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Design and analysis of a novel wheel type continuously variable transmission

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ABSTRACT

In order to explore new kinds of continuously variable transmission (CVT) with high torque capacity and transmission efficiency, a novel wheel type CVT (W-CVT) is proposed. Same as toroidal CVT and ball-type CVT, it transmits power by friction on the contact points between input and output discs. W-CVT is composed of transmission mechanism and speed changing actuator, and CATIA model is drawn to explain the component parts and working principle of W-CVT. Equations for its theoretical transmission ratio are derived based on schematic diagram. Theoretical analyses including force and kinematic analyses are carried out to evaluate the mechanical property and kinematic feasibility of W-CVT. Based on theoretical analyses, equations for its transmission ratio calculation are modified. Additionally, influences of elastic sliding coefficient and friction coefficient on transmission ratio are discussed. Finally, transmission efficiency of W-CVT is analyzed considering elastic sliding losses and geometrical sliding losses.

1. Introduction

In response to energy conservation and emission reduction, researchers have proposed many solutions to reduce the emission of the internal combustion (IC) engine vehicles [1]. One of these technical solutions is continuously variable transmission (CVT), which is able to provide an infinite number of gear ratios between two finite limits, and thus, to allow the IC engine to operate closer to its optimal efficiency line [2]. So CVT has the potential to become the world's leading transmission on fuel economy [3]. In addition, CVT can ensure good performance of driving comfort because there is no perceptible ratio change [4]. By now, many kinds of CVTs have been proposed, such as belt CVT [5,6], chain CVT [7,8], toroidal CVT [1,9], ball-type CVT [10], spherical CVT [11,12], E-CVT [13], hydrostatic CVT [14], power-split CVT [15], etc. Nevertheless, belt CVT and chain CVT are the most common CVTs used in vehicles due to their simple structure, small size and light weight. In spite of these advantages, their torque capacity is limited, which is currently limited by the strength of the steel belt and by the ability to withstand friction wear between torque source and transmission medium [16]. In order to overcome this shortcoming, toroidal CVTs have been proposed including full-toroidal CVT and half-toroidal CVT [17–19]. Torque is transmitted by means of the shearing action of one kind of special oil referred to as traction oil in toroidal CVT instead of the transmission mode of metal-metal contact [2]. Additionally, hydrostatic CVT is designed to improve torque capacity as well [20,21].

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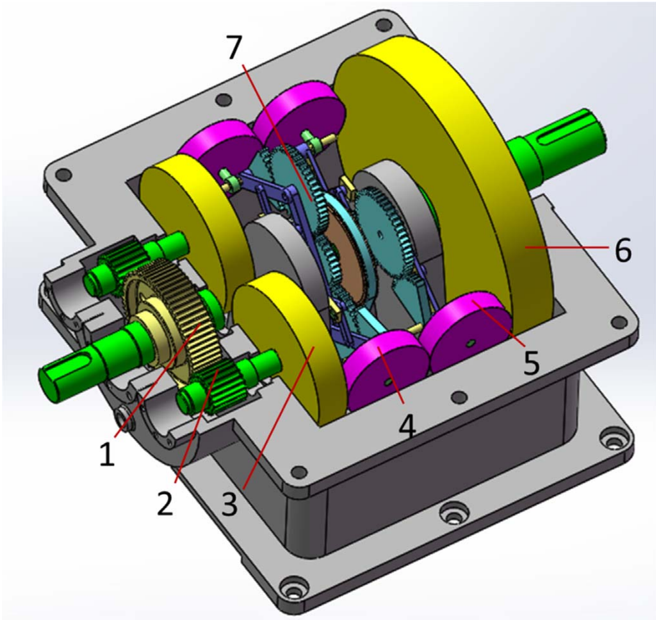

Fig. 1. CATIA model of W-CVT.

Transmission efficiency of CVT is another vital issue in addition to torque capacity. In terms of belt CVT, higher clamping force which aims to prevent the metal belt from slip results in additional friction losses in the system, which is the main reason for inadequate transmission efficiency [22]. To solve the problem, a dual-belt or multiple belt system is normally used instead of a single-belt system. Though toroidal CVT has the advantage of high torque capacity, its transmission efficiency is definitely restricted by spin losses [2,23]. Li et al. [1] have proposed a novel toroidal CVT with logarithmic disc generatrix to reduce spin losses. Delkhosh et al. [24] have done the multi-objective geometrical optimization of full-toroidal CVT to maximize CVT efficiency and minimize its mass. It is obvious that transmission efficiency of CVT is influenced by the change of transmission ratio as well [25].

In order to improve transmission efficiency of CVT, many new kinds of CVT has been designed. Spanoudakis et al. [26] have proposed Electronic Shift Variable Transmission (ESVT) and carried out researches on its transmission efficiency. Magnetic CVT has been studied to improve transmission efficiency and reliability [27,28]. Wang et al. [29] have improved GIVT which has minimal speed variations and high transmission efficiency. Guo et al. [30] have proposed a novel HCVT with high torque and efficiency.

To attain large torque capacity and high transmission efficiency, a novel W-CVT is proposed. Compared with the widely used belt CVT and chain CVT, it has larger torque capacity due to the material of high friction coefficient. To overcome the large lateral friction force, a novel speed changing actuator is designed which can realize speed changing easily by making full use of the correlative velocity. Furthermore, the W-CVT can have high transmission efficiency over 90% by choosing appropriate material. In this paper, Equations for the W-CVT's transmission ratio are derived. Besides, force and kinematic analyses are carried out to evaluate its performance. Finally, influence factors of transmission ratio and transmission efficiency are discussed.

2. Design conception

2.1. Configuration of W-CVT

Fig. 1 shows the CATIA model of W-CVT, which is a symmetrical structure. W-CVT consists of transmission mechanism and speed changing actuator, and transmission mechanism is made up of driving gear 1, driven gear 2, input friction disc 3, traction wheel 4, traction wheel 5 and output friction disc 6. In addition, 7 is speed changing actuator and its concrete configuration design is displayed in Fig. 2. Speed changing actuator is composed of synchronous belt 17, planetary reducer 18, steeping motor 19 and two sets of geared linkage mechanisms in two parallel planes. The geared linkage mechanism is a centrosymmetric structure which is primarily made up of gear 8, gear 9, gear 10, crank 11, linkage 12, linkage 13, linkage 14, slider 15 and sliding rail 16. Input friction disc 3 is installed on the right end of the shaft of driven gear 2, and output friction disc 6 is installed on the left end of the output shaft. Traction wheel 4 and 5 are pressed between input friction disc 3 and output friction disc 6 with pressing force P.

2.2. Operating principle

Under the steady state, traction wheel 4 and 5 can only rotate around their own spin axes. Once the W-CVT needs to change the transmission ratio, steeping motor will rotate with some angle, via transmission of planetary reducer, synchronous belt and geared linkage mechanism, ultimately, gear 10 will rotate with traction wheels around axis m. In the procedure of speed changing, traction