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Transmission principle and geometrical model of eccentric face gear

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ABSTRACT

Noncircular gears acquire wide application in various filed. A novel spatial noncircular gear set comprised of a cylinder gear and an eccentric face gear is presented, which has advantages of light weight, high interchangeability and convenient installation. The transmission mechanism of the eccentric face gear is expounded by kinematical analysis, with the pitch curves and drive ratio deduced. Based on the spatial meshing theory of gears, the mathematical model of the tooth surface of the eccentric face gear is built. Defining the basic design parameters of the eccentric face gear, an kinematical simulation and tooth contact analysis of the eccentric face gear and a cylinder gear are made, which demonstrate the feasibility of the transmission and the correctness of the mathematical model of the eccentric face gear.

1. Introduction

Noncircular gears can transmit accurate non-uniform motion between two shafts, which are used in many mechanical devices such as automatic machines, packaging machines, hydraulic pumps, flowmeters and printers. In addition, Librovich and Nowakowski [1] explored the use of noncircular gears in the rotary vane engine. Huang et al. [2] made the bio-inspired hexapod robot generate tripod locomotion and energy-efficient standing posture by noncircular gears. Wang and Zhu [3] used a pair of noncircular gears to eliminate the instantaneous variations of the speed ratio in an infinitely variable transmission mechanism. Muscia [4] improved the drive performance of a propulsion system for marine vessels by using elliptical gears. With the expansion of application, noncircular gears have been the one of important branch of gear transmission. For the improvement of performance and the reduction of weight of noncircular gear transmission system, a novel spatial gear set consisting of a cylinder gear and an eccentric face gear is presented in this article. As with other noncircular gears, the geometrical models of the pitch curve and tooth surface are the first issue for the gear set.

Litvin et al. developed the geometry of the face gear and presented various design methods to improve its properties. An analytical approach for generation of face gear by application of grinding or cutting worms was developed, with computer programs for TCA and stress analysis made [5]. In addition, they used the straight pinion with advanced modified profile [6] and the helical pinion [7] to avoid edge contact and reduce contact stress. Furthermore, a new type of asymmetric face gear drive was developed to reduce contact and bending stresses in the pinion denture [8]. Although these results on circular face gear may not apply to the eccentric face gear directly, the methods provide a good reference for the in-depth study of the eccentric face gear.

At present, planar noncircular gears have a theoretical geometry system of system for their design and manufacture. Litvin et al.

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Nomenclature

α	pressure angle of the pinion
e	eccentricity distance of the pitch curve of the eccentric face gear
i	transmission ratio of the pinion and the eccentric face gear
I	transmission ratio of the pinion and the circle face gear
h_a^*	addendum of the pinion
h_f^*	dedendum of the pinion
i_1	equivalent reduction ratio of the eccentric face gear
i_2	equivalent variable transmission ratio of the eccentric face gear
i_{12}	transmission ratio of the shaper and the eccentric face gear
φ	polar angle of the pitch curve of the eccentric face gear
L	radius of the pitch curve of the eccentric face gear
M_{nm}	transition matrix from coordinate system S_m to S_n
M_{sm}	transition matrix from coordinate system S_m to S_s
M_{sk}	transition matrix from coordinate system S_k to S_s
M_{2s}	transition matrix from coordinate system S_s to S_2
$\vec{n}_s$	unit normal vector of points on the tooth surface of the shaper in coordinate system S_s
θ_f	rotational angle of the pinion
θ_k	rotational angle of the shaper
θ_q	phase angle of the initial point of the involute on the shaper base circle
θ_{q1}	phase angle of the initial point of the involute on the pinion base circle
θ_s	direction angle of vector $\overrightarrow{O_sF}$ in Fig. 9.
θ_{s1}	direction angle of tooth profile of the pinion
R	pitch cylinder radius of the pinion
r	radius vector of the pitch curve of the eccentric face gear
r_{bs}	radius of the base circle of the shaper
r_{bs1}	radius of the base circle of the pinion
$\vec{r}_m^{\,P}$	vector of pitch point P' in S_m
$\vec{r}_n^{\,P}$	vector of the pitch curve of the pinion in S_n
$\vec{r}_2^{\,P}$	vector of he pitch curve of the eccentric face gear in S_2
$\vec{r}_s$	vector of points on the tooth profile of the shaper in S_s
$\vec{r}_m^{\,T}$	vector of contact point T in S_m
$\vec{r}_m^{\,O_m}$	vector of origin O_m in S_m
u_s	coordinate of points on the tooth profile of the shaper cutter at axis z_s
$\vec{r}_s^{\,N}$	vector of the meshing lines between the shaper and the eccentric face gear in S_s
$\vec{r}_2$	vector of the tooth working surface of the eccentric face gear in S_2
$\vec{r}_2^{\,f}$	vector of the fillet surface of the eccentric face gear in S_2
S_n	coordinate system fixed on the pinion
S_2	coordinate system fixed on the eccentric face gear
S_f	coordinate system fixed on the frame
S_m	coordinate system fixed on the frame
S_k	coordinate system fixed on the frame
S_s	coordinate system fixed on the shaper
$\vec{v}_s^{\,12}$	relative sliding velocity of the shaper and the eccentric face gear
$\vec{v}_s$	relative sliding velocity of the pinion and the eccentric face gear
ω	angular velocity of the pinion
ω_1	angular velocity of the shaper
ω_2	angular velocity of the eccentric face gear
$\vec{\omega}_m^{\,2}$	angular velocity vector of the eccentric face gear in S_m
$\vec{\omega}_s^{\,2}$	angular velocity vector of the eccentric face gear in S_s
$\vec{\omega}_k^{\,1}$	angular velocity vector of the shaper in S_k
$\vec{\omega}_s^{\,1}$	angular velocity vector of the shaper in S_s
Z_1	number of teeth of the shaper
Z_2	number of teeth of the eccentric face gear
Z	number of teeth of the pinion

[9] built the mathematical model of straight and helical elliptical gears by application of rack-cutter, hob and shaper. Numerical computing method is directly based on the real gear shaping process rather than deducing and solving complicated meshing equations [10]. With development of the CNC and CAD, the design and manufacture of the planar noncircular gear are not difficult problem. The research on geometry of spatial noncircular gear mainly focuses on the noncircular bevel gears. Xia et al. [11] built the

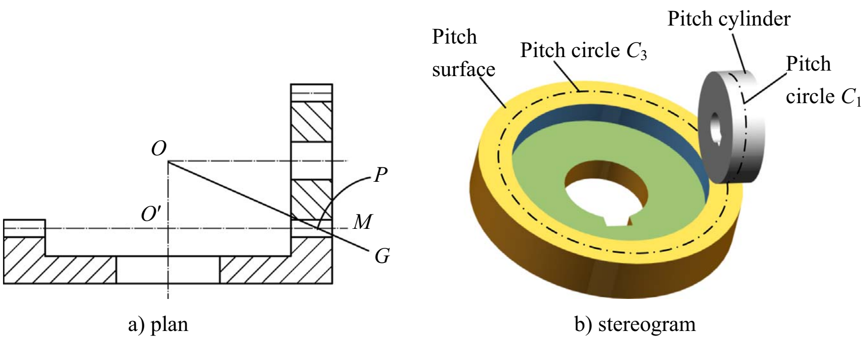

Fig. 1. Pitch circles and pitch surfaces of a pinion and a face gear.