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Head-cutter for optimal tooth modifications in spiral bevel gears

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ABSTRACT

A method for the determination of optimal tooth modifications in spiral bevel gears based on improved load distribution and reduced maximum tooth contact pressure and transmission errors is presented. The modifications are introduced into the pinion tooth-surface by using a head-cutter with bicircular profile and with optimal diameter. In the optimization of tool parameters the influence of relative position errors of the mating gears is included.

By using the computer program developed for load distribution calculation, the influence of head-cutter parameters and relative position errors of the mating gears on tooth contact and transmission errors is investigated. Based on the results obtained, the radii and the position of the circular tool profile arcs and the cutter diameter for pinion teeth finishing were optimized. By applying the optimal tool parameters, the maximum tooth contact pressure is reduced by 45% and the maximum angular position error of the driven gear by 60%, in regard to the spiral bevel gear pair with a pinion manufactured by a cutter of straight-sided profile and of diameter determined by the commonly used methods.

1. Introduction

During the last decades, many research works have been directed towards the synthesis, tooth contact analysis, and manufacture of spiral bevel gears. Handschuh [1] gave a very good review of progress for the analysis of spiral bevel gears. Local synthesis of spiral bevel gears with localized bearing contact and predesigned parabolic function of a controlled level for transmission errors is proposed by Litvin and Zhang [2]. In the paper published by Argyris et al. [3], a computerized method of local synthesis and simulation of meshing of spiral bevel gears with pinion tooth-surface generated by applying modified roll is presented. By Huston and Coy [4] an analysis of the surface geometry of spiral bevel gears formed by a circular cutter with involute, straight, and hyperbolic profile is presented. Kawasaki et al. [5] dealt with spiral bevel gears in Klingelnberg cyclopalloid system. The paper contains the design method, calculation of path of contact and transmission errors, and the investigation of the influence of assembly errors on meshing characteristics. Based on grinding mechanism and machine-tool settings for the Gleason modified roll hypoid grinder, a mathematical model for the tooth geometry of spiral bevel and hypoid gears is developed by Lin and Tsay [6]. The computer algorithm, presented by Gosselin et al. [7], uses the sensitivity of the "error surface" to selected machine setting changes to calculate new machine settings to match a theoretical tooth-surface to measurement data, within specified tolerances. In the paper published by Lin et al. [8], the sensitivity of tooth-surface due to the variations of machine settings is investigated. The corrective machine-tool settings, calculated by using the sensitivity matrix and the linear regression method, are used to minimize the tooth-surface deviations. By Stadtfeld [9] the use of a six-axis freeform machine for processing spiral bevel gears is discussed. A numerical method for the tooth

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Nomenclature

c	sliding base setting for pinion finishing, mm
e_n	composite manufacture and alignment error, mm
e_p	basic radial for pinion finishing, mm
f	machine center to back, mm
g	blank offset for pinion finishing, mm
h_{TM}	position of cutter radii's connection point, mm
i_{gp}	velocity ratios in the kinematic scheme of the machine-tool for the generation of the pinion and gear tooth-surfaces
N_1, N_2	numbers of pinion and gear teeth
p	distance of the initial contact point from pinion apex, mm
p_{max}	maximum tooth contact pressure, Pa
r_{prof1}, r_{prof2}	radii of tool profile for pinion teeth generation, mm
r_{T1}	pinion finishing cutter radius, mm
s	geometrical separation of tooth-surfaces, mm
T	transmitted torque, N mm
x_{TO1}, y_{TO1}	coordinates of the center of circular arc of radius r_{prof1}, mm
x_{TO2}, y_{TO2}	coordinates of the center of circular arc of radius r_{prof2}, mm
α_1	pinion finishing blade angle (°)
Δa	offset, mm
Δb	movement of pinion apex, mm
ΔF	concentrated load, N
Δy_n	composite displacement of contacting surfaces, mm
$\Delta\varphi_2$	angular displacement of the driven gear (°)
ε_h	horizontal angular misalignment of pinion axis (°)
ε_v	vertical angular misalignment of pinion axis (°)
φ_1, φ_2	rotational angles of the pinion and the gear (°)
$\varphi_{10}, \varphi_{20}$	initial rotational angles of the pinion and the gear (°)
γ_1	machine root angle for pinion finishing, deg.
v	head-cutter surface parameter, deg.
$\omega^{(c)}$	angular tool velocity in pinion teeth generation, s^{-1}
θ	head-cutter surface parameter (°)
ψ_1	pinion rotational angle for pinion finishing (°)
ψ_{cp}	cradle rotational angle for pinion finishing (°)
ψ_{cp0}	initial cradle angle setting angle for pinion finishing (°)

contact analysis of uniform tooth height epicyclical spiral bevel gears stemming from the Klingelnbergs cyclopalloid system is proposed by Lelkes et al. [10]. Longitudinal settings of contact patterns or contact across the surfaces from tooth root to tooth top were obtained as a function of machine settings and the influence of each cutting parameter was isolated and discussed. Gosselin et al. [11] proposed an algorithm that allows the use of a different cutter, either in diameter and/or pressure angle, to obtain the same tooth flank surface. Significant cost reductions may be obtained with the application of the method. In Ref. [12], published by Litvin et al., different cutter profiles were used to introduce the optimal tooth modifications in order to reduce the noise and vibration levels and to increase endurance.

An interesting computer-aided design and modeling technique for gear creation and processing is published by Goldfarb et al. [13]. The method is applied for spiral bevel, hypoid, and globoidal worm gears.

Refs. [14–20] deal with loaded tooth contact analysis and stress analysis in spiral bevel gears. Wilcox [14] in his paper outlined the general theory for calculating stresses in bevel and hypoid gears using flexibility matrix method in combination with the finite element method. The loaded tooth contact analysis predicting the motion error of spiral bevel gear sets, by applying influence matrices, is presented by Gosselin et al. [15]. Handschuh and Bibel [16] analytically and experimentally rolled through mesh a spiral bevel gear set to investigate the tooth bending stress by finite element method. Paper published by Falah et al. [17] summarizes the experimental and numerical results of the meshing of spiral bevel gears under load, from which the actual contact ratio is evaluated. Linke et al. [18] calculated the load distribution based on a method for using influence coefficients and also calculate the corresponding tooth root and contact stresses. By Fuentes et al. [19], the FEM was used for stress analysis in spiral bevel gears. Fang and Wei [20] considered the edge contact in loaded tooth contact analysis.

The results of recent research works on spiral bevel gears and hypoid gears can be summarized by the following papers: Wang and Fong [21] proposed a methodology to synthesize the mating tooth-surfaces of a face-milling spiral bevel gear set transmitting rotation with a predetermined fourth-order motion curve and contact path. In Ref. [22], the theory of the Glea-