Calibration method of in-line gear measuring machine

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Gear measurement technology in metrology room is well-developed, but how to inspect the gears fast in workshop is a problem. Therefore, the In-line Gear Measuring Machine (GMM) based on the double-flank gear rolling test with many degrees of freedom was developed. The radial composite deviations and tangential deviations can be evaluated during one inspection. The measurement principle was mentioned in brief, while the calibration method of the GMM and the definition & design of the special gears used in calibration including the special workpiece, special slope gear and special taper gear were introduced.

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NOMENCLATURE

$X_{R1}[i]$, $X_{R2}[i]$, $X_R[i]$ =center distance between workpiece and master gear, (μm)

$X_{L1}[i]$, $X_{L2}[i]$, $X_R[i]$ =displacement between workpiece and gimbal master gear in tangential direction, (μm)

$X_{C1}[i]$, $X_{C2}[i]$, $X_R[i]$ =displacement between workpiece and gimbal master gear in radial direction, (μm)

X_{R0} =zero position of radial sensor, (μm)

X_{L0} =zero position of helical slope sensor, (μm)

X_{C0} =zero position of helical taper sensor, (μm)

G_L =calibration coefficient of helical slope wobble

G_C =calibration coefficient of helical taper wobble

$i = 1..N$

LV , LV_0 =radial composite helical slope deviation

LT , LT_0 =radial composite helical taper deviation

F_i'' =radial composite deviation

1. Introduction

Gear measurement is very important in gears industry[1,2]. The 2010 annual gross output value of gears industry in China is nearly 140 billion RMB according to the statistics of CGMA(China Gear Manufacturers Association) [3], 2/3 of the total amount is from vehicle gears, which needs to be inspected 100% in workshop.

Gear measurement technology in metrology room is well-developed, but how to inspect the gears fast in workshop is difficult[4-6]. Generally, double-flank gear rolling test was applied to the workshop gear measurement because of the following characteristics[7-9]: simple measurement principle, high efficiency, less requirements concerning the environment, and easy manufacturing of the master gear.

The traditional double-flank gear rolling test can only inspect the radial composite deviations. The deviations as helix & taper is also very important to the gear quality. To solve the problem, the In-line Gear Measuring Machine (GMM) based on the double-flank gear rolling test with many degrees of freedom was developed[10]. The radial composite deviations and tangential deviations can be evaluated during one inspection in GMM.

This paper described the measurement principle of GMM briefly, while the calibration method and the definition and design of the special gears used in calibration were introduced as emphases. The special gears were used in calibration including the special workpiece, special slope gear and special taper gear. During the measurement the master gear and gimbal master gear was used(Fig.1).

2. Measurement Principle of GMM

2.1 Measurement Principle

The Measurement principle of the double- flank gear rolling test with many degrees of freedom is shown in Fig.1. When the produced gear (3) is meshing with one master gear (2) and one gimbal master gear (4) under the absence of backlash, the center distance discrepancies ($\Delta\alpha$) and the axial wobbles ($\Delta\omega_C$ & $\Delta\omega_L$) are simultaneously obtained by an radial sensor (1), a helical slope sensor (5) and a helical taper sensor (6). The radial composite deviations and the tangential deviations (helix, taper, etc.) of the produced gear can be assessed by a data processing system.

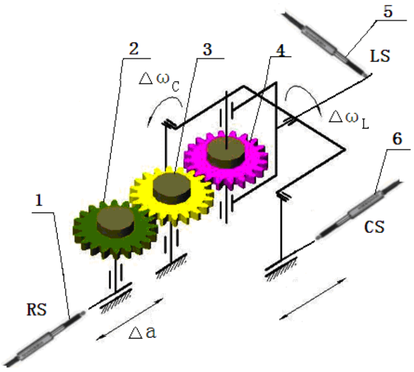

Fig.1 Measurement principle

2.2 Data Processing before Evaluation

The original data $X_{R1}[i]$, $X_{L1}[i]$, $X_{C1}[i]$ are obtained respectively through the radial sensor, the helical slope sensor and the helical taper sensor. Take into account the zero position of each sensor & the calibration coefficient, the original data should be transformed according to the following equation:

$$\begin{cases} X_{R2}[i] = X_{R1}[i] - X_{R0} \\ X_{L2}[i] = G_L \cdot (X_{L1}[i] - X_{L0}) \\ X_{C2}[i] = G_C \cdot (X_{C1}[i] \text{-} X_{C0}) \end{cases} \tag{1}$$

The zero position of each sensor is concerned in calculating the functional tooth thickness, and the meaning of the calibration coefficient is to get the calibrated enlarger scale of the helical slope & taper deviations through mechanisms.

2.3 Evaluation of the Deviations

The radial composite deviation, radial composite helical slope deviation, radial composite helical taper deviation are evaluated from the transformed data $X_{R2}[i]$, $X_{L2}[i]$, $X_{C2}[i]$ as the following equations (2)-(4).

The radial composite deviation:

$$F_i'' = Max(X_{R2}[i]) - Min(X_{R2}[i]) \tag{2}$$

The radial composite helical slope deviation:

$$LV = Max(X_{L2}[i]) - Min(X_{L2}[i]) \tag{3}$$

The radial composite helical taper deviation:

$$LT = Max(X_{C2}[i]) - Min(X_{C2}[i]) \tag{4}$$

3. Calibration Method of GMM

3.1 Calibration Method

The zero position of each sensor & the calibration coefficient of helical wobble should be calibrated before measurement. Special gears for calibration were used during calibration, including special workpiece, special slope gear, and special taper gear. The zero position of radial sensor X_{R0} is defined by the mean value of the center distance discrepancies $X_R[i]$ obtained by the radial sensor when the special workpiece is meshing with one master gear and one gimbal master gear under the absence of backlash. The zero position of helical slope sensor X_{L0} is defined by the mean value of axial wobbles $X_L[i]$ obtained by the helical slope sensor when the special workpiece is meshing with one master gear and one gimbal master gear under the absence of backlash. The zero position of helical taper sensor X_{C0} is defined by the mean value of axial wobbles $X_C[i]$ obtained by the helical taper sensor when the special workpiece is meshing with one master gear and one gimbal master gear under the absence of backlash.

$$\begin{cases} X_{R0} = \dfrac{1}{N}\sum_{i=1}^{N} X_R[i] \\ X_{L0} = \dfrac{1}{N}\sum_{i=1}^{N} X_L[i] \\ X_{C0} = \dfrac{1}{N}\sum_{i=1}^{N} X_C[i] \end{cases} \tag{5}$$

$$\begin{cases} G_L = \dfrac{\Delta T}{LV_0} \\ G_R = \dfrac{\Delta R}{LT_0} \end{cases} \tag{6}$$

The calibration coefficient of helical slope wobble G_L 、 calibration coefficient of helical taper wobble G_R was defined by equation (6), where ΔT is the theoretical value of radial composite helical slope deviation calculated by the parameters of special slope gear, LV_0 is the actual measuring value of radial composite helical slope deviation when the special slope gear is meshing with master gear and gimbal master gear under the absence of backlash. ΔR is the theoretical value of radial composite helical taperdeviation calculated by the parameters of special taper gear, LT_0 is the actual measuring value of radial composite helical taper deviation when the special taper gear is meshing with master gear and gimbal master gear under the absence of backlash.

3.2 Design of the Special Gears for Calibration

3.2.1 Design of the Special Workpiece

Special workpiece is used to calibrate the zero position of each sensor. The parameter of the special workpiece is the same of the gear to be inspected, but the accuracy 3-grades higher.

3.2.2 Design of the Special Slope Gear

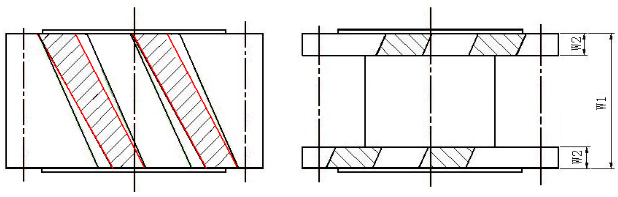

Fig.2 Special slope gear & gimbal master gear

Special slope gear is used to calibrate the calibration coefficient of helical slope wobble G_L . Special slope gear is defined with the following three characteristics: helix angle of left flank β_{LL} is equal to the helix angle of right flank β_{LR} （Fig.2）, which has increment $\Delta\beta_L$ to the helix angle of master gear β as equation (7), high accuracy.

$$\beta_{LL} = \beta_{LR} = \beta + \Delta\beta_L \tag{7}$$

The significant function of special slope gear is to supply the theoretical value of radial composite helical slope deviation ΔT calculated by the parameters of special slope gear, and inspect the special slope gear in GMM to get the measuring value, then the calibration coefficient of helical slope wobble G_L can be calculated by equation (6). ΔT is calculated through the function (8), where W_1 is the total width of gimbal master gear, W_2 is the tooth width at both sides of gimbal master gear.

$$\Delta T = (W_1 - W_2)(\tan\beta_{LL} - \tan\beta) \tag{8}$$

Example of the calculation of ΔT : $W_1 = 28mm$, $W_2 = 4.6mm$, $\beta = 24^\circ$, $\beta_{LL} = \beta_{LR} = 24^\circ 2'$, $\Delta T = 16.3\mu m$ 。

3.2.3 Design of the Special Taper Gear

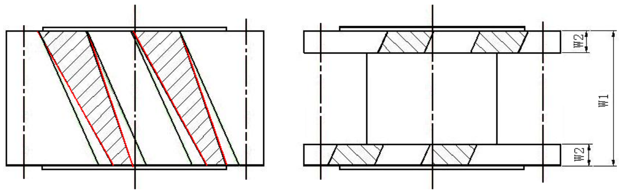

Fig.3 Special taper gear & gimbal master gear

Special taper gear is used to calibrate the calibration coefficient of helical taper wobble G_R . Special taper gear is defined with the following three characteristics: helix angle of left flank β_{CL} is different to the helix angle of right flank β_{CR} , which has increment $\Delta\beta_C$ to the helix angle of master gear β as equation (9), high accuracy.

$$\begin{cases} \beta_{CL} = \beta + \Delta\beta_C \\ \beta_{CR} = \beta - \Delta\beta_C \end{cases} \tag{9}$$

The key function of special taper gear is to supply the theoretical value of radial composite helical taper deviation ΔR calculated by the parameters of special taper gear, and inspect the special taper gear in GMM to get the measuring value, then the calibration coefficient of helical taper wobble G_L can be calculated by equation (6). ΔR is calculated through the function (10), where α is pressure angle, W_1 is the total width of gimbal master gear, W_2 is the tooth width at both sides of gimbal master gear.

$$\Delta R = (W_1 - W_2)(\tan\beta_{CR} - \tan\beta_{CL})\cos\alpha / \sin\alpha / 2 \tag{10}$$

Example of the calculation of ΔR : $W_1 = 28mm$, $W_2 = 4.6mm$, $\alpha = 20^\circ$, $\beta_{CL} = 24^\circ 2'$, $\beta_{CR} = 23^\circ 58'$, $\Delta R = -44.8\mu m$ 。

4. Measuring Procedure in GMM

Gear measuring machine was designed according to the measurement principle(Fig.1), which was shown in Fig.4, including three parts: the mechanical base unit, the measuring and auto-control hardware, and the data processing software.

During the calibration stage, the special workpiece, special slope gear, and the special taper gear was used to mesh with master gear and gimbal master gear under the absence of backlash. In the measurement stage, its the produced gear meshing with master gear and gimbal master gear under the absence of backlash.

The working principle of the GMM is as follows. After the initialization of the hardware has been executed successfully, air cylinder clamps the produced gear shaft, another two air cylinders go forward to apply the measuring force, and motor rotates subsequently to drive the produced gear, the master gear and the gimbal master gear, while the data acquisition is carried out by the radial sensor, the helical slope sensor, and the helical taper sensor. When the measurement is completed, the motor is stopped and the air cylinders are withdrawn. The deviations are evaluated by analyzing the obtained data. The inspection results can be saved and inspection reports can be browsed and printed.

Fig.4 Gear measuring machine(GMM)

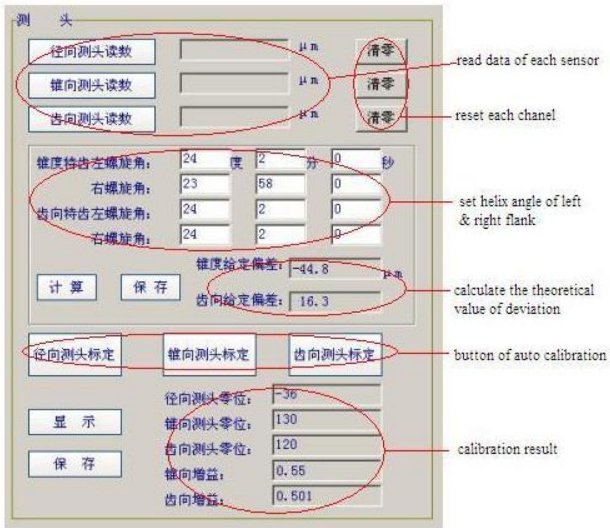

Fig.5 Calibration interface

While in the calibration stage, in the interface of calibration showed in Fig.5, the helix angle of left & right flank of special slope gear & special taper gear should be set, and the theoretical value of radial composite helical slope deviation ΔT & the theoretical value of radial composite helical taper deviation ΔR will be calculated automatically, after clicking the auto calibration button and a series action executed as described in the working principle of the GMM, the calibration result will be calculated and displayed in the interface, which will be used in the latter measurement.

5. Conclusions

To inspect the gears fast in workshop is very important. So Gear measuring machine(GMM) was designed according to the measurement principle of the double-flank gear rolling test with many degrees of freedom. Data processing method before evaluation was introduced, while the zero position of each sensor & the calibration coefficient should be calibrated. During the calibration stage, the special workpiece, special slope gear, and the special taper gear was used to mesh with master gear and gimbal master gear under the absence of backlash. The design of the special gears for calibration was given and the calibration interface of software was described.

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REFERENCES

1. GOCH G, "Gear metrology", Annals of the CIRP, Vol. 52, No. 2, pp. 659-695, 2003.
2. Rudolf, "History of Gear Measuring Machines and Traceability 1900-2006", Gear Product News, No.10, pp.20-25, 2006.
3. SHI Zhao-yao, “Gear measuring machine”, 2011China Gears Industry Yearbook, Beijing Institute of Technology Press, pp. 183-187, 2006.
4. BAI Yong-xin, “Gear accuracy and composite inspection”, Shanghai Scientific and Technical Publishers, pp. 15-30, 1986.
5. HUANG T N, "The development of gear integrated error measurement in China", Proceedings of Inter. Conf. of Gearing, pp. 25-31, 1989.
6. SHI Zhao-yao, FEI Ye-tai and XIE Hua-kun, "100 years of gear measurement technology—review & prospect", Engineering Science, Vol.5, No.9, pp. 13-17, 2003.
7. Y. Kawasaki, M. Shinoda, et al, "Development of a New Automatic Gear Selecting Machine for Automobile Transaxle Manufacturing", Annals of the CIRP, Vol.33, No.1, pp.363-368, 1984.
8. ITW Heartland, www.itwheartland.com
9. FRENCO GmbH, www.frenco.de
10. Shi Zhaoyao, Tang Jie, Wei Hualiang, et al, “Gear In-line Measuring Machine Based on Double-flank Gear Rolling Test with many Degrees of Freedom”, Chinese Journal of Scientific Instrument, 2009, Vol.30, No.2, pp.303-307.