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Torque for an electromagnetic harmonic movable tooth drive system

Lizhong Xu *, Yongli Liang

Mechanical Engineering Institute, Yanshan University, Qinghuangdao, Hebei, China

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ABSTRACT

The output torque of the mechanical harmonic drive is large but the teeth should be produced on the flexible ring which is a difficult task. To overcome the difficulty, the authors proposed an electromagnetic harmonic movable tooth drive system in which a large output torque can be obtained meanwhile the teeth are removed from the flexible ring. Here, the operating principle of the electromagnetic harmonic movable tooth drive system is illustrated. The forces on the flexible ring and the movable teeth are analyzed. The equation of the output torque for the drive system is developed. Using the equation, the output torque of the drive system and its changes along with the system parameters are investigated. The results show that large coil current, large speed ratio, large flexible ring radius and small flexible ring length, small gas gap should be selected to obtain a large output torque. The results are useful for the further study and application of the drive system.

1. Introduction

In 1959, C. W. Musser produced the first model machine of the harmonic drive with mechanical wave generator [1]. In 1963, D. F. Herdeg proposed the electromagnetic harmonic drive [2]. The harmonic drive offers a number of advantages such as high load-carrying capacity, large transmission ratio, and compactness, etc. It is used widely in the technical fields such as aviation and space flight, robots, and space manipulator, etc. [3]. Dong proposed the dynamic simulation model of harmonic gear drives [4]. Zhu proposed a new type of gear pump based on the principle of harmonic gear drive [5]. Tong presented the transmission error formula of harmonic gear reducer considering the case of gear backlash and stiffness [6]. Kayabasi completed shape optimization of tooth profile of a flexspline for a harmonic drive based on finite element modeling [7]. Rens developed a new permanent harmonic gear drive which increases speed ratio range of the drive, its reliability, and overload protection ability [8–10]. An eccentric magnetic harmonic gear drive was proposed and the eccentric air-gap magnetic field was calculated based on the boundary perturbation method [11]. Shang developed a control system to remove the eddy current through the metal flexible ring of the magnetic harmonic drive [12]. In order to attenuate adverse effects due to cogging torque on the vibratory system, Uchimura proposed a cyclic disturbance suppression control method of the harmonic magnetic gear [13]. Xu analyzed electromagnetic torque and the friction torque of the electromagnetic harmonic drives and investigated changes of the output torque for the drive system along with the system parameters [14]. Zhao et al. analyzed the parameter sensitivity and thermodynamic problem of space manipulator with harmonic drive [15,16].

In a word, a number of studies about the harmonic drives were done. The harmonic drives mainly include the mechanical harmonic gear drive and the electromagnetic harmonic drive. The electromagnetic harmonic drive includes electromagnetic

* Corresponding author.
E-mail address: xlz@ysu.edu.cn (L. Xu).

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coils and can run when it is connected to a power source. It needs not outer motor so it has a smaller size than a mechanical harmonic gear drive. However, the teeth should be produced on the flexible ring. How to produce precise teeth on the flexible ring is a difficult task. The machining errors of the flexible ring teeth can decrease operating performance of the harmonic drive.

To overcome the difficulty, the authors proposed an electromagnetic harmonic movable tooth drive system in which a large output torque can be obtained while the teeth are removed from the flexible ring.

In reference [14], the electromagnetic harmonic drive is driven by the friction forces between the flexible ring and the rigid ring in which the output torque is dependent on the friction torque between the flexible ring and the rigid ring, and the electromagnetic torque on the flexible ring.

The electromagnetic harmonic movable tooth drive system is driven by the meshing forces between the movable teeth and rigid gear. The output torque of the novel drive system has not been investigated yet.

In this paper, the operating principle of the electromagnetic harmonic movable tooth drive system is illustrated. The forces on the flexible ring and the movable teeth are analyzed. The equation of the output torque for the drive system is developed. Using the equation, the output torque of the drive system and its changes along with the system parameters are investigated. The results show that large coil current, large speed ratio, large flexible ring radius and small flexible ring length, small gas gap should be selected to obtain a large output torque. These results lay a theory foundation for the further study about design, analysis, and performance control of the drive system.

2. Design

The configuration of the proposed electromagnetic harmonic movable tooth drive system is shown in Fig. 1, which consists of three main parts: electromagnetic coils, harmonic movable tooth drive without wave generator, and flexible ring between the coils and the drive.

The flexible ring is made with ferromagnetic material. The coils and the rigid ring are fixed on the housing. The coils are energized sequentially by voltages, and the resulting rotational electromagnetic field causes periodic elastic deformation of the flexible ring. The flexible ring is fixed on the housing and does not rotate. Its periodic elastic deformation causes a running wave on the flexible ring which can result in periodic contact between the flexible ring and the movable teeth. It causes the normal pressure and the relative motion between the movable teeth and rigid gear. As the rigid gear is fixed, the meshing force drives the rotor to rotate. One circle of the electromagnetic field corresponds to two tooth distances of the movable tooth motion, and then a reduction ratio occurs and a large output torque can be obtained.

Compared with other harmonic drives, the drive system has the main advantages as below: (1) rolling contact, transmitting load by meshing, and reduction; (2) high operating efficiency; and (3) small size.

3. Forces on the flexible ring

The flexible ring subject to the electromagnetic force is shown in Fig. 2. The radial displacement of the flexible ring under the distributed electromagnetic force q is [14]

$$w=\frac{2r^4}{\pi Kl}\int_{c_1}^{c_2}\int_0^{\frac{\pi}{2}} q\left\{\sum_{n=2,4,6\ldots}^{\infty}\left[\frac{1}{(n^2-1)^2}+\frac{n^2c_0x}{(n^2-1)^2\left[\frac{1}{3}n^2l^2+2(1-\gamma)r^2\right]}\right]\cos\beta\cos n\theta\right\}d\beta dc, \quad (1)$$

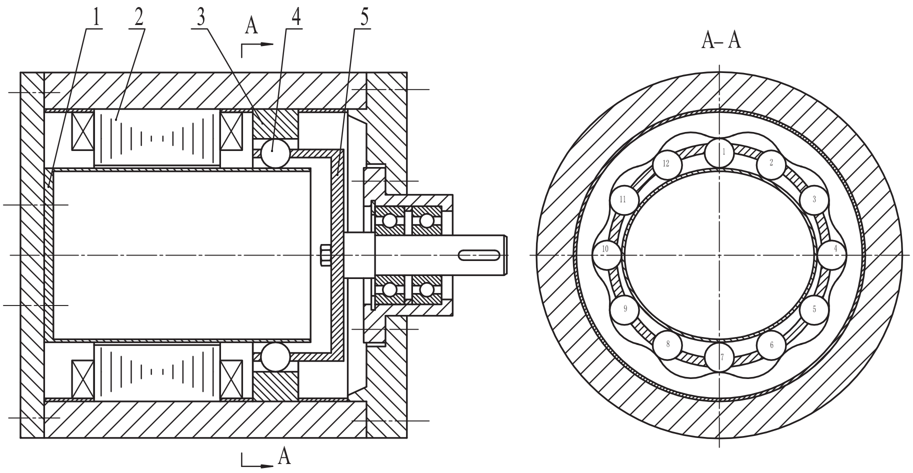

Fig. 1. An electromagnetic harmonic movable tooth drive system. 1. flexible ring; 2. coils; 3. rigid gear; 4.movable tooth; 5. rotor.