

Low Loss Gears

by: B.-R. Höhn, K. Michaelis and A. Wimmer, Technical
University of Munich, FZG

American Gear Manufacturers Association



TECHNICAL PAPER

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Bernd-Robert Höhn, Klaus Michaelis and Albert Wimmer, Technical University of Munich, FZG

[The statements and opinions contained herein are those of the author and should not be construed as an official action or opinion of the American Gear Manufacturers Association.]

Abstract

In most transmission systems one of the main power loss sources is the loaded gear mesh. High losses there lead to high energy consumption, high temperatures, early oil ageing, increased failure risk and high cooling requirements. In many cases high efficiency is not the main focus and design criteria as load capacity or vibration excitation predominate the gear shape design. Those design criteria mostly counteract highest possible efficiency.

The influences of gear geometry parameters on gear efficiency, load capacity, and excitation are shown. Thereof design instructions can be derived which lead to low loss gears with equivalent load capacity. According to the designers preference these guidelines can be followed to a varying extent which leads to more or less unconventional, but more efficient gear design.

Low loss gears can save substantial energy in comparison to conventional gears. The power loss reduction is dependent on the operating conditions and can add up to some 70 % of the power loss of conventional gears. Such low loss gears have significant advantages in terms of energy consumption, heat development, and cooling requirements. For same load carrying capacity and adequate vibration excitation they have, however, to be designed with increased centre distance or face width.

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LOW LOSS GEARS

B.-R. Höhn, K. Michaelis, A. Wimmer
FZG (Gear Research Centre), Technical University of Munich, Germany

1 INTRODUCTION

Power losses occur in different components of a gearbox. Each gearbox element produces some power losses. The total power loss is the sum of the power losses of the single elements. Basic gearbox elements are bearings, gears, and seals. Their power losses are usually individually mentioned. Other potentially integrated elements, such as clutches or oil pumps, also produce losses, their power losses are merged in auxiliaries. According to their types losses can be further divided into no-load losses and load-dependent losses. Equation (1) shows the summation of all power losses P_V in a typical gearbox. Losses in bearings and gears usually predominate in a gearbox.

No-load losses comprise all losses which also exist when a gearbox is not transmitting power but rotating without power output. No-load losses derive from seals or from windage and churning etc.

Load dependent losses occur only in elements

which carry the transmitted power or portions of it, i. e. bearings and gears. They encompass all power losses that vary with the power transmission in the concerned element. They evolve when two surfaces under pressure move relatively to each other. Power losses in this case depend on the acting force between the solids, the sliding speed, and on the coefficient of friction established in the contact of the surfaces.

For the composition of total power losses P_V in a gearbox the following four main components are investigated:

- no-load power losses in bearings
- load dependent power losses in bearings
- no-load power losses in gears
- load dependent power losses in gears

The investigations are based on calculations for which the FVA-software "WTplus" [1], "STplus" [13], and "RIKOR" [10] is used.

Index	Z: gears	L: bearings	D: seals	X: auxiliaries
	$\underbrace{\hspace{2cm}}$ $P_V = P_{VZ0} + P_{VZP}$	$\underbrace{\hspace{2cm}}$ $+ P_{VL0} + P_{VLP}$	$\underbrace{\hspace{2cm}}$ $+ P_{VD}$	$\underbrace{\hspace{2cm}}$ $+ P_{VX}$
	$\downarrow$ $\downarrow$	$\downarrow$ $\downarrow$	$\downarrow$	$\downarrow$
0: no-load				
P: load dependent				

(1)

2 GEARING MODEL

For the calculations a gearing model is necessary. This is aligned to a existing test rig gearbox. Figure 1 (overleaf) shows the main data of the reference gearbox model and a transverse section of the reference gear shape on which the calculations are based. Starting from that gearing single modifications are applied in order to investigate the influence of one single parameter.

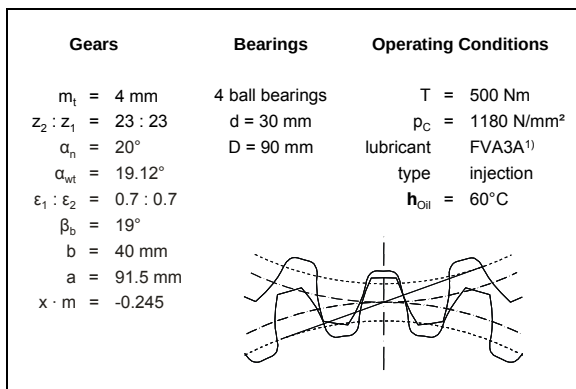


Figure 1: Main data of reference gearing model and gear cross section.

¹⁾ mineral oil ISO VG 100 with 4% sulphur-phosphorus additive (Anglamol 99)

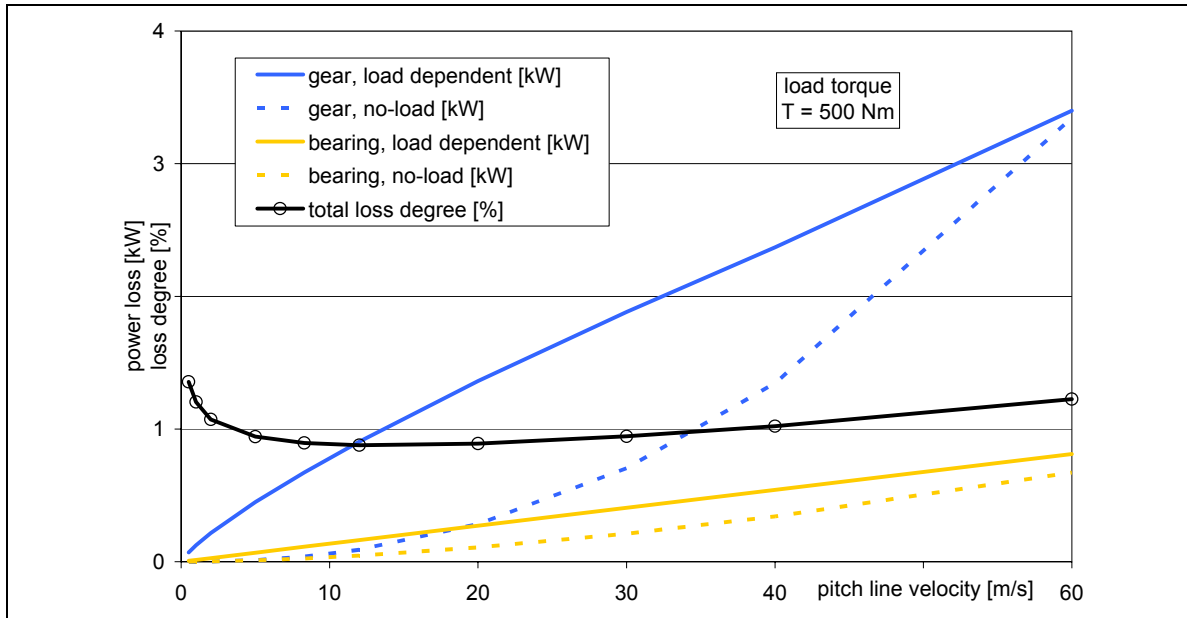


Figure 2: Power loss composition in the model gearbox vs. pitch line velocity.

3 POWER LOSS PORTIONS

In Figure 2 the amount of power losses for each of the four considered components is depicted versus the rotational speed at the operating conditions given in Figure 1. The investigation of power loss composition in Figure 2 is done with example of a modified reference gearing with spur gears ($\beta = 0^\circ$). It shows that the gear no-load losses increase progressively with speed, while the other components seem to depend fairly linearly on the speed. For the vast range of rotational speeds the main portion of losses are load dependent gear losses. Only for very high speeds no-load losses prevail, though the load dependent gear losses may still occupy an important portion. Bearing losses have only subordinate portions of the total losses throughout the whole speed range. In addition, the sum of these losses is rated against the power transmission which results in the loss degree ζ , the complement of the degree of efficiency η :

$$\zeta = \frac{P_V}{P_{in}} = 1 - \eta \quad (2)$$

with P_V total power loss [W], P_{in} input power [W], η degree of efficiency [-].

The loss degree ζ shows a significant minimum

between 10 and 20 m/s rotational speed. This reflects the basic changes in the coefficient of friction in the mating gears from the mixed lubrication regime for low speeds towards elasto-hydrodynamic (EHD) friction at higher speeds. Depending on the geometry of the transmission and the operating conditions this minimum occurs at different speed ranges.

The prevailing power loss portion is as well dependent on the operating conditions. However, in order to minimise the power losses a focus must always be set onto load dependent gear losses since their portion is always significant, but with increasing speed no-load losses of gears need to be considered increasingly.

4 BASICS OF LOAD DEPENDENT GEAR LOSSES

The load dependent losses depend on both gear and lubricant properties. The calculation of load dependent power losses in gears is based on the law of friction according to Coulomb (3)

$$F_R = \mu \cdot F_N \quad (3)$$

$$P_{VP} = F_R \cdot v_g = \mu \cdot F_N \cdot v_g \quad (4)$$

with F_R friction force [N], μ coefficient of friction [-], F_N normal force [N], P_{VP} load dependent power loss [W], v_g sliding speed [m/s].