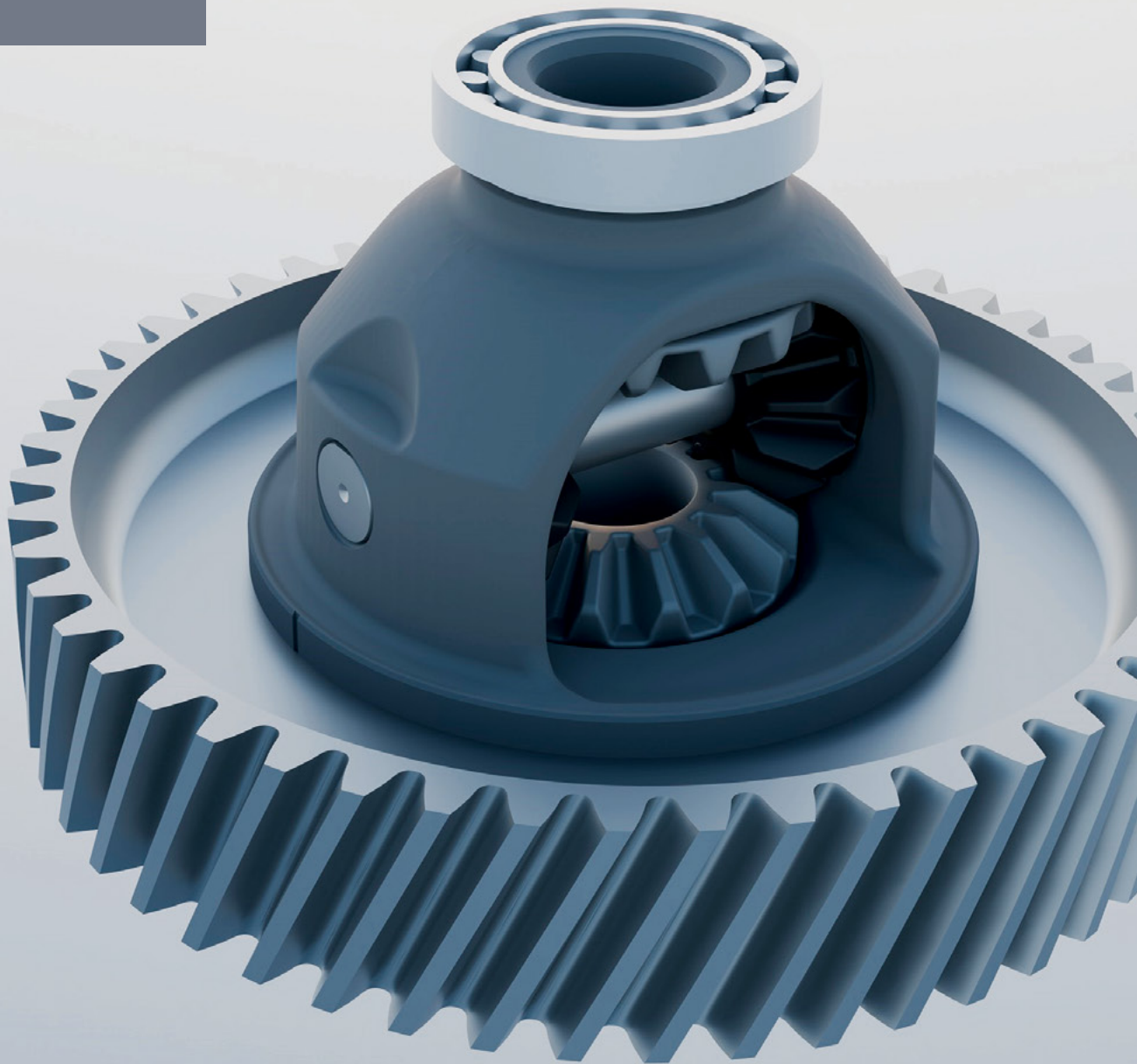


MTZ extra



TRANSMISSION

Optimization of Gear Teeth in Electric Axle Drives



Hirschvogel
Group



© Hirschvogel

Optimized Gears for Highest Performance

Electric powertrains place high demands on modern gearbox development due to the combination of high rotational speeds, limited installation space, lubrication conditions, and strict NVH requirements. To meet these demands, Hirschvogel uses a holistic, system-oriented design strategy for the geared transmission components. Unlike conventional drives with combustion engines, efficiency and acoustic properties are of high importance alongside traditional strength considerations.

Through the intelligent combination of targeted geometry optimization and modern manufacturing technologies, the typical trade-offs in gearbox development between efficiency, strength, and noise behavior can be significantly reduced. A system-oriented approach that

considers the interactions between gearing, bearings, and gear bodies opens up new degrees of freedom in gear design and significantly enhances the performance of electric axle drives.

With a new process for developing geared components, the Hirschvogel

Group is strategically leveraging the potential of forged parts to enhance drivetrain performance [1]. In this process, the individual components are not only considered in isolation but analyzed and optimized in terms of their interactions within the over-

WRITTEN BY



Dr.-Ing. Uwe A. Rütjes
is Product Manager at Hirschvogel Umformtechnik GmbH in Denklingen (Germany).

all system. The following sections illustrate selected correlations in the design of various transmission components and present proposed solutions. The focus is on the final reduction stage of a gearbox, as this stage is particularly critical with regard to efficiency, wear, and noise behavior.

SHAPE-OPTIMIZED COMPONENTS FOR IMPROVED EFFICIENCY

The efficiency of the mechanical drive system is becoming increasingly important, as it has a significant impact on the range of battery-electric vehicles. Even small improvements in overall system efficiency can noticeably affect the practically usable range. At the same time, noise behavior is playing an increasingly important role in customer perception. The absence of acoustic masking by the engine means that noises that would go unnoticed in conventional drives can be perceived as disturbing in electric vehicles.

These boundary conditions result in a complex interaction between efficiency, mechanical strength, and NVH behavior (Noise, Vibration, Harshness). Every change to the gear geometry affects all three aspects simultaneously, often in opposing directions. For example, measures to improve strength can worsen efficiency or negatively impact noise behavior.

In addition to the classic strength verifications for surface durability (pitting) and fatigue strength (tooth root strength), additional stresses must be considered for highly loaded gears. Modern transmissions operate under extreme loads, requiring particularly careful design. The final reduction stage of a gearbox is also characterized by increased wear due to high torques and a severely limited installation space, which further complicates the design process.

For the analysis of a system, the gears of the final reduction stage in a gearbox, together with the bearings, is considered. The analysis

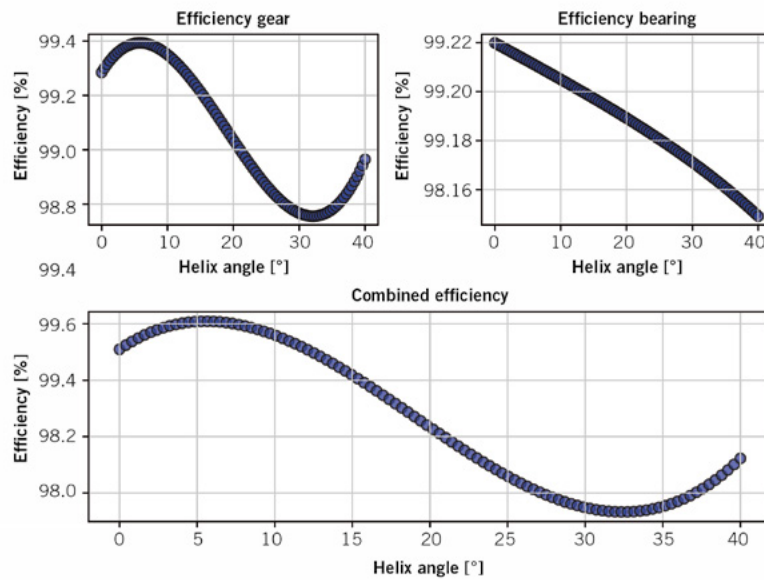


FIGURE 1 Influence of gear design on efficiency (© Hirschvogel)

combines the evaluation of both the gear mesh and the bearing arrangement. In parametric studies, the helix angle (β) and gear geometries were varied while keeping the installation space constant. The strength verification was based on ISO 6336 and included pitting resistance, tooth root strength (fatigue fracture), and flank fracture. In addition the efficiency was calculated both locally for the gear mesh and for the entire system, including the bearings. FIGURE 1 illustrates the relationship between gearing and efficiency.

FIGURE 1 (top left) illustrates, as an example, the influence of the helix angle on the efficiency of a gear mesh. In this analysis, the helix angle was varied while the pressure angle, number of teeth, and center distance were kept constant. It can be seen that the efficiency of the gear mesh depends on the helix angle. The reason for this is the relative velocities on the tooth flank and the associated friction.

In FIGURE 1 (top right), the bearing efficiency is shown as a function of the variation in the gear's helix angle. Changing the helix angle also alters the axial

forces acting on the bearings, which affects their efficiency. When both aspects are combined, FIGURE 1 (bottom), a clear dependency of the overall system efficiency on the gear design becomes evident.

In modern component designs, the helix angle of a gear is typically increased to enlarge the contact ratio and improve load-carrying capacity. However, as shown, this has a negative impact on the overall efficiency. For this example, the efficiency reaches a minimum between $\beta = 30^\circ$ and $\beta = 35^\circ$.

This simple analysis can illustrate the trade-off. The design of a gear must already take numerous boundary conditions into account, and considering additional parameters significantly affects the results.

To analyze the various gear parameters, a comprehensive parametric study was carried out while keeping the available installation space unchanged. TABLE 1 lists the results for three selected components as examples, illustrating the impact of the parameter changes.

	Gear design 1	Gear design 2	Gear design 3
Tooth root strength	100.00 %	88.93 %	90.61 %
Pitting resistance	100.00 %	97.93 %	99.57 %
Efficiency gear	100.00 %	100.13 %	100.08 %
Efficiency overall	100.00 %	103.27 %	105.29 %

TABLE 1 Gear design comparison (© Hirschvogel)

Gear design 1 serves as the reference variant, optimized for maximum strength without accounting for efficiency or other parameters. All of its characteristics are normalized to 100 % for a better comparability. This variant represents a gearbox design approach where load-carrying capacity is the dominant criterion.

Gear design 2, on the other hand, has a goal to achieve an optimal compromise between gear efficiency and pitting resistance. In this variant, the focus was on the efficiency of the gear mesh itself, while interactions with the bearings were not yet explicitly considered. This corresponds to a first step toward an efficiency-oriented design.

Finally, gear design 3 is a variant focused on pitting resistance and the overall system efficiency, including the bearings. This variant explicitly considers the interactions between gearing and bearing arrangement and thus represents the systemic optimization approach presented here.

For gear design 2, the gear mesh efficiency was improved, while the calculated pitting resistance slightly decreased. Tooth root strength, however, deteriorated significantly. Over-

all, the system efficiency including the bearings improved considerably due to the enhanced gear mesh efficiency.

In the next step, the evaluation was shifted from considering gear mesh efficiency alone to assessing overall system efficiency together with pitting resistance. As a result, a variant was selected in which the gear mesh efficiency is still better than in the baseline design, while the overall efficiency improved by 5 %. With regard to the efficiency-optimized variant, both pitting resistance and tooth root strength were further improved. This surprising result highlights the significant benefits of a systemic approach. However, it is important to note that tooth root strength is still about 10 % lower compared to the baseline design.

An optimized root geometry, as proposed by Brömsen [2] and discussed already for a long time, can provide improvement. A schematic representation of this optimized geometry is shown in **FIGURE 2**. By optimizing the root geometry, stresses can be reduced in real-world applications by up to 20 to 30 %. Observations even show that these optimizations can overcompensate for the reduction in tooth root strength. These possibilities

have long been successfully applied to other types of gearing [3].

Thanks to new manufacturing methods, these optimizations are now also feasible for cylindrical gears. Previously, these geometries were difficult to achieve from a manufacturing standpoint. Modern forming processes combined with subsequent hard finishing enable cost-effective production, opening up new degrees of freedom in design and providing a comprehensive solution for all requirements.

PERCEPTIVE PROGRESS IN COMPONENT DESIGN

Considering safety factors alone is often insufficient. The noise behavior in real-world operation is of critical importance, as well. It is influenced by impact, displacement, and parameter excitations [4]. In addition to microgeometry the gear body stiffness and bearing arrangement affect NVH characteristics. The presented optimizations of the root geometry also influence parameter excitations, that is, stiffness variations in the gear mesh. Positive effects of an optimized root geometry on excitation behavior have already been observed.

The influence of the gear body on structure-borne sound transmission, which plays a decisive role in NVH behavior, should not be underestimated. Shape-optimized solutions for the gear body offer an effective way to disrupt the gear mesh frequency, such as a faceted gear body, **FIGURE 3**.

At the face sides of the gears, natural vibrations cause movements that affect noise generation and running behavior. These natural vibrations and movements vary depending on the geometry of the gear web. Although simulations show that the natural frequencies of the gear are only slightly affected, the changing yield of the teeth has a positive effect on noise behavior.

SUMMARY

The design of the final reduction stage in electric axle drives requires a holistic, system-oriented approach that considers efficiency, mechanical strength, and NVH characteristics. Isolated optimization of individual components or parameters typically leads to sub-

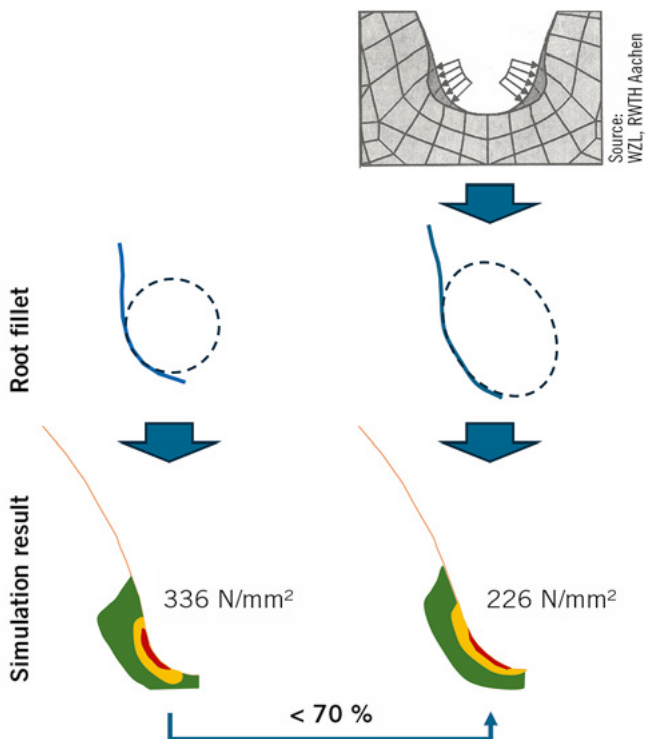


FIGURE 2 Effect of the root fillet on stresses (© Hirschvogel)

optimal overall results. Only by systematically accounting for the complex interactions between gearing, bearings, gear body, and other components, truly optimal solutions can be achieved.

The results presented here demonstrate that the typical trade-offs between efficiency, strength, and noise behavior can be significantly mitigated through intelligent shape optimization of components and the use of tailored manufacturing processes. In particular, the combination of optimized root geometry, system-level efficiency analysis, and shape-optimized gear bodies opens up new possibilities that would not be accessible in conventional design approaches. Thanks to advanced forming technologies, especially precision forging, these shape optimizations can also be implemented economically at Hirschvogel Group.

REFERENCES

[1] Rütjes, U. A.: Rethinking Gears: From Idea to Virtual Assembly. 35th Aachen Colloquium Sustainable Mobility, Aachen, 2025

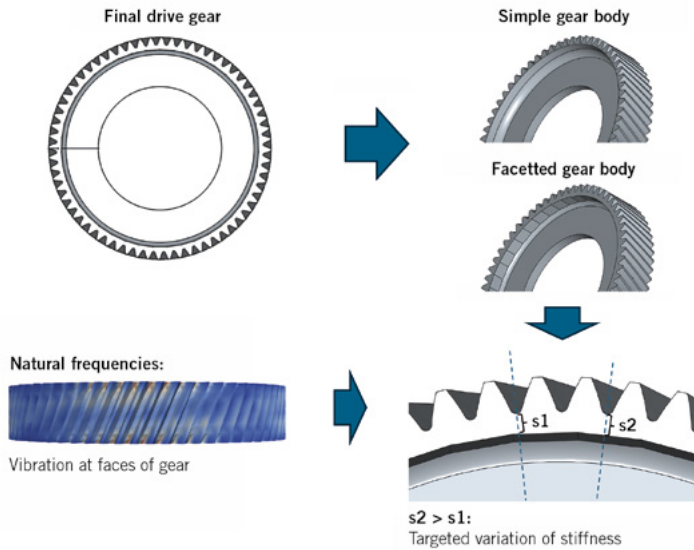


FIGURE 3 Optimization of the gear body to improve running and noise behavior (© Hirschvogel)

[2] Brömsen, O.: Steigerung der Zahnfußtragfähigkeit von einsatzgehärteten Stirnrädern durch rechnerische Zahnfußoptimierung. Aachen: Shaker Verlag, 2005

[3] Rütjes, U. A.: Differential bevel gears - the overall system as a result of optimized compo-

nents. Innovations in bevel gear technology: March 14-15, 2018. Aachen: Apprimus Verlag, 2018

[4] Gacka, A.: Neue Ansätze bei der Dynamiksimulation von Kegelradgetrieben. Seminar: Innovationen rund ums Kegelrad 2008, WZL-Forum, Aachen, 2008

FOLLOW US:

www.hirschvogel.com



IMPRINT:

Special Edition 2026 in cooperation with Hirschvogel Holding GmbH, Dr.-Manfred-Hirschvogel-Strasse 6, 86920 Denklingen; Springer Fachmedien Wiesbaden GmbH, Postfach 1546, 65173 Wiesbaden, Amtsgericht Wiesbaden, HRB 9754, USt-IdNr. DE81148419

MANAGING DIRECTORS:

Stefanie Burgmaier | Andreas Funk | Alexandra Dambeck

PROJECT MANAGEMENT: Anja Trabus

COVER PHOTO: © Hirschvogel



**Hirschvogel
Group**

Traditionally innovative.

HIDDEN CHAMPIONS



Differential Bevel Gear

Manufactured to transmit large torques, especially in electric vehicles, this part withstands high loads, demonstrates optimum gearing quality, and has minimum surface roughness. And, thanks to the high degree of automation, cost- and resource-optimized production is guaranteed.

You may not be able to see it, but a component of ours is on board almost every car on the road. When it comes to forged and machined components made of steel and aluminum, the quality advantage of Hirschvogel – the greater robustness and durability – is valued just about everywhere.

Discover more for yourself!

hirschvogel.com/product-portfolio

