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Mathematical model for design and analysis of power skiving tool for involute gear cutting

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A B S T R A C T

Power skiving is an efficient means of producing high accuracy gears; particularly internal gears. However, the literature lacks a systematic mathematical model for the design and analysis of such tools. Accordingly, the present study proposes a comprehensive yet straightforward methodology for the design of resharpening power skiving tools based on conjugate surface theory and full-field angle analysis. The proposed methodology has three important features. First, mathematical models of the virtual-conjugate-surface and rake surfaces are derived, and thus the cutting edges can be obtained. Second, the power skiving is modeled by transformation matrices, and the normal/tangent vectors of the relative surface can be explicitly obtained. As a result, the working rake and clearance angles can be investigated in accordance with recommended ISO-standards. Finally, a method is prescribed for determining the working rake angles, clearance angles and wedge angles of the cutter based on the ISO-defined reference planes. Utilizing this method, a simple technique is proposed for redesigning the power skiving tool so as to avoid negative working clearance angles. The results of the illustrative example are shown that the proposed approach provides a comprehensive, simple and versatile technique for modeling a wide range of power skiving tool design features.

1. Introduction

Power skiving is a kind of gear machining method first proposed by Wilhelm von Pittler in 1910 [1]. The advantages of power skiving result from combining the traditional machining processes of hobbing and shaping. However, due to its continuous chip removal capability, power skiving is faster than shaping, and more flexible than broaching; particularly in the machining of internal gears. Power skiving has always presented a significant challenge to machines and tools due to their low stiffness and high wear characteristics, respectively. However, over the past few years, developments in manufacturing engineering have overcome these limitations, and power skiving technology now provides an efficient and flexible approach for the machining of gear components.

Power skiving methods can be broadly classified into two types, namely a simple type, in which only a shaft angle Σ is applied to the tool in the machining process, and a general type, in which both a shaft angle Σ and a tilt angle δ are applied (see Fig. 1). It is noted that the simple type is just a special case of the general type in which the tool tilt angle δ is set to zero. The simple type of power skiving has attracted significant attention in the literature in recent years. For example, Spath and Huhsam [2] performed a numerical investigation into the tool design, cutting angles and cutting load in the skiving of periodic structures. Bouzakis et al. [3] investigated the efficiency of various types of gear cutting process for the manufacturing of cylindrical gears, including power skiving. Guo et al. [4] proposed a method for the design and analysis of skiving tools for internal gears. Chen

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Nomenclature

$S\theta$	$\sin(\theta)$
$C\theta$	$\cos(\theta)$
$(xyz)_t$	power skiving tool frame
$(xyz)_g$	gear frame
$(xyz)_w$	rack frame
θ_g	rotation angle of gear
θ_t	rotation angle of power skiving tool
δ	tilt angle of meshing gear
Σ	shaft angle of meshing gear
s_t	feed distance of tool along gear axis
r_g	standard pitch radius of gear
r_{ga}	active pitch radius of gear
r_{ta}	active pitch radius of power skiving tool
z_g	teeth number of gear
z_t	teeth number of power skiving tool
m_n	normal module of gear
α_n	normal pressure angle of gear
α_{nt}	operating normal pressure angle of gear
β_g	helix angle of gear
$w_{\mathbf{r}}$	spur rack surface
$w_{\mathbf{q}}$	generation curve of spur rack surface
d_{am}	addendum of gear
d_{dm}	dedendum of gear
$w_{\mathbf{n}}$	unit normal vector of rack
Σ_0	shaft angle of meshing spur rack
$r_{t.}$	pitch radius of power skiving tool
s_w	motion distance of spur rack
${}^t\mathbf{r}$	surface with respect to tool frame $(xyz)_t$
${}^t\mathbf{n}$	unit normal vector with respect to tool frame $(xyz)_t$
$\mathbf{r}_{VCS}$	VCS of tool
$\mathbf{R}_{rake}$	rake surface
$\mathbf{R}_{clearance}$	clearance surface
$\mathbf{E}$	cutting edge
L_{tp}	leading pitch of power skiving tool
${}^g\mathbf{v}$	linear cutting velocity with respect to gear frame $(xyz)g$
ω_t	tool rotation speed
$f_{t.}$	tool feed speed
γ_{rake}	working rake angle
$\alpha_{clearance}$	clearance angle
μ_{wedge}	wedge angle
${}^g\mathrm{m}_{re}$	unit normal vector of working reference plane
${}^g\mathrm{m}_{n}$	unit tangent vector along cutting edge
${}^g\mathrm{m}_{se}$	unit normal vector of cutting edge plane
${}^g\mathrm{m}_{rake}$	normal vector of rake surface
${}^g\mathrm{m}_{flank}$	unit normal vector of flank surface
t_{chip}	chip thickness along tool feed direction
ξ_{t0}	profile shifting coefficient of cutting edge
ξ_t	change rate of profile shifting coefficient

et al. [5] presented a design approach for realizing error-free spur slice cutters [6]. However, general power skiving has attracted little attention since its introduction by Stadtfeld [7] in 2014. Accordingly, this study presents a comprehensive method for the design of power skiving tools for involute gear cutting based on conjugate surface theory and full-field angle analysis.

Section 2 derives a mathematical model of the power skiving system. Section 3 determines the virtual conjugate surface (VCS) of the power skiving tool by means of conjugate surface theory. Section 4 analyzes the linear cutting speed in power skiving. Section 5 defines the working rake angles, working clearance angles and working wedge angles of the power skiving tool in accordance with the normal vectors of the ISO recommended reference planes. Section 6 presents a methodology based on full-field angle analysis for redesigning the power skiving tool so as to avoid negative working clearance angles. Section 7 provides an