

Development of Ultra precise Gear Measuring Instrument

First report: Evaluation on the Accuracy of Principal Axis

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1. Introduction

High precision gears, with geometrical accuracy of sub-microns in the field of motion control machine systems such as high precise industrial robots, are steadily becoming required for their accurate operation and for their smaller sizing demands by means of finer module gears and less-back lash system.

In order to produce such high precise gears, every tools and machines used in the process must be ultra precise. At the same time the measuring instrument with accuracy of one order higher than the quality of finished products should be used.

However, the reality of attainable accuracy of existing measuring instruments in the market is at most around 3~5 [μm].

The authors keenly felt that an ultra-precise measuring machine should be developed urgently for the purpose of research, experimental make and actual production as well.

The obtained result on the accuracy of the principal axis movement, will be described within the first report of this project.

2. The Target of the Accuracy on the Measuring Machine

The accuracy target with this Measuring Machine

We plan to construct an Ultra-precise three dimensional gear measuring machine with pure mechanical open system to measure the individual deviations (tooth profile, tooth lead, pitch, run-out etc.), also to eliminate the measuring errors and to improve the accuracy less than 0.1~0.3 [μm] in linear deviation and less than 1 [arc-sec'] in index deviation.

3. The Mechanism and Specifications

The machine consists of the two dimensional (X, Y) rectangular traveling table attached with measuring probe, and the traveling axis in vertical (Z) together with rotational (θ) motion for gear to be measured. The most remarkable point of the structure with this measuring instrument is that the indexing (θ) axis has vertical (Z) axis up and down motion.

The positioning mechanism for each axis in three rectangular directions (X, Y, Z) are using high precise trapezoidal lead screws, thread with 20°in (half) angle, which are driven by pulse-motors through Harmonic-drive

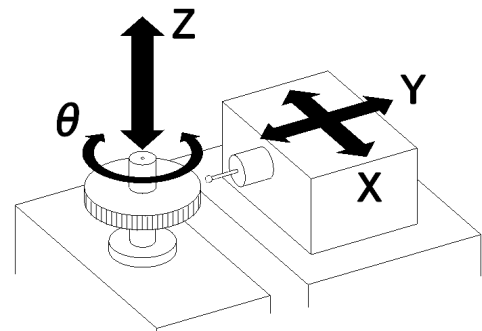


Fig. 1. Schematic view of mechanism.

reduction units.

The strokes along X, Y and Z directions are 160, 150 and 130 mm respectively.

The X-axis is guided with parallel guide bars of different diameter, having a pair of cylinder type air bearings for each guide bars. And the Y-axis is guided with a pair of parallel V-groove slides and two pair of cylinder type air bearings on each side for the table weight balancing.

The Z-axis is linearly guided with two pairs of cylinder type air bearings with different diameter, the upper pair is guide for Z-axis motion and indexing θ -rotation and the lower pair is for linear Z-motion guide only. For the purpose of indexing torque bearings a pair of additional guide ways along with Z-axis are equipped with a cylinder type air bearings for each guide bars.

The center support for the gear to be measured on upper portion of the machine is linearly guided with a pair of cylinder type air bearings.

The θ -rotation axis is guided with the cylinder type air bearing which shares its function with Z-axis guide, and is equipped with ultra precise axial type air bearing at the connecting area between upper Z- θ -axis and lower Z-feed mechanism.

The ultra-precise internal gear indexing system is installed between these axes and is driven by pulse-motor. Additional rotary-encoder of 0.4 [arc-sec] guaranteed accuracy is installed between these axes for comparison measurement of the indexing error.

The differential Capacitance type two dimensional micro-displacement measuring probe is used as the sensor. The resolutions of the sensor are 10 [nm] in X-axis direction and 50 [nm] in Y-axis direction respectively. The measured data of the deviations is digitalized and stored into personal computer and analyzed to obtain required values.

The machine is settled in a climate controlled room at 23 ± 0.1 in temperature and less than 35% in humidity in order to eliminate unreliable deviations as due to heat expansion.

4. The Positional Deviations of Movement along the Guides and the measurement method of the Deviation.

For obtaining the positional deviations within 0.1~0.3 [μm], the positional deviations along X,Y,Z and θ -axis should be kept within 0.1 [μm]. Especially, the deviation on the most important axis "principal axis (Z, θ)" should be less than the above mentioned value. We aimed to keep value less than 1/10 of the mentioned value, therefore the aimed value becomes less than 10 [nm] when the axis is turning.

a) Measurement of run-out in horizontal plane.

Precisely finished inner surface of a cylinder is used as the standard surface of the measurement and the disc with 12 electrodes on the outer cylindrical surface is used as the capacitance sensor carriage. The gap between the electrodes and the standard surface is about 10 [μm] which

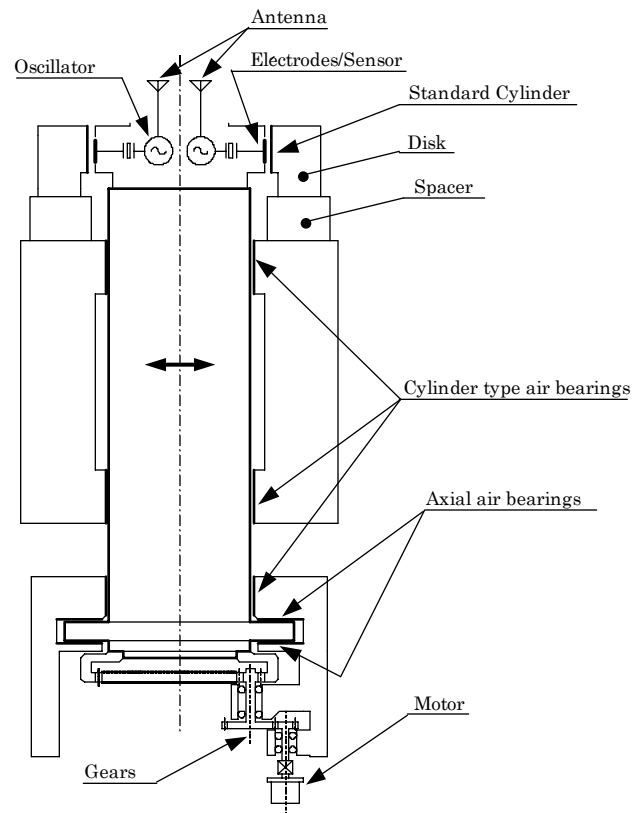


Fig. 2. Outline diagram of principal axis.

gives aimed resolution of the deviation. By turning the sensor carriage and measured signals are wireless transmitted to the computer. The measured values : $F_i(\theta)$ are expressed by the following equations.

$$F_i(\theta) = r(\theta) \cdot \cos\{\theta - (\alpha_i) + \beta_i\} + Q_i(\theta + \alpha_i)$$

$$G_i(\theta) = K_i \cdot F_i(\theta)$$

There, $r(\theta)$: run-out amplitude of principal axis
 (α_i) : phase angle from X axis in counter clockwise direction
 i : number of sensor,
 θ : rotational position of principal axis,
 β_i : angle between the first and i-th electrode,
 K_i : magnification factor of i-th electrode,
 $Q_i(\theta)$: run-out amplitude of standard surface,

By self compensation processing, the effect of geometrical deviation on the standard cylinder can be neglected and the values of the run-out are obtained through Fourier analysis with 12 phases of data.

b) Measurement of the deviation in vertical direction.

The capacitance type micro-displacement measuring probe is set on the top of the principal axis and the measured data is sent to the computer.

5. Some examples of measurements

a) Figure 3 shows the measured result of the horizontal run-out on the principal axis. Ten diagrams of datum are shown on one chart and it can be seen that the maximum value of the amplitude is less than 20 [nm].

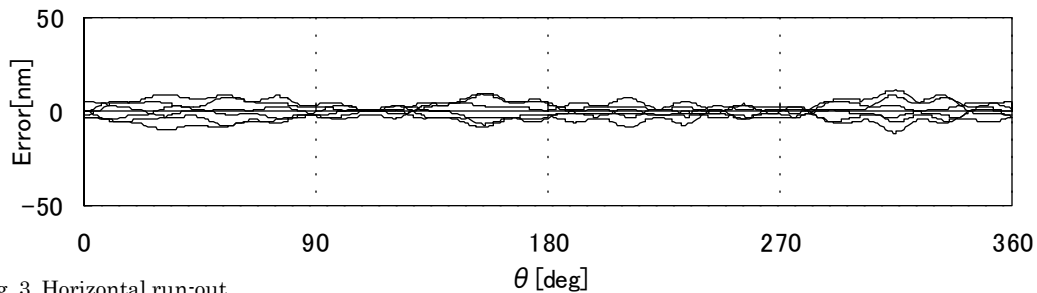


Fig. 3. Horizontal run-out.

b) Figure 4 shows the measured result of the vertical run-out on the principal axis. It can be seen also that the maximum value of the amplitude is less than 20 [nm].

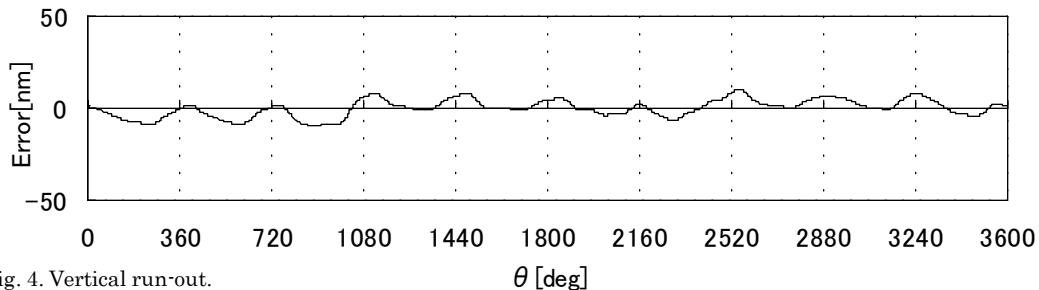


Fig. 4. Vertical run-out.

6. Discussion

- a) From the Fourier analyzed results of the measured datum on the horizontal run-out of the principal axis, 15th and 17th harmonic components in one revolution were detected with amplitude of around 3 [nm]. We are discussing about the reasons of these deviations. However, the amounts of these values are negligibly small. It is suspected that the 16th and 18th harmonics can be detected since the reduction ratio with the two stages of the gear train in this indexing system are 1/9 and 1/16. However, these were not detected actually. The unstable waving was recognized from the chart in continuous driving of the principal axis. It seems to be the result of the variation of air pressure for the air bearings, but was because of the small restriction on the way out of discharging air.
- b) The measured value of axial run-out was less than 20 [nm].
And there is one more step to achieve to the aimed value of 10 [nm]. Also, it seems to be caused by the same reason discussed above.

7. Conclusion

By combining the above discussed result with our past obtained technical result, we can foresee realization of the Ultra-precise Gear Tester.