Precision Engineering 34 (2010) 667–674

Contents lists available at ScienceDirect

Precision Engineering

journal homepage: www.elsevier.com/locate/precision

Evaluation of instruments for helix measurement using wedge artifact

Yohan Kondo[a,*], Koshi Kondo[a], Sonko Osawa[a], Osamu Sato[a], Masaharu Komori[b], Fumi Takeoka[b], Aizo Kubo[b], Kazuhiko Okamoto[b], Kazuyuki Sasajima[c]

[a] Dimensional Standards Section, National Metrology Institute of Japan, AIST, Umezono 1-1-1, Tsukuba, Ibaraki, Japan
[b] Department of Mechanical Engineering and Science, Kyoto University, Yoshidahonmachi, Sakyo-ku, Kyoto-shi, Kyoto, Japan
[c] Department of Mechanical and Environmental Informatics, Tokyo Institute of Technology, Ookayama 2-12-1, Meguro-ku, Tokyo, Japan

ARTICLE INFO

Article history:
Received 10 March 2009
Received in revised form
11 November 2009
Accepted 9 January 2010
Available online 19 March 2010

Keywords:
Gear measuring instrument
Wedge artifact
Helix
Plane
Calibration

ABSTRACT

The degree to which the helix measurement accuracy of a gear measuring instrument (GMI) can be calibrated on the sub-micrometer order is limited when using a gear artifact. We propose a new method conducting GMI accuracy evaluation using a wedge artifact (WA) whose plane is treated as the tooth flank. This paper reports (i) a method of measuring the WA with a GMI, (ii) theoretical equation for calculating geometric deviation between a helicoid generated around a reference cylinder by the GMI and the plane of the WA, (iii) useful equations for designing the WA obtained from an analysis of the theoretical equations, (iv) a method of evaluating the helix measurement accuracy with respect to the obtained result, (v) the effect of the setting accuracy of the WA on the GMI, and (vi) evaluation result of a GMI helix measurement accuracy using a WA which we fabricated. Finally, sub-micrometer evaluation was found to be possible.

© 2010 Published by Elsevier Inc.

1. Introduction

Gears manufactured in many countries are traded actively worldwide. Products of high reliability by common world standards are therefore required. ISO standard [1] recommends that a series of traceably calibrated gear artifacts be used to verify the measurement uncertainty of gear measuring instruments (GMIs). The literature [2] discusses the results of round-robin test between the national metrological institutes (NMIs). Currently, measurements for tooth profile and helix are performed at an uncertainty (U_{95}) of 1–2 μm.

On the other hand, high-accuracy gears (ISO 1328-1, grades 0–2) are required to have an accuracy allowance in the sub-micrometer to few micrometer range. But it has been pointed out that no system for ensuring this accuracy allowance exists [3]. A major reason for this is that high-accuracy calibration has been difficult because the gear artifact has waviness and roughness owing to the complex shape of the tooth flank. In order to overcome this problem, the National Metrology Institute of Japan/AIST (NMIJ) developed the double ball artifact (DBA) as a new artifact for evaluating tooth profile measurement accuracy [4]. By measuring a cross-section circle of a high-accuracy ball instead of a gear profile, the GMI could be evaluated to the sub-micrometer order from the deviation between the ball and gear tooth profile [5]. Also, we proposed a multiball artifact (MBA), which is an extension of the DBA, for evaluating tooth profile and pitch measurement accuracy [6,7].

Based on the same thinking of using a simple feature, Kubo, one of the authors, conceived of the evaluation method of helix measurement accuracy using a plane. The idea was discussed at the Japan Gear Manufacturers Association (JGMA) committee on the tooth lead standard and a wedge artifact (WA) was proposed but evaluation to the sub-micrometer order was not achieved [8].

We developed a new GMI evaluation method for helix tooth form using a novel WA and realized sub-micrometer order GMI evaluation for the first time. This paper sets forth the following:

(i) WA measurement method,
(ii) theoretical equation for calculating geometric deviation between a plane and a helix curve,
(iii) useful equations for designing the WA,
(iv) evaluation method of GMI helix measurement accuracy,
(v) effect of setting accuracy of the WA,
(vi) evaluation result of a GMI helix measurement accuracy.

2. Principle of measurement

2.1. Wedge artifact

The WA is for evaluating the helix measurement accuracy of GMIs. It consists of a reference axis, a measurement plane making

* Corresponding author. Tel.: +81 29 861 6801; fax: +81 29 861 6801.
E-mail address: kondou.y@aist.go.jp (Y. Kondo).

0141-6359/$ – see front matter © 2010 Published by Elsevier Inc.
doi:10.1016/j.precisioneng.2010.01.008

Nomenclature

r	radius of reference cylinder (circle)
d	diameter of reference cylinder (circle)
r_b	radius of base cylinder (circle)
r_p	radius of probe tip
b	face width
α_n	normal pressure angle
α_t	transverse pressure angle
β	helix angle on reference cylinder
Ω	angle between wedge artifact measurement plane and reference axis
O	origin of work (WA) coordinate system
ξ	axis of work (WA) coordinate system in measurement plane
η	axis of artifact in a right-handed coordinate system
η_0	distance in η axis direction from origin to center of probe tip at initialization
ζ	axis of work (WA) coordinate system coinciding with reference axis
X	axis of GMI in a right-handed coordinate system
Y	axis of measuring (GMI) coordinate system parallel to line of action
Y'	axis parallel to Y axis that contacts gear base circle (line of action)
y_0	Y coordinate of center of probe tip at initialization
Z	axis of measuring (GMI) coordinate system that is gear rotation axis
z_w	Z-axis coordinate of center of probe tip
z_{wp}	Z coordinate of WA helix deviation curve peak or bottom
z_{pp}	Z axis direction difference between WA helix deviation curve peak and bottom
ε_0	angle between X axis and ξ axis at initialization
δ_h	WA helix deviation
δ_{hpp}	height difference between WA helix deviation curve peak and bottom
e_η	eccentricity in η axis direction of reference axis (ζ axis)
$e_{\Omega\max}$	Displacement of ζ axis in η axis direction at z_w of end of (+) side of evaluation range
L_e	evaluation range for helix measurement accuracy
F_β	total helix deviation
Q	accuracy grade (ISO 1328-1:1995)

a certain angle with the reference axis, and a reference for the origin of the work coordinate system of the WA. The WA is obtained by cutting a cylinder of slightly greater diameter than the reference cylinder of the subject gear at an angle nearly the same as the helix angle of the gear being measured. An example is shown in Fig. 1. The reference axis of the WA is treated as the rotation axis of gear, the measurement plane is treated as the tooth flank, and the GMI measures the helix of the plane. The measurement accuracy of the GMI is evaluated by comparing the theoretically calculated deviation between helicoid generated around the reference cylinder by the GMI and the WA measurement plane.

In the work coordinate system of the WA, as shown in Fig. 1, the reference axis is denoted by the ζ axis, the axis lying in the measurement plane and orthogonal to the ζ axis as the ξ axis, and the axis orthogonal to the ξ axis and ζ axis as the η axis. In the example of Fig. 1, the reference axis is defined as the center axis of cylinder. The origin of work coordinate system can be defined as the intersection of the measurement plane and the reference axis.

2.2. Measurement scheme

Fig. 2 shows a typical GMI for gear helix measurement. The GMI has three orthogonal axes X, Y and Z. The Z axis is the rotation axis. The probe tip exhibits sensitivity in the direction of the line of action. The Y axis is parallel to the line of action. The helicoid curve is generated in the way that the probe moves straight in the direction of the Z axis and the subject gear rotates around the Z axis. The WA is set in the GMI so that the WA reference axis (ζ axis) coincides with the rotation axis (Z axis) of the GMI (see Fig. 3). The origin of the measuring coordinate system at this time is established at the same location as the origin of the WA.

In ordinary helix measurement [9], the probe tip is first brought into contact with the tooth flank to set the position of the gear in the measuring coordinate system. The probe tip scans the tooth flank from one end of the face width to the other end. In the WA measurement method proposed in the paper, helix measurement can be performed in the ordinary manner. However, the probe tip must be spherical, because a contact point of the probe tip with the WA measurement plane varies by the position of the probe tip. First, the probe tip center coordinate (x_0, y_0, z_0) is defined as:

$$\begin{pmatrix} x_0 \\ y_0 \\ z_0 \end{pmatrix} = \begin{pmatrix} r_b \\ \pm(r_b \tan\alpha_t + r_p) \\ 0 \end{pmatrix}, \tag{1}$$

where r_b, α_t are the base circle radius and transverse pressure angle of the subject gear and r_p is the probe tip radius. The (+) and (−) of the double sign indicate gear with left hand teeth and gear with right hand teeth, respectively. α_t and r_b are calculated by:

$$\alpha_t = \tan^{-1}\left(\frac{\tan\alpha_n}{\cos\beta}\right) \tag{2}$$

$$r_b = r\cos\alpha_t, \tag{3}$$

where α_n, β and r are the normal pressure angle, helix angle on reference cylinder and radius of the reference cylinder of the subject gear.

With the probe tip in the aforesaid position, only the WA is rotated around the Z axis and brought into contact with the probe tip. Once the probe tip and WA have been initialized, measurement is performed as in ordinary helix measurement. The GMI outputs the difference between the plane and the helicoid. Fig. 3 shows the initially set state and Fig. 4 shows the helix measurement state after the probe tip has moved by z_w in the Z axis direction from the initial position.

3. Evaluation method of GMI helix measurement accuracy

3.1. Calculation of theoretical WA helix deviation

The theoretical equation for calculating the deviation between the WA measurement plane and the helix curve of the gear being measured is derived as follows. Considering the initial state of Fig. 3, assume that in the normal section to the Z axis that passes through the coordinate origin, the probe tip and the imaginary involute curve passing through the intersection of the reference circle radius r and the line of action meet at point I. Assume that the GMI measures the helicoid around the reference cylinder that passes through the point I. Then the following equations are obtained:

$$\eta_0 = \frac{r_p}{\cos\Omega} \tag{4}$$

$$\tan\varepsilon_0 = \frac{r_b\,|y_0| - \eta_0\sqrt{r_b^2 + y_0^2 - \eta_0^2}}{r_b^2 - \eta_0^2} \tag{5}$$

In the state of the helix measurement after the center of the probe tip has moved by z_w in the Z axis direction (see Fig. 4), the

Download English Version:

https://daneshyari.com/en/article/805228

Download Persian Version:

https://daneshyari.com/article/805228

Daneshyari.com