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Pitch deviation measurement and analysis of curve-face gear pair

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ABSTRACT

The curve-face gear pair is proposed as a new type of gear pair which was put forward in recent years. It can achieve variable ratio transmission of motion and power between the intersection axes. In the matter of the inspection of the pitch deviations of this gear pair, there is no practical possibility for a reliable metrological traceability to national or international measurement standards can be provided. Hence, a new method was proposed in this article, which was based on the CNC gear measuring center, aimed at the gear artefacts processed by the five-axis machining center. With the coordinate data which were obtained by the gear measuring center, the pitch deviations of the gear pair were obtained. In addition, based on the values of the pitch deviations, the angular deviations of curve-face gear pair can be worked out, and the results turn out that the measurement method is feasible.

1. Introduction

Among all the mechanical products, machine or instrument which contains gear transmission, structure performance, working accuracy, bearing capacity and service life are all related to accuracy of gear transmission [1,2]. In order to ensure the quality of gear transmission, requests must be made to the gear precision, strict control gear tolerances, and one of the important factors that affect the precision of gear transmission is the gear precision. Pitch deviation as an important indicator of the accuracy of the gear, the deviation value affects stability and driving precision gears.

For the common cylindrical gears, bevel gears, etc., there already have mature testing instruments, detection methods and quality evaluation standards, both in China and abroad [3–5]. In terms of pitch deviation measurement, the measurement methods can be broadly classified into two types, namely the relative and absolute. Relative measurement method has high efficiency, wide application, but lower accuracy, and the instruments often used are Universal gear measuring instrument, gear circular pitch measuring instrument, etc. Absolute measurement has high measurement accuracy that usually can reach grade 4, measuring instruments are gear measurement center (GMC), coordinate measuring machine, etc., they are characterized by high precision, strong function, easy operation, and other advantages in precision measurement and quality control of products which have obtained more and more widely used. The gear measuring machine mainly adopts two kinds of measurement methods: generating method and coordinates method. Generating method is synchronized measuring machine with rotary table moving way, realizes the error of tooth profile and tooth to measure. When using static coordinate measuring method, the workbench remains stationary, the rotary worktable does indexing motion, only by measuring probe records point coordinates, and the error value can be obtained by comparison with the theoretical value [4–8].

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Curve-face gear pair is a new gear pair, which is made up of a curve-face gear and a non-circular gear that meshing with each other in order to achieve variable ratio transmission of motion and power between the intersection axes. Curve-face gear is based on face gear, combined with the transmission characteristics of non-circular gear and non-bevel gear, its teeth uniformly distributed in the space section curves. Currently, its related research work is just underway, to extend it from basic research to practical applications, there are many problems to be solved. In the matter of the inspection of the pitch deviations of this gear pair, there is no practical possibility for a reliable metrological traceability to national or international measurement standards can be provided. Combined with the existing pitch deviation detection methods of non-circular gear, face gear, bevel gear and non-bevel gear [9–13], based on the P26 automatic CNC controlled gear measuring center from Klingelnberg of German, this paper puts forward a kind of pitch deviation detection and evaluation method of curve-face gear pair and carries out related research.

2. Pitch curves of the curve-face gear pair

2.1. Pitch curve of non-circular gear

Non-circular gear (driver) has both advantages of cam and cylindrical gear; it is widely used in various occasions. Generally, it can be categorized as follows: ellipse gear; eccentric gear and Pascal spiral gear. In this article, the pitch curve of non-circular gear is elliptic curve and its polar equation is as follows:

$$r(\varphi_1) = \frac{a(1-e^2)}{1-e\cos(n_1\varphi_1)} \tag{1}$$

where r is the polar radius of pitch curve of non-cylindrical gear, a is the semi-major axis of ellipse curve, e is the eccentricity of ellipse, n_1 is the order of ellipse, and φ_1 is the polar angle of ellipse.

The pitch curve of non-circular gear must be closed in order to ensure the continuity of motion transmission, thus it must satisfy the following equation:

$$r(0) = r\left(\frac{2\pi}{n_1}\right) = r(2\pi) \tag{2}$$

Furthermore, the teeth of the non-circular gear must be distributed uniformly on the pitch curve, consequently, the perimeter of the pitch curve is:

$$L = \int_0^{2\pi} \left[r^2(\varphi) + r'^2(\varphi)\right]^{1/2} d\varphi = z_1 p = z_1 \pi m \tag{3}$$

Finally, according to the given value of the eccentricity, number of teeth, module, the value of the semi-major axis of elliptic pitch curve can be calculated as

$$a = \frac{m z_1 \pi}{2n_1(1-e^2)\int_0^{\frac{\pi}{n_1}} f(\varphi_1)d\varphi_1} \tag{4}$$

where

$$f(\varphi_1) = \frac{\sqrt{1-2e\cdot\cos(n_1\varphi_1) + e^2[(1+(n_1^2-1)\sin(2n_1\varphi_1)]}}{[1-e\cdot\cos(n_1\varphi_1)]^2} \tag{5}$$

2.2. Pitch curve of the curve-face gear

In the process of curve-face gear pair meshing transmission, two pitch curves are doing pure rolling for specific performance. Hence, according to the spatial meshing theory and coordinate relation, the complex pitch curve of curve-face gear can be deduced from the readily available non-circular gear.

The pitch curve of non-circular gear is elliptic, as shown in Fig. 1. The coordinates of each point on the pitch curve in static coordinate $S_1(X_1Y_1Z_1)$ is certain, it's moving coordinate $S_1'(X_1'Y_1'Z_1')$, which is rigidly connected to the non-circular gear, rotates company with gear around axis O_1Z_1 with an angular velocity of ω_1 in clockwise direction. And coordinates S_1, S_1' are overlapped at the initial time. Likewise, the moving coordinate $S_2'(X_2'Y_2'Z_2')$ is rigidly connected to the curve-face gear, which rotates around axis O_2Z_2 with an angular velocity of ω_2 in counter-clockwise direction, and overlapped with the static coordinate $S_2(X_2Y_2Z_2)$ in the initial time as well.

In Fig. 1, point P_1 is a point on the pitch curve of the non-circular gear; point P_2 is a point on the pitch curve of the curve-face gear. They are overlapped at point P when the non-circular gear rotates an angle of φ_1 in clockwise direction and the curve-face gear rotates an angle of φ_2 in counter-clockwise direction. And the two pitch curves are tangent, hence

$$r(\varphi_1)\cdot\omega_1 = R\cdot\omega_2 \tag{6}$$

Afterwards, the value of ϕ_2 can be calculated as

$$\varphi_2 = \int_0^{\varphi_1} \frac{1}{i_{12}} d\varphi = \int_0^{\varphi_1} \frac{\omega_2}{\omega_1} d\varphi = \int_0^{\varphi_1} \frac{r(\varphi)}{R} d\varphi \tag{7}$$

In the light of the movement relationship between the two gears of the curve-face gear pair, a relationship about the axis O_1Z_1 of rotation exists between the static coordinate $S_1(X_1Y_1Z_1)$ and the moving coordinate $S_1'(X_1'Y_1'Z_1')$, so do the curve-face gear about axis O_2Z_2. And the static coordinate $S_1(X_1Y_1Z_1)$ and $S_2(X_2Y_2Z_2)$ have a relationship about O_1Y_1 (O_2Y_2) of rotating 90°.

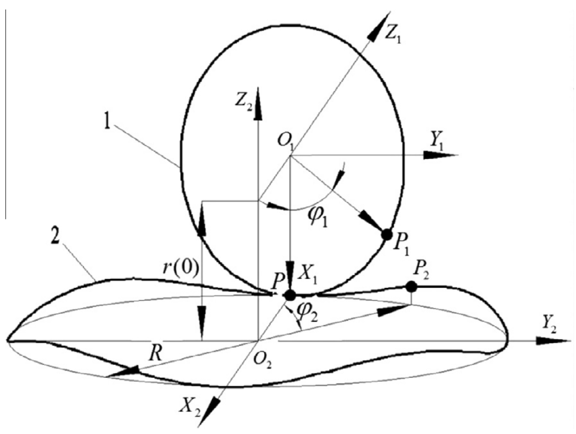

Fig. 1. Pitch curves of the curve-face gear pair. 1-non-circular gear, 2-curve-face gear, a = 35.822, k = 0.1, n_1 = 2, n_2 = 4.