



Research paper

The kinematics of the rotary into helical gear transmission



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ABSTRACT

A higher kinematic pair that converts rotary motion into helical motion is presented as an alternative to the screw joint (a lower kinematic pair). First, the existence of a rolling transmission pair for a rotary-to-helical motion conversion is proven. Then, the corresponding pair of rolling surfaces (pitch surfaces) and their relative position is defined for any set of kinematic transmission parameters. Some calculated examples are presented. A method for gear-tooth forming from the pitch surfaces using Boolean operations with a computer-aided design (CAD) program is proposed. Finally, applying this methodology, a pair of gears for rotary into helical transmission has been obtained using a 3D printer. The prototype presents negligible clearances and backlash, high reversibility, as well as continuous gearing without interference. The meshing equation for a simple generating surface is also provided.

1. Introduction

On the subject of rotary into helical transmission, the literature is very scarce. In fact, helical motion is historically achieved by any kind of combination of a linear actuator with a rotary actuator, or by a low order kinematic pair (screw joint), where the friction is not negligible, such as described in Thomas A. Edison's phonograph design [1]. No published work on rotary into helical transmission by gears has been found by the authors.

Actually, the motivation of this work comes from a patented mechanism “Dispositivo Automático para Biopsias Cutáneas (Automatic Device for Skin Biopsy)” [2] for generating helical motion with a single actuation. The performance of this device worsens to the extent that actual slipping occurs in the kinematic pair it is based on, and could be improved by the rotary-helical transmission presented in this work.

A mechanism partly equivalent to that proposed in this manuscript is the patented “Adjustable Angle Helix Generator for Edge and Radial Relief Sharpening” [3]. In the opinion of the authors, the disadvantage of this mechanism is that it is based on a rather weak rotary-helical transmission kinematic pair, since it is provided by a point contact rolling between non-parallel cylinders. A similar mechanism, but having the gear transmission kinematic pair proposed in this paper, could lead considerably more thrust.

The “spiral motor” [4–7] is an actuator that produces helical motion, but it is used primarily as a linear actuator (see [5] or [6], for example). However, in [7], a two degree of freedom induction motor prototype with rotor helical motion, “suitable for several industrial applications as grinders, augers, drilling and milling spindles, robotic arms and drives for medical tools and prostheses” [7], is described. In this respect, the transmission mechanism proposed here shares the latter applications, and it could also be used as a rotary-linear transmission. Additionally, new geometries such as those proposed in this article could be considered in the design

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of linear actuators based on electromagnetic gears and/or helical electromagnetic motors, which can provide a wide range of future research.

Gear mechanisms are commonly used to transform rotary motion into either rotary or linear motion. In rotary-to-rotary-motion transmissions, where both axes are parallel or intersecting, it is easy to obtain the corresponding pair of rolling contact surfaces (pitch surfaces); they are their axodes. These are two cylinders and two cones, respectively, having either the diameter ratio or the cone base diameter ratio equal to the transmission ratio. Conversely, no set of rolling surfaces exists for transmission between two skew axes (i.e., non-parallel and non-intersecting) since their axodes do not roll without sliding. However, the operating pitch surfaces are defined for gears with crossed axes [8,9]. Based on these pitch surfaces (either cylinders or cones), helical or spiral gears can be used for any two crossed axes at any angle, by a suitable choice of helix angle, in addition to worm and hypoid gears for the case of axes crossed at a right angle.

This paper addresses the existence of a pair of rolling surfaces for transmitting rotary motion into helical motion between crossed axes, at any distance and angle between them. The method of tooth-generation on these surfaces in order to obtain a rotary-helical transmission is also considered.

2. A rolling kinematic pair for the rotary to helical transmission. Pitch surfaces

In this section two rigid solids are considered: one performing a pure rotation (body 1), and the other performing a helical motion (body 2). It is shown that, i) for any set of values of their angular velocities, ii) for any value of the helical linear velocity of body 2, and iii) for any orientation of the corresponding axes relative to each other; there is a line where the velocity fields corresponding to each body are equal. Therefore, a pair of ruled surfaces (each one attached to each body) exists such that each rolls, without slipping, on the other. These are the so-called pitch surfaces for the rotary into helical transmission.

Without loss of generality, we will consider the helical motion of body 2 around the z-axis. The motion is then characterized by the following linear and angular velocities, respectively:

$$\vec{v} = v\vec{k} \quad (1a)$$

$$\vec{\omega}_2 = \omega_2\vec{k} \quad (1b)$$

Meanwhile, body 1 rotates around the R-axis, which lies in a plane defined by $x = d$, and is parallel to the y-z plane (see Fig. 1), so that its angular velocity can be expressed as Eq. (2).

$$\vec{\omega}_1 = \omega_{1y}\vec{j} + \omega_{1z}\vec{k} \quad (2)$$

Let $\vec{r} = x\vec{i} + y\vec{j} + z\vec{k}$ be the position vector for a generic point. If this point belongs to body 2 (helical motion) its velocity can be expressed as Eq. (3), which is the velocity field of body 2.

$$\vec{v}_2(\vec{r}) = \vec{v} + \vec{\omega}_2 \times \vec{r} = -\omega_2 y\vec{i} + \omega_2 x\vec{j} + v\vec{k} \quad (3)$$

The velocity field of body 1 can be written as

$$\vec{v}_1(\vec{r}) = \vec{\omega}_1 \times (\vec{r} - d\vec{i}) = [\omega_{1y}z - \omega_{1z}y]\vec{i} + \omega_{1z}(x - d)\vec{j} - \omega_{1y}(x - d)\vec{k} \quad (4)$$

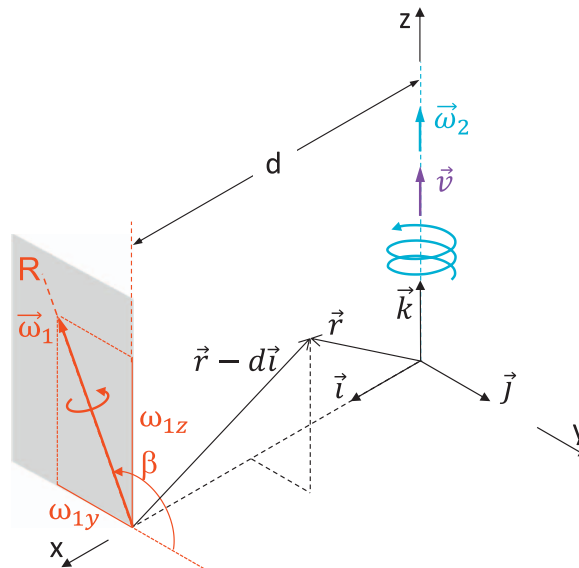


Fig. 1. The kinematic and geometric parameters of the rotary-to-helical motion transmission.

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