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Precision compensation method for tooth flank measurement error of hypoid gear

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ABSTRACT

When measuring the tooth flank of hypoid gear, the measurement datum surface (the large end surface of the gear) does not always coincide with the design bases (the theoretical mounting distance), and this non-coincidence error would affect the tooth flank measurement results. Based on the measurement theory of the hypoid gear tooth flank, a precision matching method of the theoretical tooth surface and the measured tooth surface is designed, the objective function of the tooth flank matching method is established, and the search iterative method was used to calculate the compensation value of the measurement error of the tooth flank, when the two gear tooth surface is most accurately matched. As the mounting distance of the hypoid gear changes, two experiments are done to verify the proposed method. The experiment results show that, for different tooth flank of the measured gear, the measuring error of the tooth flank along *Z*-axis dropped significantly after compensated by this method, more than 80% of the error along *Z*-axis are compensated. It is obvious that this method could improve the measurement accuracy of the tooth flank form of hypoid gear.

1. Introduction

For the measurement of gear tooth form, many research and development have been conducted, regarding to high-precision measurement method [1] and evaluation method of measurement accuracy [2–7]. But those research were conducted on super and helical gears, and not so much research have been conducted for bevel and hypoid gears.

Hypoid gears are widely applied in the automotive industry for transformation of rotation between crossed axes. The accuracy of the tooth flank would directly affect the lifetime, noise and vibration of the hypoid gears [8,9]. However, the tooth surface of the hypoid gear is an inclined complex twist surface, and it is difficult to measure accurately [10].

When measuring the tooth flank by CNC gear measuring machine, the gear is mounted on the rotary table of the measuring machine, and the measurement datum surface is the large end surface and its center axis. For the completed hypoid gear set, this datum surface could be different from the theoretical mounting distance, which is considered as the design bases, because the differences can be adjusted by shims when the gear set is assembled, by checking tooth contact pattern. But this non-coincidence error of datum surface affects the tooth flank form measurement results significantly. To improve the measurement accuracy of the tooth flank form of the hypoid gear, the non-coincidence error should be researched and compensated.

Recently, some methods are used in tooth flank form modification and tooth contact analysis [11–16], coordinate measurement of tooth form [17–20], and so on. And the research of gear performance analysis based on measured tooth form was also conducted [2] and it is shown that to predict the performance actual gear set, it is important to utilize accurate measured data of them.

Simon discussed the influence of the offset and misalignment error along the pinion and gear axis, and designed the corresponding computer program to compensate the errors [21]. Peng et al. researched the eccentricity error of the hypoid gear off its rotational axis, and proposed methods to investigate the effects on the gear dynamic analysis [22]. Chen and Yan provided that using the truncated singular value decomposition and the *L* curve method to solve the identification equation of the tooth surface deviation could got more precisely results [23]. By compare the experiment results, Gabiccini et al. showed that the least squares method presents some advantages on the compensation and modification of the tooth surface [24]. Using the virtual conjugate tooth flank as the reference flank, Kubo et al. researched the measurement error of the tooth flank and the corresponding tooth contact

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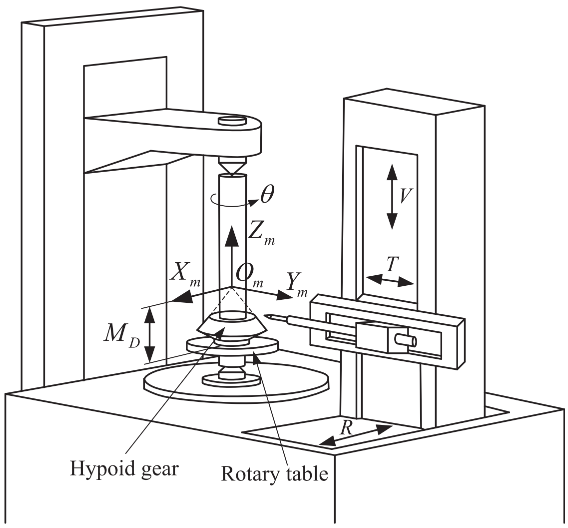

Fig. 1. The schematic drawing for the measurement and theoretical coordinate systems.

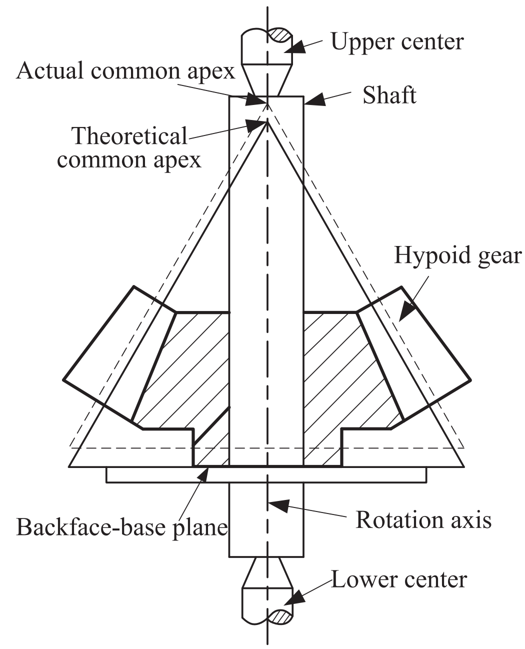

Fig. 3. The measurement error of the hypoid gear.

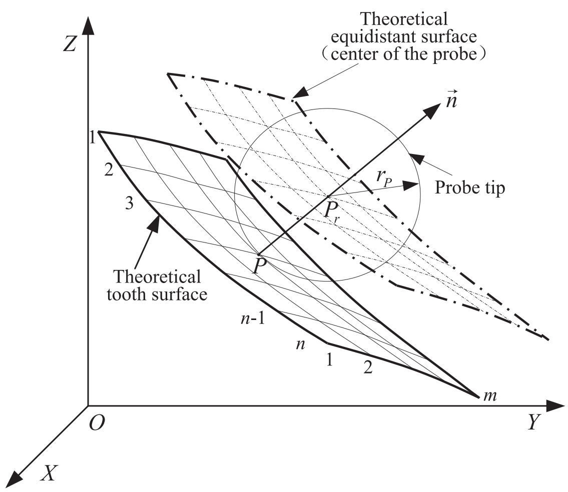

Fig. 2. The theoretical tooth surface and its equidistant surface.

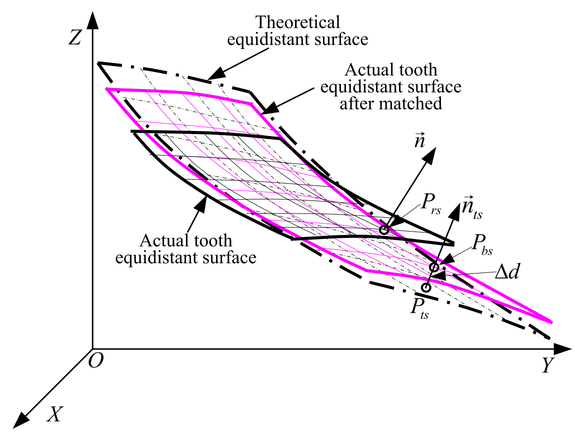

Fig. 4. The matching between the theoretical and actual equidistant surfaces.

patterns [25]. Shunmugam reported a method of determining the normal deviation from the idealized surface of the bevel gear, and do experiment to obtain the bevel gear's normal deviation to verify the proposed method [26]. However, few work have been focused on the measurement error of the hypoid gear that caused by the non-coincidence error of the datum surfaces of the gear.

This paper designs the precision matching method between the theoretical tooth flank and the actual measurement tooth flank. And as a first step using measurement data of each flank separately, compensates the measurement error along and around the Z-axis precisely. The experiments shows that the accuracy of the tooth flank measurement results improve significantly after compensated by the proposed precision compensation method.

2. Measuring theory of the hypoid gear

When measuring the hypoid gear by the CNC gear measuring machine, the measured gear is mounted on the rotary table, the table rotates around the rotation axis between the upper center and the lower center. The rotation axis of the measured gear will be coincide with the θ-axis (the theoretical axis of the gear), and vertical to the base plane (the large end of the gear). The theoretical pitch cone apex of the gear will be determined by the V-axis coordinate value of the base plane and the mounting distance M_D of the gear, as shown in Fig. 1, and the actual pitch cone apex is considered coincided with the theoretical apex.

Establish the coordinate system as shown in Fig. 1, the theoretical gear axis is coincided with the θ-axis, and the large end of the gear is mounted on the rotary table. The measurement coordinate system (O_m: X_m, Y_m, Z_m) coincides with the gear theoretical coordinate system (O: X, Y, Z), the origin of the measurement coordinate system O_m locates on the theoretical pitch cone apex, the Z-axis has the same direction as θ-axis (parallel to V-axis), the X-axis and Y-axis parallel to the R-axis and T-axis, respectively.

The measured tooth surfaces are defined by a grid of discrete points (the measured points), each of them combined with its unit normal vector [20–27]. The measured points are named as (i, j), where $(i = 1, 2, \ldots, m)$ is the row number along the profile direction, and $(j = 1, 2, \ldots, n)$ is the column number along the face width direction.