Impact of improved oils and additives on gearbox power losses

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ABSTRACT

Transmission losses represent 5 to 7% of the fuel energy, as they occur after the engine losses, the use of low-viscosity oils containing Friction Modifiers can save 1 to 2% fuel on manual transmission cars.

Most of the gearbox tests demand costly equipment, restricting the more fundamental research to large corporations. In this work, a relatively simple gearbox rig was used to evaluate the effect of oil viscosity and additives on gearbox losses. The methodology can be easily adapted to larger and actual gearboxes.

The experimental results showed that churning losses increase with the immersion depth elevated by 3. On the other hand, the influence of oil viscosity was lower than the ISO prediction. Combining low-viscosity oils with advanced Friction Modifiers brought the best results.

The test rig can investigate novel oils and additives at a much lower cost and time than current models. The current test rig accounts only for the non-lad losses, but an improved version, considering the effects of loading and temperature, is under construction.

INTRODUCTION

There is a growing interest in improving gearbox reliability and efficiency with optimized lubricants due to the need for machinery with higher efficiency and lower operation costs. From relatively small transmissions for electric vehicles, where the same fluid works as transmission lubricant as well as motor cooling [1], to very large, slow multiplier gearboxes on wind turbines, the challenges and opportunities to develop optimized fluids are of great interest for both academia and industry.

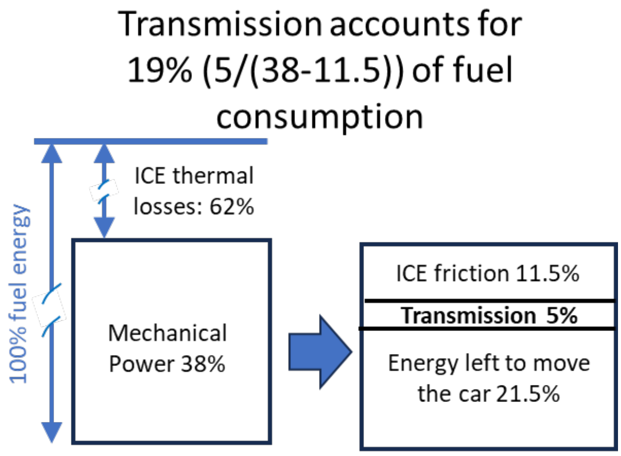


Figure 1. Vehicle power losses and its impact on fuel consumption, adapted from [2].

In passenger cars, the transmission losses account for 5% of the fuel energy [2], but 19% of fuel consumption. As the transmission losses occur on the engine mechanical output, for each kW reduction in the gearbox losses, up to 4 kW gain can be achieved [3]. Improved, low-viscosity lubricants can be one of the paths to reduce the gearbox losses. Despite existence of standardised rig tests like the FZG [4-6], as well as full-size in-house equipment [7]. Both are usually expensive to acquire and operate, restricting the more fundamental research to large corporations.

Gearbox power losses can be divided into load and non-load-dependent. See figure 2.

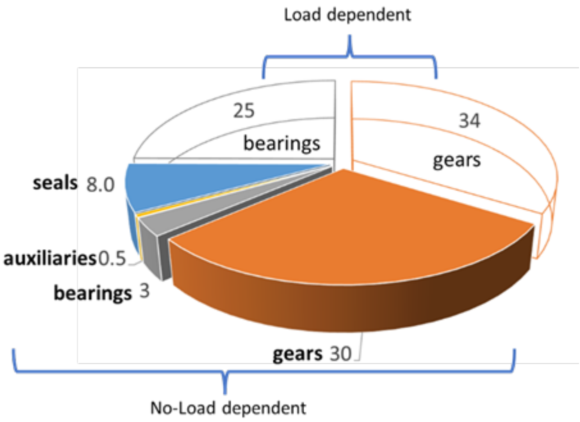


Figure 2. Gearbox percentage losses.

Concli and Gorla [8] published a critical review of available models to calculate the power losses caused by churning, windage and oil squeeze. Hildebrandt et al. [9] did a comprehensive review and classification of numerical, analytical and experimental methods to estimate the gearbox power losses at no-load conditions. Power losses can also be estimated by the ISO equations or using computer models. However, there is still a need to investigate churning losses for different lubricants and especially new lubricant additive. The current paper describes using a simple gearbox. This work uses the rig test and procedure described in a previous author work [10] to investigate churning losses of automotive transmission oils.

GEARBOX TESTER FOR POWER LOSSES

The main gearbox parameters are listed and ahead. See also Figures 2.

- 1:9 gear rate
- Gears module 2, 39 and 13 teeth, 20mm wide
- Roller bearings: SKF W 61902-2RS1
- No load, only inertia and internal losses.
- Test at ambient temperature, 22±1 °C

The main body inertia is the purposely made inertia steel pulley. Gearbox rotational inertia moment is 5.87E-03 kg.m^2. At a given speed, the Inertia pulley accounts for 96.1% of the kinetic energy, the large intermediate gear for 2.1%.

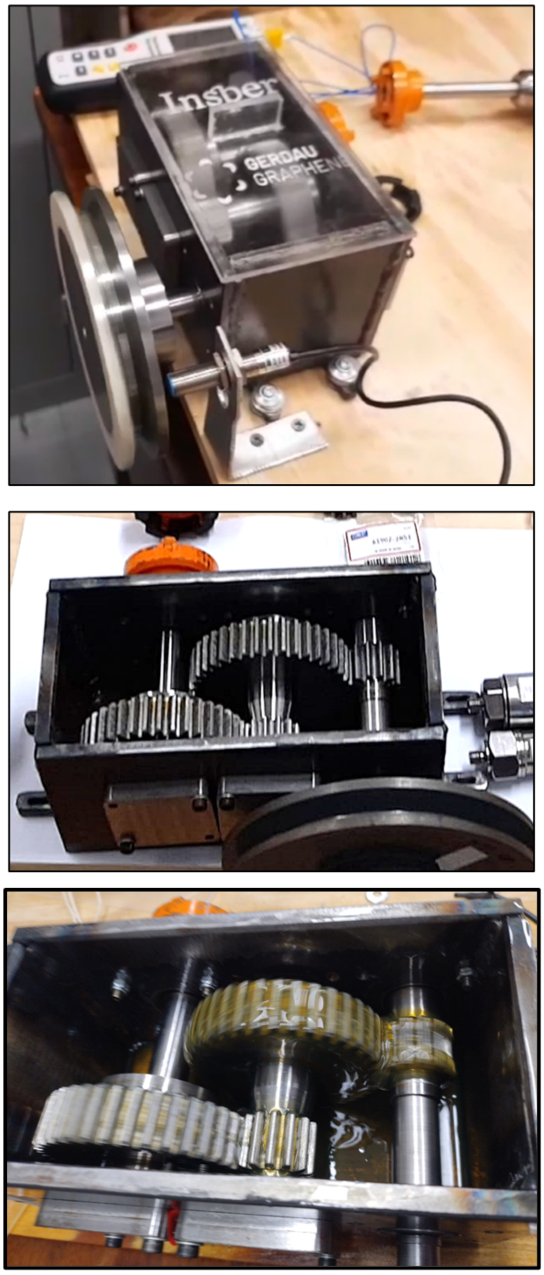


Figure 3. Gearbox test rig.

Table 1 shows the tested oils. All of them are for automotive transmission. The 75W-90 is lubricating oil, OEM approved for manual transmission, gear multipurpose. The other two oils are from MOTUL® marketed for competition and more severe applications.

Table 1 – tested oils

	75W-90	**G300**	**DCTF**
SAE grade	75W-90	75W-90	N.A.
	API GL5, MIL-L-2105D	API GL 4&5, MIL-L-2105D	For double-clutch transmissions
	Semi-synthetic	Synthetic	Synthetic, Ester
additives	EP	EP	N.A.
KV40 [cSt]	129	86.5	33.2
KV100 [cSt]	21.5	14.2	6.5
IV	195	170	154
KV*22°C [cSt]	287	199	71.9

* calculated

Each oil variant was sequentially tested with only 2 drops of oil in each gear pair and then with 50, 100 and 200ml of oil. With 50 ml, the gears barely touch the oil. See figure 4. Crescent volumes of oil, off course, increase the gear depth in the oil and the churning losses. Gears and the case are cleaned with gasoline after each oil variant.

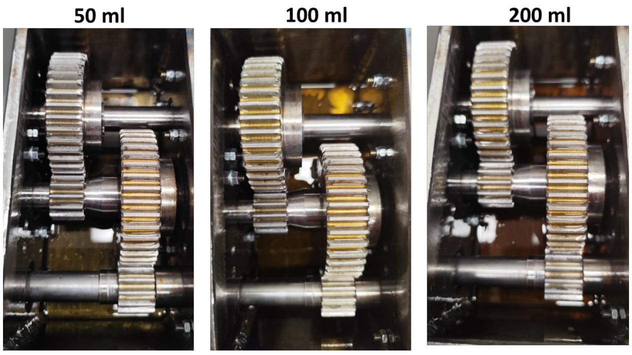


Figure 4. Photos of the gears with different oil volumes. Slow rotation to allow visualization.

For test, the gearbox is put to rotate and then let to decelerate only due to the internal losses. Instantaneous rpm is acquired using a Hall sensor and 4 triggers in the inertia pulley. Test start is considered when the speed rpm reaches 1500 rpm to harmonize the different replications, . calculation of Energy. Figures 5 and 6 show as an example the 15 replications for 75W90, with 50 and 200ml.

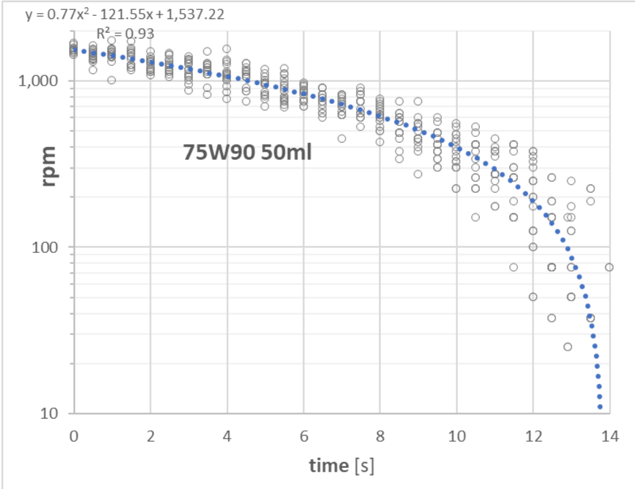


Figure 5. 15 replications with 75W-90, 50 ml and the calculated trend line.

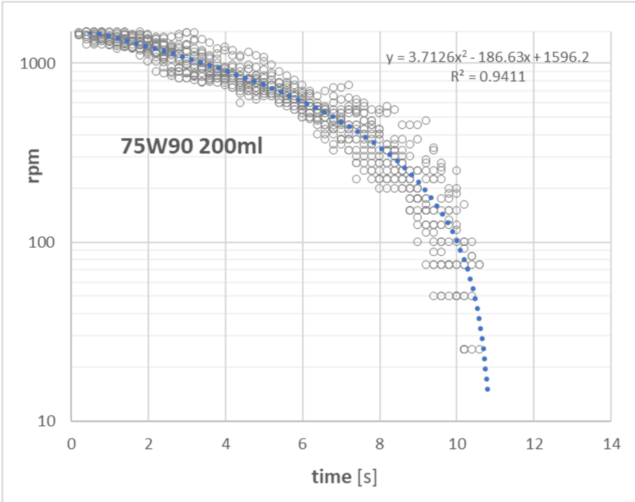


Figure 6. 15 replications with 75W-90, 200 ml and the calculated trend line.

The speed over time is approximated using a 2nd-order polynomial. The instantaneous Rotational energy is calculated by the Rotating Moment of Inertia x Speed, and the Power losses are calculated by dK / dt. Figure 7 summarizes the methodology [10] used in the current work.

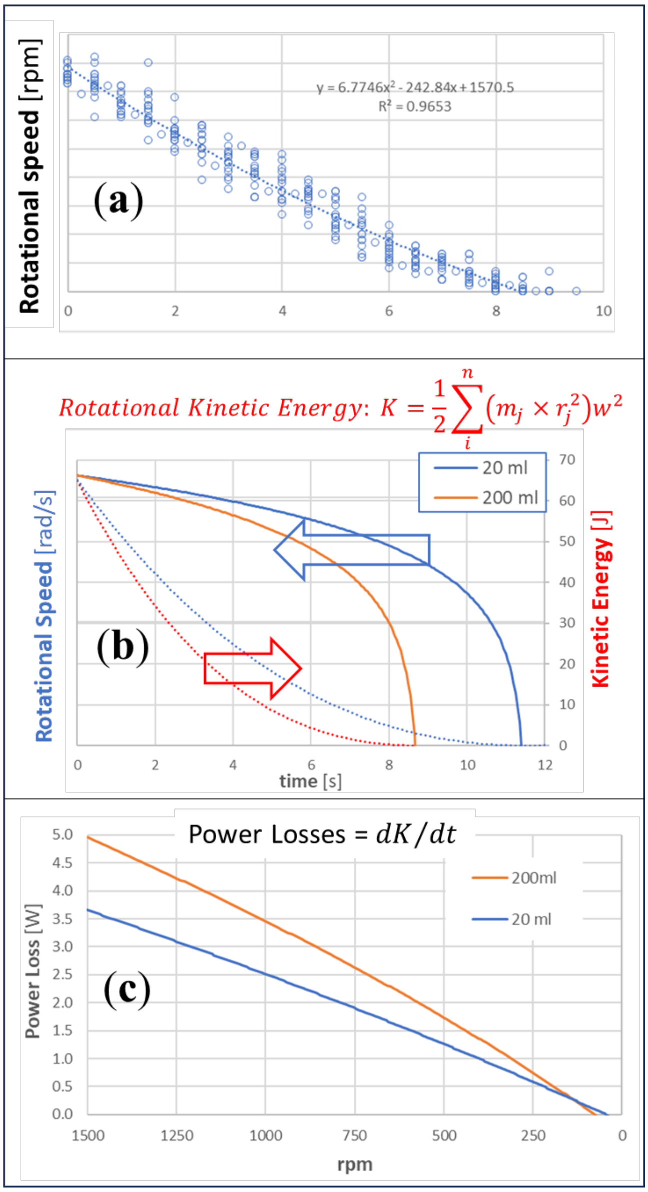


Figure 7. Power loss calculation: (a) instantaneous speed is interpolated by 2nd-order polynomial. (b) Instantaneous Kinetic energy is calculated using the rotational inertia moment. (c) Power loss is calculated by deriving the Kinetic Energy. Adapted from [10].

RESULTS

Figures 8 and 9 show the 75W-90 test replications, respectively for 50 and 200ml. The interpolated polynomial of 2nd order shows correlation higher than 0.9. See details and discussion in [10]. As expected, time to stop decreases with large volume oil due to the higher churning losses. At 1500 rpm, reducing the oil volume from 200 to 100 ml reduced the power losses in 13.6%.

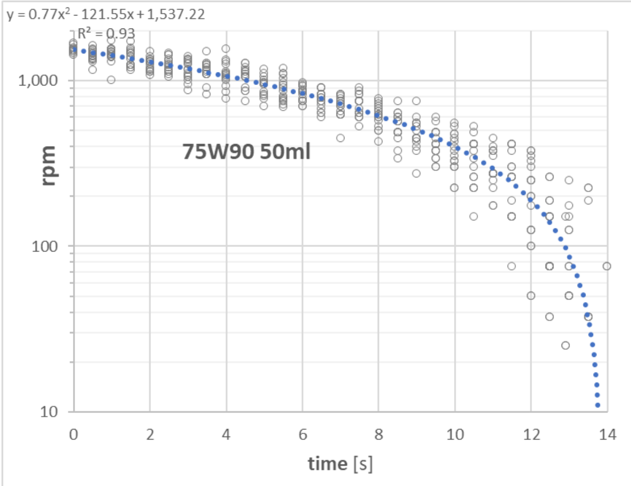


Figure 8. 75|W90, 50 ml tests.

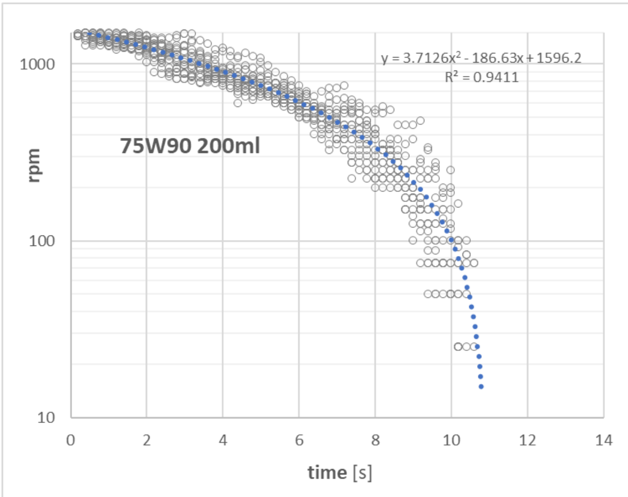


Figure 9. 75|W90, 200 ml tests.

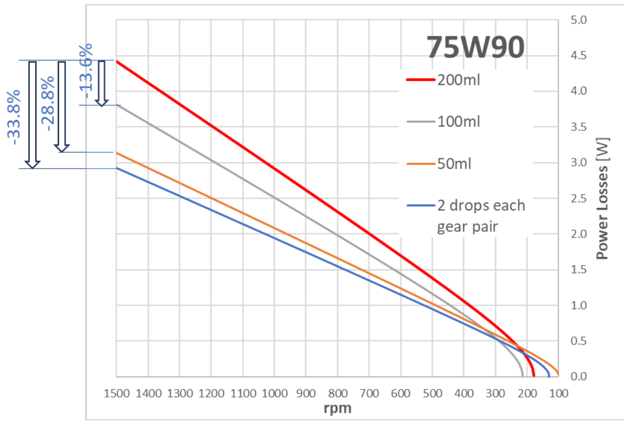


Figure 10. Power losses with different oil volumes, 75|W90.

At 1500 rpm, the premium G300 75W-90 oil presented around 10% lower power losses than the standard one (see figure 11).

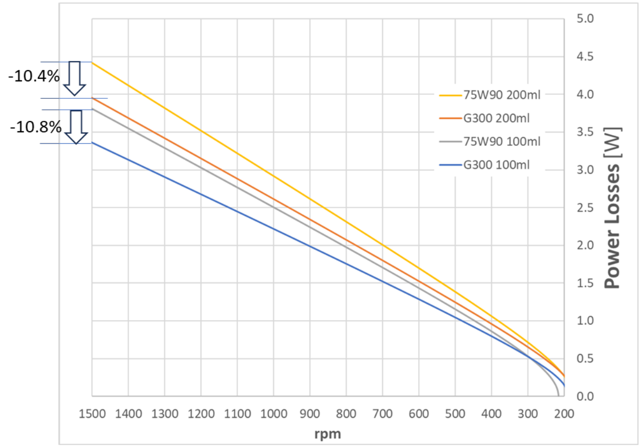


Figure 11. Power losses with the 75W-90 oils.

Figures 12 to 14 compare the power losses of the tested oils. No significant difference was observed with only two oil drops in each gear pair. With 50 ml, the G300 oil shows slightly higher losses. Its significantly lower viscosity (despite the same SAE grade) probably increases the contact friction, while with 100 and 200ml, its lower viscosity reduced the churning losses, resulting in around 10% lower power losses.

Compared to the 75W90, the much lower viscosity DCTF oil showed, as expected, less power losses, around 35%, with 100 and 200ml volumes. Different from the G300 oil, the DCTF oil leads to power losses reduction, even with lower oil volumes, which suggests the presence of Friction Modifier additives.

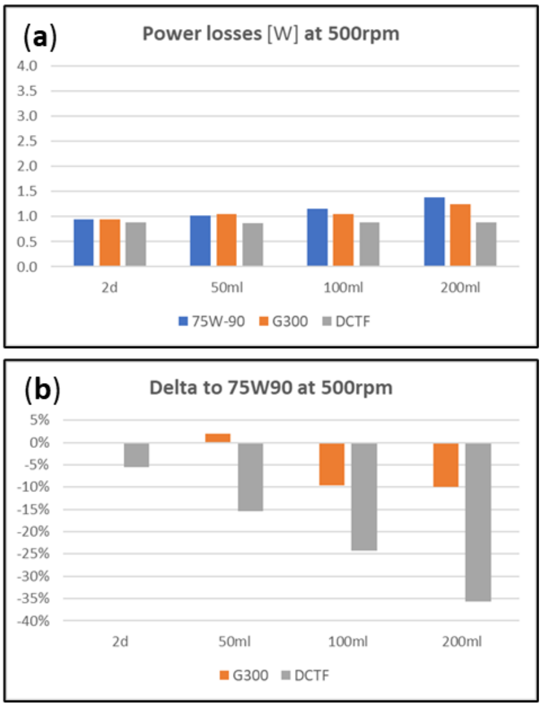


Figure 12. Power losses at 500 rpm. (a) absolute values. (b) delta in comparison to the 75W-90.

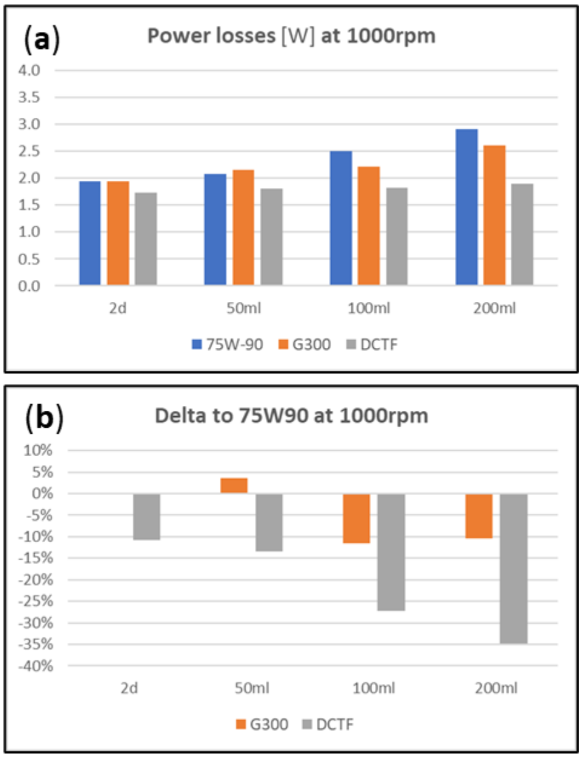
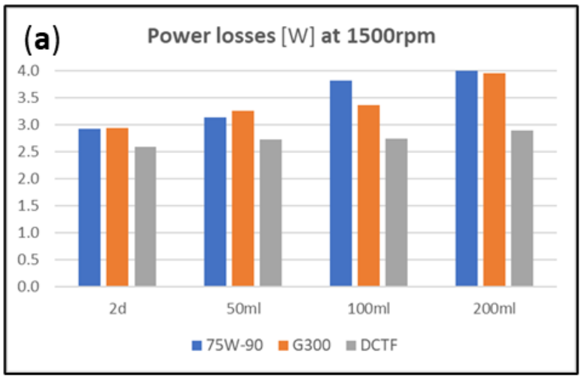


Figure 13. Power losses at 1000 rpm. (a) absolute values. (b) delta in comparison to the 75W-90.



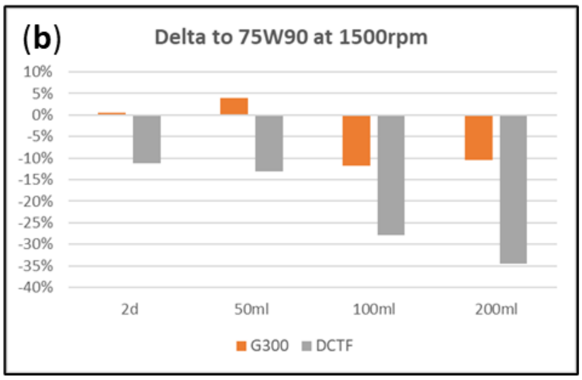


Figure 14. Power losses at 1500 rpm. (a) absolute values. (b) delta in comparison to the 75W-90.

CONCLUSIONS

The develop test gearbox test ring showed good reliability and allowed the test of different oil viscosities and potentially also of the effect of friction modifier additives.

As expected, large oil volumes increase the churning losses. In the standard 75W-90, reducing the oil volume from 200 to 100 and 50 caused 13.6 and 28.8 lower power losses, respectively.

Compared with the standard 75W-90 oil, the premium G300 oil presented around 10% lower power losses with 100 and 200ml volume.

The much lower DCTF showed lower power losses in all tested conditions, suggesting the presence of FM additives.

REFERENCES

1. Canter, N. Tribology and Lubrication for E-Mobility: Findings from the Inaugural STLE Conference on Electric Vehicles, 2022
2. Holmberg, K., Andersson, P., Erdemir, A. Global energy consumption due to friction in passenger cars, Tribology International, V. 47, 2012, p. 221-234, ISSN 0301-679X, https://doi.org/10.1016/j.triboint.2011.11.022.
3. Michaelis, K., Hohn, B., Hinterstoisser, M. Influence factors on gearbox power loss. Industrial Lubrication and Tribology 63/1 (2011) 46–55. [DOI 10.1108/00368791111101830].
4. ISO 14635-1:2023 Gears — FZG test procedures. Part 1: FZG test method A/8,3/90 for relative scuffing load-carrying capacity of oils
5. ISO, "Gears-Thermal Capacity – Part 1: Rating gear drives with thermal equilibrium at 95°C sump temperature," ISO/TR 14179-1, 2001.
6. ISO, "Gears-Thermal Capacity – Part 2: Thermal load-carrying capacity," ISO/TR 14179-2, 2001.
7. Fernandes, C.; Marques, P.; Martins, R.; Seabra, J. Gearbox power loss. Part II: Friction losses in gears, Tribology International, V 88, 2015, p. 309-316, ISSN 0301-679X, https://doi.org/10.1016/j.triboint.2014.12.004
8. Concli, F., Gorla, C. Windage, churning and pocketing power losses of gears: different modeling approaches for different goals. Forsch Ingenieurwes (2016) DOI 10.1007/s10010-016-0206-9
9. Hildebrand, L. et al. Classification of numerical, experimental, and analytical approaches for gearbox oil flow and no-load gear power loss. Engineering Science and Technology, an International Journal, 2024, ISSN 2215-0986, https://doi.org/10.1016/j.jestch.2024.101661
9. Guegan, J., Southby, M. & Spikes, H. Friction Modifier Additives, Synergies and Antagonisms. Tribol Lett (2019). https://doi.org/10.1007/s11249-019-1198-z.
10. Tomanik E, Getschko N, Papoulias G, Lemos B, Silva J. Development of a gearbox test rig to evaluate the impact of oil formulations on churning and friction losses. Proc. of the Inst. of Mec. Eng., Part J. 2024;0(0). doi:10.1177/13506501241301833.