Increased Load Capacity of Worm Gears by Optimizing the Worm Wheel Bronze

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The lifetime of worm gears is usually delimited by the bronze-cast worm wheels. The following presents some optimized cast bronzes, which lead to a doubling of wear resistance.

Introduction

Worm gears are of growing importance in the field of power transmission. Above all, increasing environmental consciousness, which comes along with strict legal restraints concerning noise control, leads to an increased spread of this low-noise type of gearing. Apart from soundproofness, the great range of gear ratios (i = 5–80) that can be realized within a single stage, is counted among the positive properties.

The low noise levels result from high sliding rates during meshing. High sliding velocities in combination with relatively high hertzian pressures at incomplete initial contact patterns require a pairing of materials that enables running-in. Therefore, material pairings of the combination soft/hard are used in worm gears. Normally, case-hardened steel worms are paired with worm wheels made of CuSn alloys (bronze). This material selection causes wear, which might restrict the lifetime of such gears. On the other hand, wear is of little importance for other types of gears with different material pairings. Thus, strong efforts are made for substituting the bronze with materials of higher wear resistance at lower costs.

Today, research work focuses on materials like steel (Ref. 1) or cast iron (Refs. 2 and 3). The results show that bronze can be partially replaced. However, these materials do not reach the well-balanced properties and the wide range of use of bronze. Consequently, bronze will remain the universal material for worm wheels in the future. The aim of today's work on optimizing the bronze is to increase wear resistance while keeping the specific advantages of the material. This will lead to an improved efficiency and a higher endurance in worm gears.

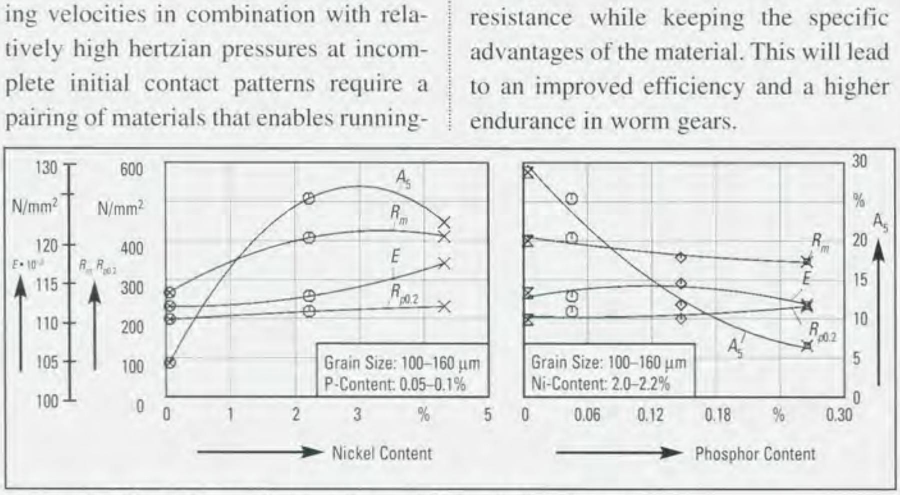

Figure 1—Dependence of strength on nickel and phosphor content.

Copper-Tin Alloys

The bronze GZ-CuSn12Ni according to DIN 1705 (Ref. 4) is seen as the standard worm wheel material nowadays. It is composed of approximately 12% tin, 2% nickel, 0.2% phosphor and 0.2% lead. Copper-tin alloys feature a heterogeneous structure, which consists of α-solid solution (mixed crystals) and an incorporated fraction of (α + δ) eutectoid. The wide solidification range of copper-tin alloys leads to significant segregation, which causes varying concentrations of tin within the α-solid solution.

Adding nickel to the binary copper-tin alloy leads to an increased fraction of eutectoid and consequently improves the strength of the bronze. Phosphor is added for casting reasons, as it reduces the viscosity of the melt and thus improves the foundry characteristics. Phosphor additives higher than 0.075% cause embrittlement. Lead additives enhance machin-

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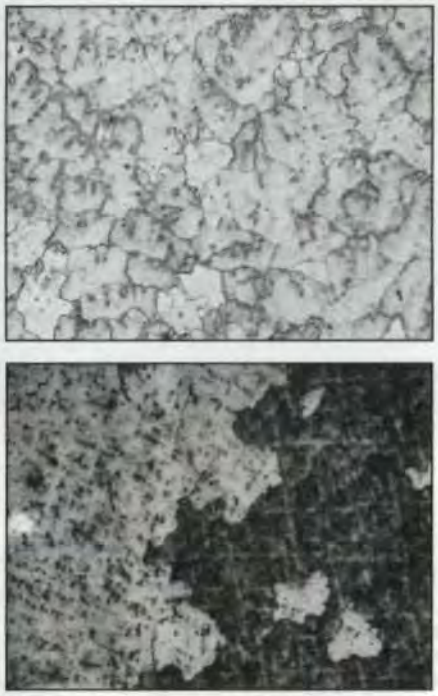

Figure 2—Micrographs of centrifugally cast bronze (top) and conventional continuously cast bronze.

ability and resistance to galling. The lead is not dissolved in the melt but dispersed in the structure. The influence of nickel and phosphor additives on the macroscopic strength is shown in Figure 1.

Young's modulus E, flexural strength A_5, limit of elasticity $R_{p0.2}$ and tensile strength R_m increase unless they reach 3% nickel content. Compared to the rest, the bronze without addition of nickel shows inferior physical properties. Phosphor additives cause embrittlement. Tensile strength R_m and limit of elasticity $R_{p0.2}$ nearly remain the same.

Today, sand casting, centrifugal casting and continuous casting are the most commonly used casting procedures. Centrifugal casting provides an optimal fine-grained and uniform structure. However, the use of centrifugal casting is restricted to medium diameter worm wheels. The minimum outer diameters of centrifugally cast worm wheel rims are in the range of around 100 mm. Smaller diameters are realized by continuous casting. Especially for small worm gears, the wear behavior is of particular importance for the life cycle of the gearing. Continuously cast materials often feature very poor wear behavior, which shows high variance. Large diameter wheel rims are manufactured by sand casting.

Results

Experiments on cylindrical worm gears with a center distance $a = 100$ mm and a gear ratio $i = 20.5$ clarify the influence of the different material parameters on the wear behavior of the bronze. Overall, 13 different bronzes are provided. Based on the standard bronze, GZ-CuSn12Ni (Ref. 4), a specific variation of the parameters medium grain size, nickel content, phosphor content and casting procedure is executed. Among others, a new, specially treated continuously cast bronze is examined and shows a modified crystal structure. Centrifugally cast bronze features circular shaped grains, while the grains of the conventional continuously cast bronze are elongated and aligned in a preferred orientation. The structure of the modified continuously cast bronze is similar to the structure of the centrifugally cast bronze. This was obtained by a specific variation of parameters, like the speed of raking out the slag, the intensity of cooling or the casting temperature. Figure 2 compares the polished micrograph sections of centrifugally cast bronze and conventional continuously cast bronze.

The experiments provide the operational wear rates depending on the output torque T_2 at two different values of rotational speed n_1. As an example, Figure 3 gives the experimentally determined operational wear rates Δm_B of the standard bronze, GZ-CuSn12Ni. They form the reference for the evaluation of the following experiments. The operational wear rate represents the mass loss of the worm wheel in relation to the operating time. Wear of the harder worm is insignificant.

In DIN 3996 (Ref. 5), the wear intensity J_W is defined as the flank loss in normal section related to the wear path of the toothing. Charting the wear intensity by the lubricant film thickness parameter K_W in a double-logarithmic diagram reveals a linear dependence. Figure 4 represents the calculated wear intensity values $J_{W.B2}$ of the standard bronze, GZ-CuSn12Ni.

The marked interval results from a statistical evaluation of the wear intensi-

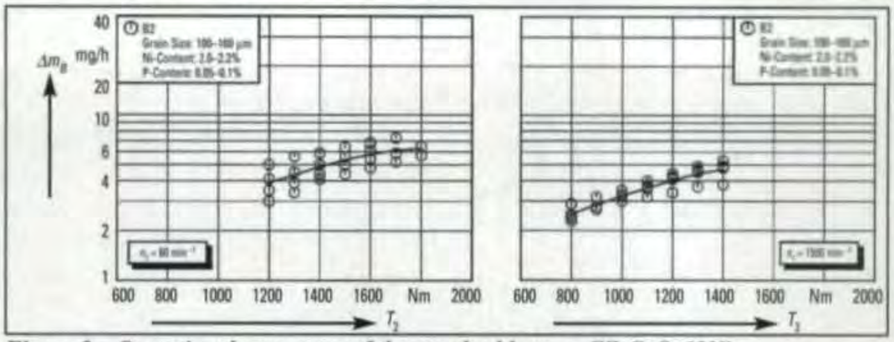

Figure 3—Operational wear rates of the standard bronze, GZ-CuSn12Ni.

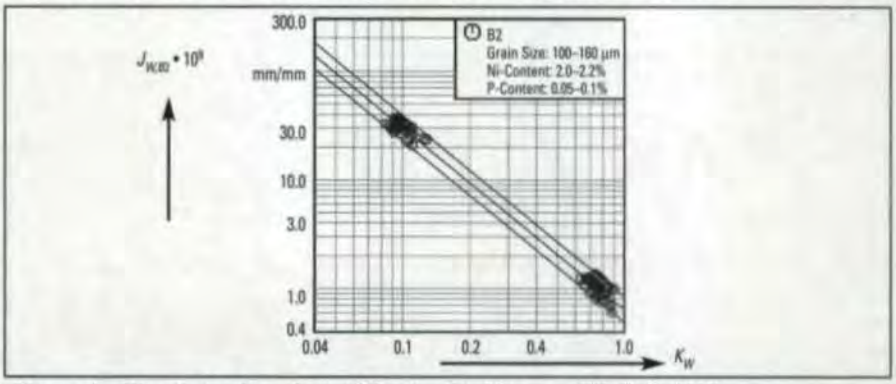

Figure 4—Wear intensity values of the standard bronze, GZ-CuSn12Ni.

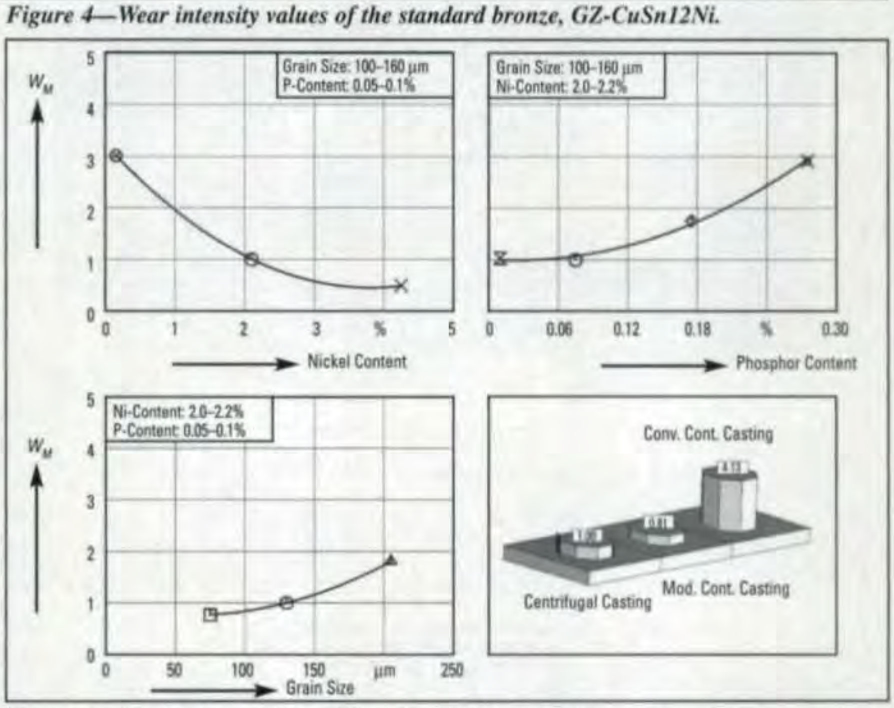

Figure 5—Material wear factor W_M, depending on nickel content, phosphor content, grain size and casting procedure.

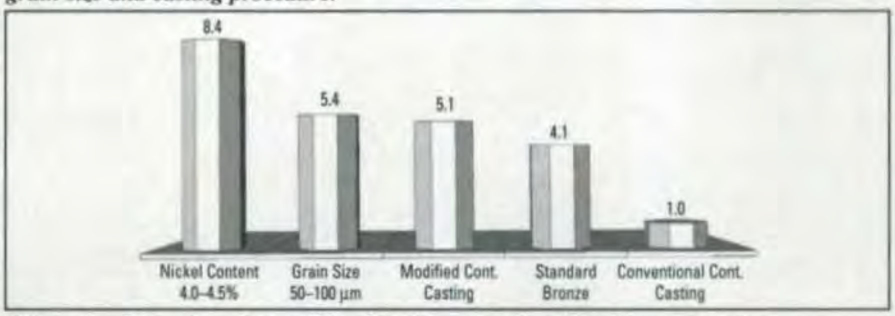

Figure 6—Extension of wear life related to conventional continuous casting.

ties. This interval indicates the range where the wear intensity of the next test run will occur with a probability of 90%. The best-fit straight line gives a reference standard for the other test bronzes. The material wear factor W_M results in

$$W_M = \frac{J_W}{J_{W,B2}} \qquad (1)$$

Figure 5 illustrates the influence of the nickel and phosphor content and of the grain size and casting procedure on the material wear factor.

In reference to the standard bronze, GZ-CuSn12Ni, material wear factors < 1 denote a better wear behavior while material wear factors > 1 stand for a worse wear behavior. Figure 5 leads to the following conclusions:

- With increasing grain size, the wear increases along with the material wear factor W_M.
- Adding nickel results in a strong wear reduction. Bronze with a nickel content higher than 4% reveals the best wear behavior of all bronzes examined.
- Phosphor contents of more than about 0.06% lead to increased wear.
- The conventional continuously cast bronze features the most inferior wear behavior of all bronzes tested. In contrast, the modified continuously cast bronze shows a wear behavior similar to centrifugally cast bronze. So, for the first time, a bronze material with a superior wear behavior is available even for smaller worm gears.

Based on the determined wear intensities, the wear life can be calculated according to DIN 3996 (Ref. 5). The life factor is defined as the respective wear life divided by the wear life of the conventional continuously cast bronze. According to Figure 6, the life factors give the extension of wear life in relation to conventional continuous casting.

The figure clarifies that, when substituting a conventional continuously cast bronze with a bronze having an increased nickel content of 4.0–4.5%, an extension of the wear life by the factor 8.4 is possible. Even compared to the common standard bronze, GZ-CuSn12Ni, the wear life can be nearly doubled.

It is evident to the caster and the designer that it is necessary to predict the wear behavior of a bronze from its physical properties and that, starting from a desired wear behavior, it should be possible to specify the appropriate physical properties of a bronze and therefore to choose a suitable casting procedure. These considerations led to a first approach to calculate a wear characteristic W_{Mcal} from physical basics, which permits estimating of the wear behavior of CuSn alloys from their material parameters. Developed from wear fatigue theory, the following equation is derived:

$$W_{Mcal} = 230.47 \cdot \left(\frac{E_{red}}{165{,}211}\right)^{-10.71} \cdot (R_m \cdot A_5)^{-0.61} \qquad (2)$$

E_{red}: Equivalent E-module in N/mm^2, DIN 3996

R_m: Tensile strength in N/mm^2

A_5: Flexural strength, as a percent

Equation 2 permits prediction of the material wear factor from tensile testing data with high accuracy. The equivalent E-module denotes the actuating variable on the expected wear behavior.

Summary

This article presents some new results on how to select and influence material parameters of worm wheel bronzes regarding wear resistance. Extensive studies on cylindrical worm gears lead to the following recommendations concerning an advantageous wear behavior:

- Higher nickel contents cause a drastic decrease of wear,
- Phosphor contents higher than 0.06% should be avoided,
- A homogenous and fine-grained crystal structure is favorable, and
- In smaller worm gears, modified continuously cast bronze should be used instead of conventional continuously cast bronze.

Further information on this topic can be found in the final report on the *Forschungsvorhaben 205* (Research Project No. 205) of the Forschungsvereinigung Antriebstechnik e.V., Germany (Ref. 6).

References

1. Forschungsvereinigung Antriebstechnik e.V. "Bericht zum Vorhaben Nr. 236, Schneckenräder aus gehärtetem Stahl," *FVA-Forschungsreport 1993*, 1993.

2. Forschungsvereinigung Antriebstechnik e.V. "FVA-Forschungsvorhaben 141: Fressen bei Schneckengetrieben," *Forschungsvereinigung Antriebstechnik, Issue 390*, 1993.

3. Vill, D. "Schneckengetriebe zur Leistungsübertragung mit der Laufpaarung Stahl/Grauguß," *Schriftenreihe des Instituts für Konstruktionstechnik, Issue 89.7*, Ruhr-Universität Bochum, 1989.

4. Deutsches Institut für Normung e.V. "DIN 1705—Kupfer-Zinn und Kupfer-Zinn-Zink-Gußlegierungen, Gußstücke," Beuth Verlag, November 1981.

5. Deutsches Institut für Normung e.V. "DIN 3996—Tragfähigkeitsberechnung von Zylinder-Schneckengetrieben mit Achsenwinkel Σ=90°," Beuth Verlag, September 1998.

6. Forschungsvereinigung Antriebstechnik e.V. "FVA-Forschungsvorhaben 205: Tragfähigkeitssteigerung von Schneckengetrieben durch Optimierung der Schneckradbronze," *Forschungsheft der Forschungsvereinigung Antriebstechnik e.V., Issue 476*, 1995.

7. Predki, W. "Hertzsche Drücke, Schmierspalthöhen und Wirkungsgrade von Schneckentrieben," *Schriftenreihe des Instituts für Konstruktionstechnik, Issue 82.4*, Ruhr-Universität Bochum, 1982.

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