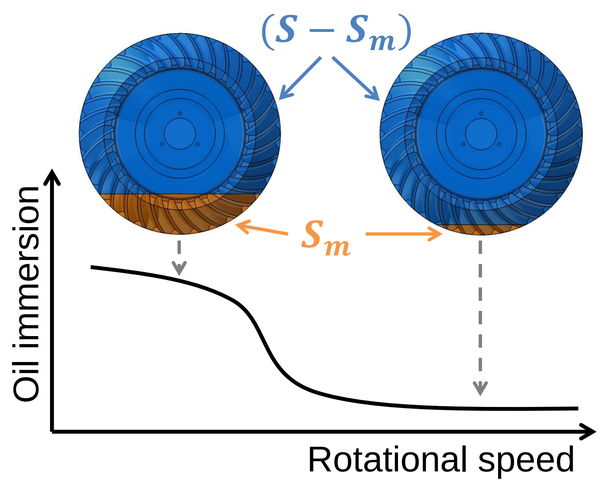
$$Fr^* = \frac{\omega R_0}{\sqrt{gh}}$$

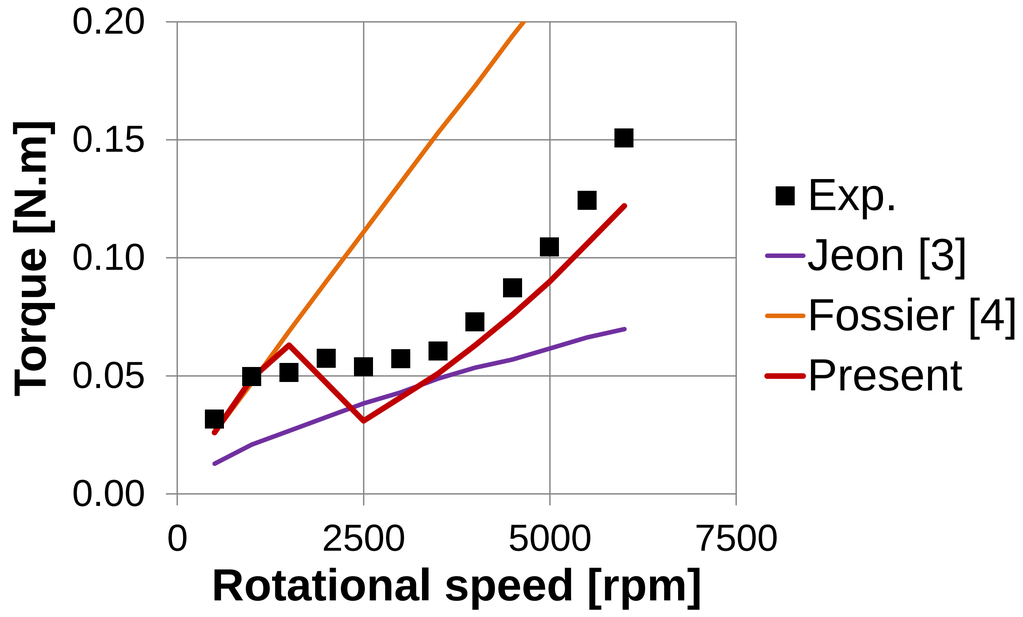
where ω is the rotational speed, R_0 the external radius of the gear, g the gravity acceleration and h the oil immersion depth. The same evolution of torque with Fr* is reproduced with spiral-bevel gears of several size, with different oils and at different immersions.



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‡ with 810 kg/m³ 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.

†Spiral bevel wheel of 205 mm outside diameter, 30 mm width and 40 teeth rotating at 3000 rpm in an 850 kg/m³ and 18 cSt oil at h/R=0.5.

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

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