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Design of a two-stage cycloidal gear reducer with tooth modifications

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ABSTRACT

The cycloidal gear reducer is a compact, high-ratio, and low-backlash speed reduction device. It has been commonly used for transmitting motion and torque in machinery. This paper presents the design of a new two-stage cycloidal speed reducer with tooth modifications. The topological structure of cycloidal drives is discussed and analyzed with the aid of graphs. New cycloidal gear reducers are enumerated through the topological analysis and a new two-stage cycloidal gear reducer with simpler structure is then proposed. The design of the proposed cycloidal gear reducer is also performed, including profile generation and modifications. Subsequently, kinematic errors are analyzed by using the tooth contact analysis, and the results caused by different combinations of the gear profile modifications are presented quantitatively. Finally, based on the analysis, a mock-up of the cycloidal gear drive is constructed to validate the feasibility of the new mechanism.

1. Introduction

Cycloidal gear reducers (or cycloidal drives) are high-efficiency and high speed reduction ratio motion and torque transmission devices. They are commonly used in equipment where precise output and large drive payloads are needed. Recently, with the increasing demand of high efficiency and high speed reduction and torque ratio transmission devices in industry, applications of cycloidal gear reducers have become popular in the automation field as robotics, machine tools, and automatic machinery. Nonetheless, compared to involute gear drives, manufacture of cycloidal gear reducers requires a more dedicated process because of the non-standard characteristics of the devices. Further, tools for manufacturing cycloidal gears are not as specialized as for manufacturing involute gears. These features make accuracy control and cost reduction of manufacturing cycloidal drives a great challenging task. The research and development of the cycloidal gear reducers have been investigated by many researchers, including profile generation [1–6], conditions for non-undercutting manufacturing [7–9], manufacturing errors and their influence on output speed [10,11], force analysis and efficiency [12,13], and development of new mechanisms [14–17]. The early literature that studied cycloidal drives can be dated back to Botsiber and Kingston [1] and Pollitt [2] where the cycloidal speed reducer was initially introduced. Then, papers on cycloidal drives deal with the geometry and profile generation of the cycloidal disc. Other research considers profiles generated from different types of tooth [5]. Blanche and Yang [3] used a vector method to generate the cycloidal profile while Yan and Lai [4] approached the problem by means of the theory of conjugate surfaces. Hsieh [6] studied the epitrochoidal and hypotrochoidal profiles by the theory of gearing thoroughly. Fong and Tsay [7] and Hsieh and Hwang [8] derived the conditions for non-undercutting and obtained the constraint of parameters for non-undercutting. Sensinger [9] presented a unified approach to cycloidal drive profile, stress and efficiency with closed-form equations. Blance and Yang [10] investigated machining tolerances of cycloidal drives and their influence on output speed by means of instant centers. Huang [11] also studied the profile modification and

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Nomenclature

ω_i	angular velocity of link i
z_i	number of teeth of link i
m	speed reduction ratio
r_p	roller position
r_{rp}	radius of the roller
$\mathbf{r}_1$	position of P with respective to coordinate system 1
$\mathbf{r}_2$	position of P with respective to coordinate system 2
$\mathbf{M}_{ij}$	transformation matrix from system j to system i
a	eccentricity of crank
α	surface parameter of the point P on the roller
Δr_p	value of modification of roller position
Δr_{rp}	value of modification of roller radius
$\mathbf{n}_{cl}$	contact normal of the 1st-stage cycloidal disc
$\mathbf{n}_{r1}$	contact normal of the 1st-stage roller
$\mathbf{n}_{c2}$	contact normal of the 2nd-stage cycloidal disc
$\mathbf{n}_{r2}$	contact normal of the 2nd-stage roller

tooth contact analysis of the cycloidal drive. On the other hand, the development of new cycloidal drives can also be found in patent literature [14,15]. Li et al. [16] proposed a new drive for high load capacity. Blagojevic et al. [17] introduced a new two-stage cycloidal speed reducer of which speed reduction ratio was increased compared with the one-stage cycloidal drive. In view of the demand for the development of a new design, it can be seen that the development of a device with a higher speed reduction ratio, more compact size and high accuracy is continuing and indeed in need. Thus, the aim of this work is to address the development and design of a new two-stage cycloidal gear reducer. The cycloidal gear reducer from the topological view point is first investigated such that the structural characteristics can be further realized. Subsequently, new configurations of the two-stage structure are enumerated from the topological analysis and a new mechanism with simple structure is proposed. Then, the design of the proposed two-stage cycloidal gear drive with tooth modifications is performed by the theory of gearing [18]. The profile tolerances that compensate the errors of assembly and manufacturing will also be studied. The kinematic errors caused by the tooth modifications are simulated via tooth contact analysis. Finally, a mock-up of the device is constructed to validate the feasibility of the new mechanism.

2. Structural analysis of the cycloidal gear reducer

As shown in Fig. 1, the conventional one-stage gear reducer mainly consists of the case (1) (as fixed frame), crank (2), cycloidal disc (3) and output disc (4). When operating, the input crank deflects the cycloidal disc such that the cycloidal disc orbits and wobbles about the center of the crank shaft because of the crank's eccentricity and meshing between the disc and rollers on the case. Since the motion of the cycloidal disc is epicyclic and wobbling, it is necessary to convert such motion to pure

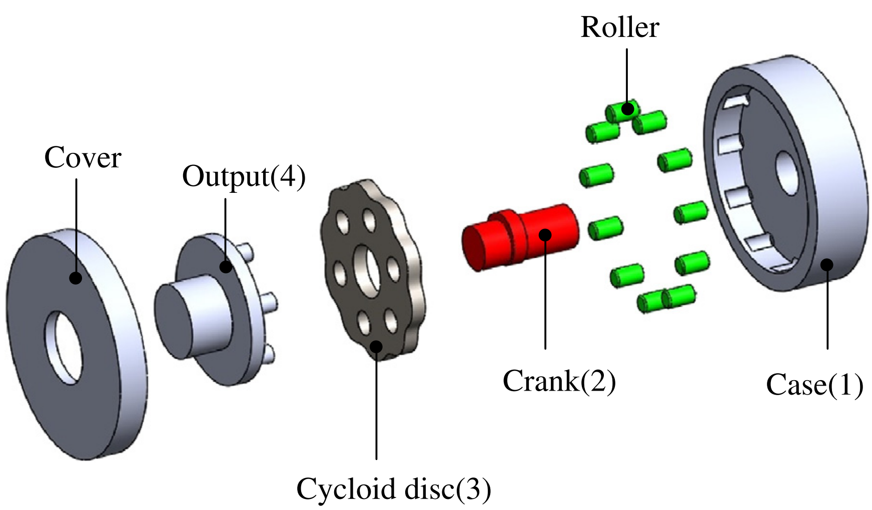

Fig. 1. Main structure of the conventional one-stage cycloidal gear reducer.