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Accuracy verification of gear measurement with a point autofocus probe

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Abstract
It is common to use contact stylus measuring instruments for tooth flank form measurements, however, miniaturization and higher precision of parts demand for non-contact type measuring instruments. Also, the demand for measuring soft and delicate materials, such as plastic, with non-contact measuring instruments has been increasing. However, it is very difficult to measure tooth flank with a non-contact probe due to their steep angles. In order to solve the difficulty, we developed a gear measurement method with a point autofocus probe which has high angle tracking capability. In this study a master gear was measured by the gear measurement method and compared with a contact stylus measuring instrument. The result shows that the gear measurement method has correlation with the contact stylus measuring instrument in sub-micrometer level.

Keywords: point autofocus probe, non-contact, gear measurement, tooth flank form

1. Introduction

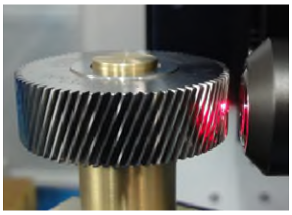
Evaluation of deviations relevant to flanks of gear teeth (ISO 1328-1) is generally carried out by contact stylus gear measuring instruments. However, microfabrication technology has been improving and high precision small gears can be mass produced in recent years. Since it is very difficult to measure contours of a small gear tooth flank with a contact stylus due to its tip diameter and its contact pressure against the tooth flank, image processing method with a microscope is used to detect edge profiles. However, the data obtained by this method is not accurate as it does not directly measure the tooth flank. Hence, direct measurement of the tooth flank by non-contact methods is in great demand. The gear measurement method with a point autofocus probe instrument (PAI) [1] was developed in order to meet this demand. This study describes this measurement method and reports on the data comparison with a contact stylus measuring instrument by measuring profile and helix forms of the master gear.

2. Measuring methods

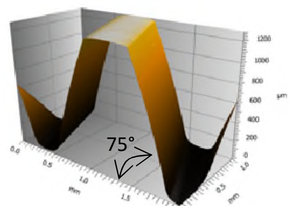
2.1. Form deviation against inclination angle

Figure 1 shows the PAI measuring the master gear (m = 0.5, z = 74, b = 13, β = 22˚) and the 3D measurement of one tooth of the master gear.

A 100X objective (NA = 0.8, WD = 3.5 mm) was used and the laser spot diameter of PAI is 1 µm. The 3D measurement result shows that the maximum inclination angle of the tooth flank is 75˚. When using an objective with numerical aperture (NA) = 0.8, the calculated maximum measurable angle is 44˚. [2] However, the master gear is grind-finished and its tooth flank has Ra = 0.15 µm surface roughness. Due to this physical property, PAI is capable of measuring even greater inclination angle. Figure 2-a shows a profile measurement result of a 1/8-inch reference sphere (roundness = 0.06 µm) which has the equivalent surface roughness to the master gear. The autofocus (AF) measured the maximum inclination angle at 89˚.

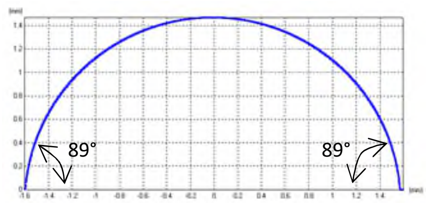


a) Master gear

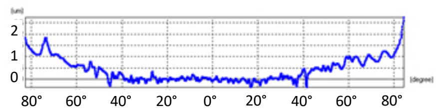


b) Tooth in 3D

Figure 1. Non contact gear measurement



a) 1/8 inch reference sphere profile



b) after removing R form

Figure 2. Form deviation against inclination

Figure 2-b shows the form deviation after removing R profile. The form deviation from the apex to ± 60˚ is within 1 µm, and the deviation becomes larger as the inclination angle increases. From this result, it is necessary to measure the tooth flank within the maximum inclination angle at 60˚ for high precision measurement with the form deviation of less than 1 µm.

2.2. Offset gear measurement method

In order to carry out the high precision measurement of the tooth flank with a steep angle, an offset gear measurement method was developed (Figure 3). This method enables to measure the tooth flank having 75˚ angle by offsetting the measuring position from the gear center at ± 8 mm. This decreases the tooth flank angle down to 50˚ for the precision measurement.

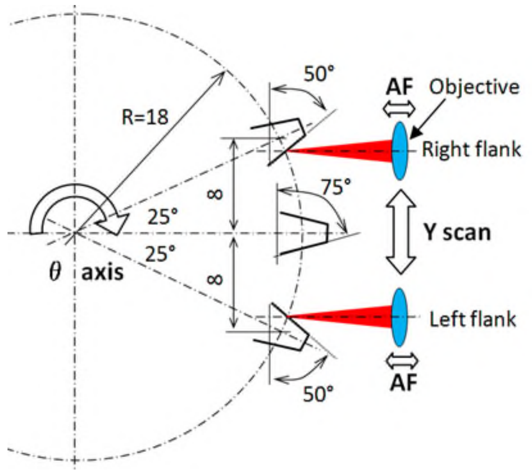


Figure 3. Offset gear measurement method

The right and the left tooth flank are individually measured. This method not only enables to measure steep angles in high precision but also to measure the tooth flank that has undercut angle greater than 90˚. For gear measurements pitch and transmission errors need to be evaluated. Hence, each profile form data is converted to polar coordinates based on the rotation center in order to generate the entire contour profile. The helix form measurement is also executed in this condition on the pitch diameter, and the helix deviation is evaluated by the tangential component of the AF axis displacement.

2.3. Gear measurement with contact stylus probe

For the comparison with a contact stylus measuring instrument, a gear measuring instrument (Osaka Seimitsu Kikai Co., Ltd.) with a tip diameter = 100 µm and the contact pressure = 0.2 N was used to measure the total profile form and helix forms.

3. Measurement result

Figure 4 shows the profile form measurement result. The tendency of the deviation curves coincide with each other, and the difference is less than 0.3 µm. Figure 5-a shows the comparisons of the profile deviations of the entire 74 teeth. The average total profile deviation of the contact stylus is $F\alpha$ = 1.08 µm where as that of the non contact (PAI) is 0.97 µm, indicating a good correlation. On the other hand, the average total helix deviation with the evaluation length = 9.3 mm for the contact stylus is $F\beta$ = 0.61 µm whereas that of PAI is 1.27 µm, indicating a slight difference. (Figure 5-b). This difference may have caused by the measurement conditions of PAI for not fixing the gear with a both end support mechanism and the axial tilt error was added to the measurement result.

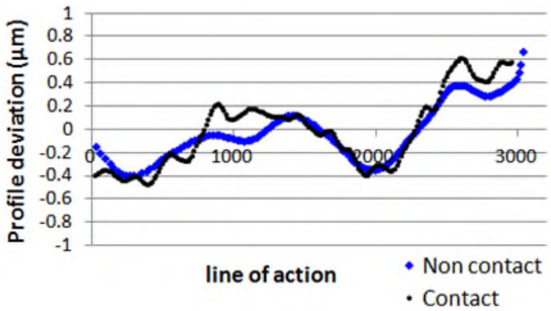


Figure 4. Profile deviation comparison

Also, the contact stylus measures flank forms in a perpendicular direction whereas PAI measures them at the inclination angle = 50˚ with the surface texture in a lateral direction (i.e. grinding tool marks). PAI may have measured the lateral surface texture, hence the result was affected.

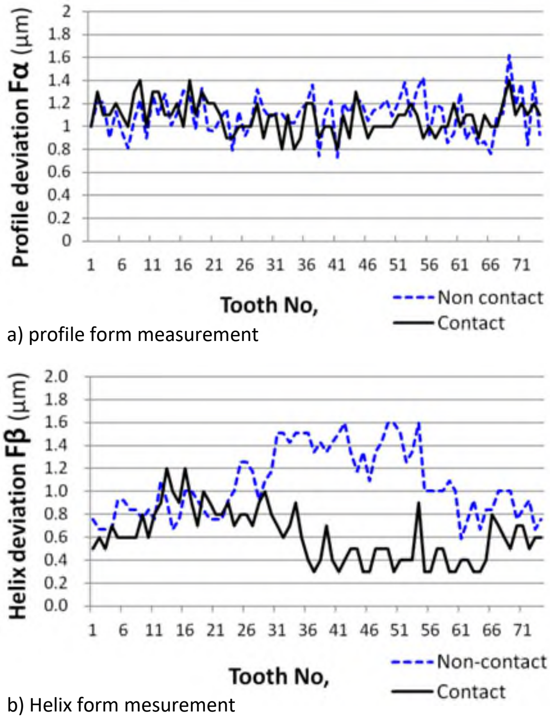


Figure 5. Comparison between contact stylus and non-contact

4. Conclusion

The non-contact gear measurement method using the point autofocus profiling was developed and compared to the contact stylus instrument by measuring the master gear. And, the following results were obtained.

1. The maximum measurable inclination angle for the machined surface with Ra = 0.1 level is 89˚ and that for the form deviation less than 1 µm is less than 60˚.
2. The offset gear measurement method with setting the measurement surface less than 60˚ allows PAI to measure the undercut with over 90˚ in high precision.
3. The average difference of the profile deviation ($F\alpha$) is 0.1 µm. On the other hand, the average difference of the helix deviation ($F\beta$) is 0.61 µm. The cause of the slight difference may have generated by the tilt error of the workpiece setting and the lateral surface texture. Hence, it is critical to select a suitable filter cutoff value for the evaluations to reduce noise such as the influence of the lateral surface texture.

Point autofocus profiling method has a high correlation with the contact stylus on roughness measurement [3], however, this study proved that it also has the high correlation in gear profile and helix form measurements in the sub-micrometer level.

References

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