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Research paper

Numerical approach for determination of rough-cutting machine-tool settings for fixed-setting face-milled spiral bevel gears

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ABSTRACT

Spiral bevel gear drives manufactured by the so-called *five-cut* method are designed to achieve the best conditions of meshing and contact since convex and concave pinion tooth surfaces are generated independently, allowing the achievement of optimized contact patterns and favorable functions of transmission errors for both flanks of gear tooth surfaces, and reducing with it noise and vibration and increasing the endurance of the gear drive. As part of the process of manufacturing, roughing of both flanks of the pinion tooth surfaces is needed. In this paper, a novel numerical approach for determination of machine-tool settings for roughing of the pinion by using a spread-blade face-milling cutter is proposed. The main purpose of the proposed procedure is the reduction of the manufacturing cycle time and maximizing the material cut during the rough-cutting operation, without damaging the to-be-finished surfaces. The procedure is based on the resolution of a constrained optimization problem. A numerical example shows the applicability of the developed numerical approach. The obtained numerical results disclose that acceptable rough-cut geometries are possible to be managed during the first iterations as trade-off solutions.

1. Introduction

Spiral bevel gear drives represent the most widely used gear transmission for transmitting rotation and torque between intersected axes. This type of gear drive provides a smooth and quiet tooth action together with high load carrying capacity. Moreover, they have a low sliding velocity and a high contact ratio because of the additional overlapping tooth action [1]. Spiral bevel gear drives are well suited to applications in which tooth loads and operating speeds are high, as in aircrafts, vehicles, reducers and many other branches of industry [2–4].

Face-milled spiral bevel gear drives are manufactured either through the *Five-Cut Process* or through the *Completing Process*. The *Five-Cut Process* represents the firstly developed manufacturing process and it is still used by many companies for high technological content and responsibility face-milled spiral bevel gear drives [5]. Basically, the *Five-Cut Process* consists of five independent operations, which are: (i) gear roughing by means of a spread-blade roughing cutter, (ii) gear finishing by means of a spread-blade finishing cutter, (iii) pinion roughing by means of a spread-blade roughing cutter, (iv) pinion convex tooth surface finishing by means of a fixed-setting finishing cutter comprised of all-inside cutting blades, and (v)

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Nomenclature

b	face width
$b_k (k \equiv 2, 3, 4)$	modified roll parameters
d_e	outer pitch diameter
h_{ae}	outer addendum
h_e	outer whole depth
h_{fe}	outer dedendum
h_{we}	outer working depth
i	tilt angle
j	swivel angle
m	number of constraints (optimization process)
m_{et}	outer transverse module
m_{wc}	velocity ratio
n	number of variables (optimization process)
q	basic cradle angle
s	generating profile parameter (surface parametric coordinate)
z	number of teeth
B_w	spread-blade cutter bottom width
C, D, E	modified roll coefficients
H_{20}	helical motion parameter at 20°
M	points in lengthwise direction
N	points in profile direction
P_w	spread-blade cutter point width
R_e	outer cone distance
$R_k (k \equiv i, o)$	profile point radius
R_u	spread-blade cutter mean radius
S_r	radial setting
$\alpha_k (k \equiv i, o)$	profile pressure angle
$\beta, \gamma, \varepsilon, \mu$	COBYLA algorithm parameters
β_m	mean spiral angle
γ_m	machine root angle
δ	pitch cone angle
δ_a	face cone angle
δ_f	root cone angle
θ	head-cutter blade angular position (surface parametric coordinate)
λ	blade edge generating profile angular parameter (surface parametric coordinate)
$\rho_k (k \equiv i, o)$	profile edge circular-arc radius
δ_s	offset distance
$\phi_k (k \equiv c, w)$	rotation angle
$\omega_k (k \equiv c, t, w)$	rotation velocity
Δ	trust region radius
Δ_f	final trust region radius
Δ_i	initial trust region radius
Δn	distance between the objective and rough-cut geometries
ΔE_m	blank offset
ΔX_B	sliding base
ΔX_D	machine center to back
$\Delta X_{D,0}$	machine center to back at $\phi_c = 0$
Σ	shaft angle

Subscript

c	hypoid gear generator cradle
i	inside blade generating profile
o	outside blade generating profile
t	hypoid gear generator cutting tool (grinding wheel)
w	workpiece (to-be-machined gear)

pinion concave tooth surfaces finishing by means of a fixed-setting finishing cutter comprised of all-outside cutting blades [5,6].