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Computerized design, simulation of meshing, and finite element analysis of two types of geometry of curvilinear cylindrical gears

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ABSTRACT

Two different versions of geometry of circular-arc curvilinear shaped teeth gears, commonly known as curvilinear gears, are proposed based on generation by face-milling cutters. These cutters are: (i) a spread-blade cutter that generates simultaneously both sides of the gear tooth surfaces, and (ii) fixed-setting cutters that generate by single-side cutting each side of the gear tooth surfaces. The computerized processes of virtual generation of both members of the gear set are described and algorithms for simulation of meshing, tooth contact analysis, and finite element analysis are applied. Numerical examples of design show the advantages and disadvantages of the proposed two versions of geometry.

1. Introduction

Curvilinear gear drives are a kind of cylindrical gear set in which the longitudinal geometrical shape of the gear tooth surfaces is a circular arc. Initially, curvilinear cylindrical gear drives were developed in Russia and by The Gleason Works (USA) [1,2], and their first industrial applications appeared in China in 1980 in steel plants, aluminium rolling mills, and cement equipment plants, having shown their mechanical performance superiority with respect to other types of gears [3]. The geometry of curvilinear cylindrical gears contributes to avoid axial thrust forces (similar to herringbone helical gear drives) during mechanical high power transmission, and helps to achieve better lubrication conditions due to the fact that the oil is retained within the concave tooth surface during operation.

Curvilinear gears with line bearing contact manufactured by two different face-milling cutters were proposed in [3]. Additionally, the main advantages of curvilinear gears with respect to classic cylindrical gears were exposed. The mathematical model of curvilinear cylindrical gears generated by the same face-milling cutter was proposed in [4,5]. The generated gear drive showed localized bearing contact. Additionally, undercutting conditions and contact characteristics of this type of curvilinear cylindrical gears were analyzed. In [2], the mathematical model of curvilinear cylindrical gears with teeth of variable height and generated by a pair of independent face-milling cutters was proposed, which was compared with a real curvilinear cylindrical gear drive manufactured in Nylon. Additionally, contact characteristics were analyzed and stress analysis was accomplished. In [6,7], a new continuous indexing methodology of manufacturing of curvilinear cylindrical gear drives by hob-cutters was proposed. The mathematical model of the geometry of that type of gear was described, and their undercutting conditions and contact characteristics analyzed. Finally, in [8], the mathematical model of curvilinear cylindrical gears manufactured by a pair of complemented face-milling cutters provided with circular-arc blade profiles was

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proposed. Additionally, contact characteristics of this type of curvilinear cylindrical gears were analyzed. This type of gear drive also showed localized bearing contact.

This paper aims to achieve the following goals:

(i) The computerized generation of two versions of geometry of curvilinear cylindrical gear drives with localized bearing contact. The simultaneous generation of both sides of the gear tooth surfaces by a spread-blade face-milling cutter is proposed in one version. The separate generation by two fixed-setting face-milling cutters is proposed in the other version.
(ii) The comparison of the two versions of geometry, based on two different ways to localize the bearing contact, through the application of algorithms for simulation of meshing, tooth contact analysis, and stress analysis. Both geometries will be compared in terms of the sensitivity of the contact pattern to errors of alignment and in terms of contact and bending stresses.

Several numerical examples of design will show the advantages and disadvantages of the proposed two versions of geometry.

2. Geometry of generating tools

2.1. Geometry of spread-blade face-milling cutters

A spread-blade cutter is a type of face-milling cutter comprising groups of pairs of alternating cutting or finishing blades: an outside blade and an inside blade. The inside blade generates the convex side of the gear tooth surfaces and the outside blade generates the concave side of the gear tooth surface. Considering that the inside blade has a lower pitch curvature radius than the outside blade, and the bearing contact is achieved between the concave side of the pinion tooth surfaces and the convex side of the wheel tooth surfaces, or vice versa, the curvatures of generated mating surfaces will be different and, as a result, curvilinear cylindrical gears generated by this type of cutters will be in point contact. The pitch curvature radii of the outside blade, r_{ob}, and the inside blade, r_{ob}, are given by:

$$r_{ob} = r_c + \frac{\pi m}{4}, \quad r_{ib} = r_c - \frac{\pi m}{4} \tag{1}$$

Here, r_c is cutter mean pitch radius and m is the module. Fig. 1 shows a schematic model of a spread-blade face-milling cutter.

2.2. Geometry of fixed-setting face-milling cutters

A fixed-setting cutter is a type of face-milling cutter comprising groups of pairs of alternating cutting or finishing blades for just one generating side, so that it is provided with outside blades or inside blades. Therefore, two independent fixed-setting face-milling cutters are used for the curvilinear gear generation: (a) the cutter for generation of the concave side of the gear tooth surfaces that will be provided with outside cutting blades; (b) the cutter for generation of the convex side of the gear tooth surfaces that will be provided with inside cutting blades. In this case, the generation processes of concave and convex gear tooth surfaces become independent, the radii of the cutters can be optimized according of the sought-for type of contact, and in this way, generated curvilinear gears might be in line or localized point contact. The main drawback for this type of generation is that manufacturing time will be increased. Fig. 2 shows a scheme of the cross section of a fixed-setting cutter provided with outer cutting blades for generation of the concave side of the gear tooth surfaces (Fig. 2(a)) fixed-setting cutter provided with inner cutting blades for generation of the convex side of the gear tooth surfaces (Fig. 2(b)).

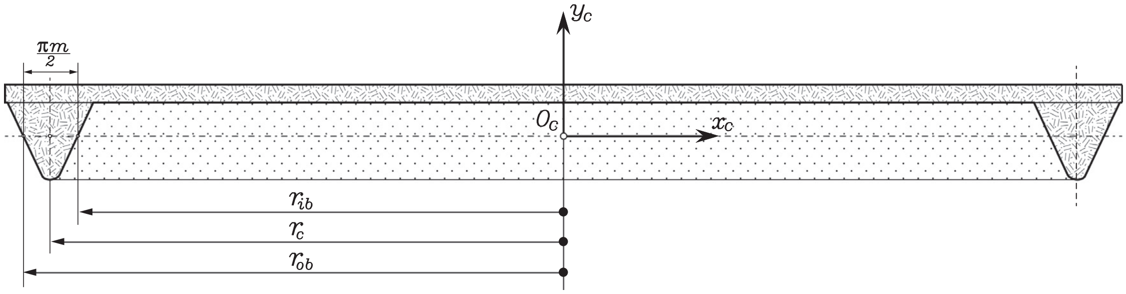

Fig. 1. Schematic representation of a spread-blade cutter cross section.