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Conference Paper

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Publication date:
2020-10

Permanent link:
https://doi.org/10.3929/ethz-b-000448279

Optical Gear Inspection Using a Triangulation Sensor and an Areal Evaluation

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INTRODUCTION

Precision gears are widely used in automotive industry and wind energy applications. Gears play a major role in the quality of transmission systems in terms of generated noise, vibration, transmission capacity, lifetime, and weight. Manufacturing precision gears requires precision metrology to control the gear geometry in size and shape. So far, the classical gear measurement is based on a tactile measurement of two lines per flank, which is widely used to assess gear parameters. Because standard gear measurement is limited to four gear teeth, a line-oriented classical measurement of a cylindrical automotive gear can be performed within a few minutes period; however, it cannot represent the entire gear flank. Furthermore, modern gears have more and more sophisticated flank modifications to improve functional properties of the gearbox. Yet these geometrically structured modifications might not be captured by the line-oriented evaluation. To address these deficiencies, a new area-oriented evaluation approach was presented by Goch et al. [1]. The new method, however, requires a large number of measured gear flank points, which is time-consuming when using tactile measurement. All of these challenges including partial measurement and evaluation of a gear, tactile measurement time, and sophisticated flank modifications highlight the pressing need for an appropriate optical measurement in gear metrology.

Today, some new optical devices are commercially available and able to scan dense point clouds on each gear flank in a reasonable time. The instrument used for this investigation is equipped with light section triangulation sensor. However, there have always been some serious concerns in optical measurements of commercial gears, such as:

- Evaluation time
- Acceptance in automotive industry
- Multiple light reflection in the root area of gear flank
- Form deviation

Due to the physics of laser optical measurement, speckles and other scattered light phenomena are inevitable in optical inspection. This light deflection can lead to large form deviations when using triangulation sensors. Large form deviations that increase measurement uncertainty have always been a serious challenge, when the evaluation results of optical inspection are to be compared with reference results, i.e. obtained by tactile measurement. Moreover, the detection and correction or avoidance of multiple light reflection are vitally important because they can lead to wrong flank surface points determined by the optical instrument. Also, comprehensive areal inspections need to be consistent with current classical line-oriented inspections within a few microns range to be accepted by the automotive industry. This needs more investigations and therefore more simulations and measurements which are addressed in this work.

In this paper the above-mentioned issues are addressed using data of some commercial gears measured by an optical instrument equipped with a light section triangulation sensor. Beside some suggested methods to reduce form deviation and multiple light reflections, the new areal evaluation method is improved by adding some complex gear modifications. Then the improved evaluation method is implemented to practically compare the evaluation results of optical areal measurements with the results of tactile areal measurements, performed with a Leitz PMM-F. Both types of measurements refer to the same set of commercial gears.

FORM DEVIATION

Since the triangulation principle based on laser light source is used to measure a gear flank surface, there might occur some speckles and other scattered light phenomena on the sensor camera as a result of the deflected laser section line. Those phenomena might cause some inaccurate peak position detection in the current evaluation method. The peak shift in sensor x-y direction leads to a deviation in the evaluated distance, approximately perpendicular to the gear flank's surface in the third direction. This is considered as the reason for the obtained form deviation parameter values, which are not plausible in physical or technical terms, since the measured gear has finished surfaces with a form deviation in the single digit micrometer range (e.g. 3-5 μm). The objective of the performed research work was to develop a mathematical approach improving the detection of the ridge line, which is the line in x-y domain with the highest intensity as illustrated in the contour plot in Figure 1 as a dashed line. Each scanned ridge line is transferred to actual XYZ coordinates and combining all the consecutive ridge lines will later form the entire surface. Some alternative mathematical approaches are going to be considered for the instrument to detect the peak position even more accurately.

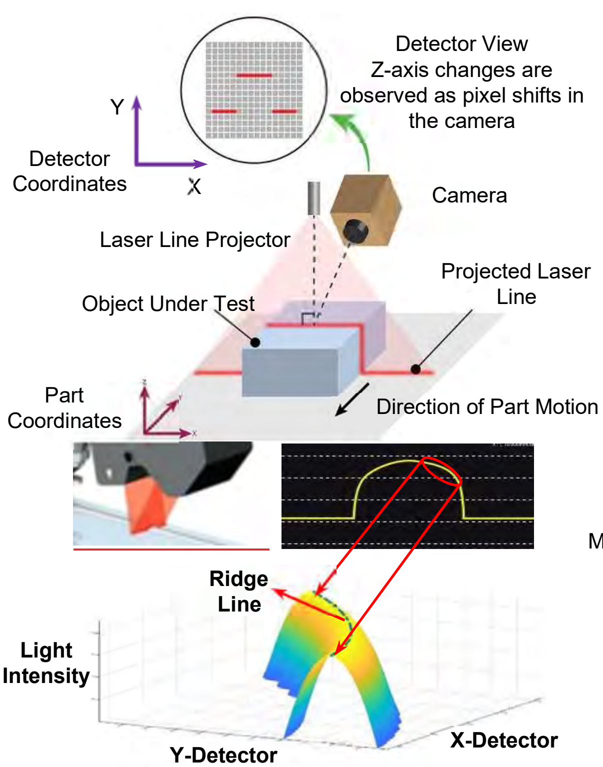

FIGURE 1. The intensity of the sensor data vs the ridge line in triangulation sensor [2, 3]

MULTIPLE LIGHT REFLECTION

When applying a triangulation sensor, the surface is detected based on scattered light intensity on the sensor camera. If there occurs a multiple light reflection due to shiny surfaces or small curvature radii, e.g. root area of the flank, a wrong surface is detected where actually that surface does not exist as shown in Figure 2.

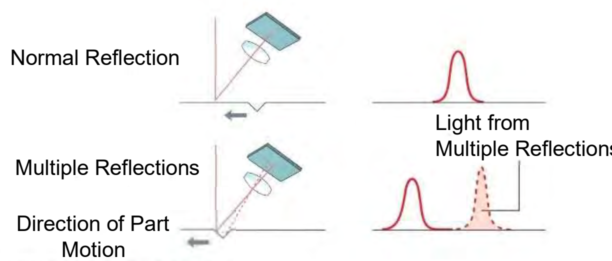

FIGURE 2. Multiple light reflection [2]

To eliminate the undesired reflected light on the sensor plane during a gear flank surface scan, there are manual parameters control the desired evaluation area called generation area. Only scattered light captured inside this area would later form one small portion of the scanned surface. Adjusting this desired area so that firstly it covers the entire ridge line and secondly it eliminates undesired light reflection while it is wide enough for the small predicted movement of the ridge line over a flank scan, the majority of the multiple light reflection can be avoided. Figure 3 shows how the generation area concept eliminates the undesired multiple light reflection in the root area of the gear flank.

Additionally, the instrument used for this study has 6 moving axes including three rotational and three translational axes. After adjusting the flank position so that the ridge line is at the center of the sensor plane, there are some setting parameters that can be changed to adjust the light intensity throughout the ridge line.

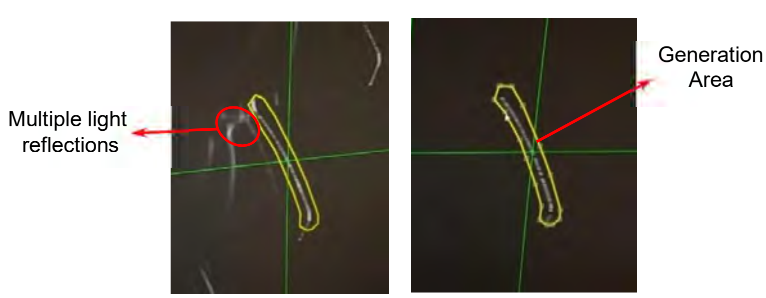

FIGURE 3. Generation area and multiple light reflections

By adjusting two rotational axes, A and B (tilt head axis and rotary table axis), a more or less uniform intensity, in which the maximum intensity does not vary significantly over the line, can be achieved. This can also play an important role in reducing too high intensities, especially at the tip and root area, thereby reducing the multiple light reflections.

ACCEPTANCE IN AUTOMOTIVE INDUSTRY

Optical sensors are adopted in gear measurement for the advantages of high-density data sampling and short cycle time, while the evaluations of geometric parameters are still based on standardized line-oriented algorithms dominantly. Areal evaluations with extended modification and deviation parameters [1] enable three-dimensional representation of surface features and holistic assessments of the entire gear. The areal parameters characterize features that are currently used in industrial inspections, such as profile and helix slope and pitch deviations. In addition, complex surface features, such as triangular relief modifications and waviness, which require measurements of multiple lines with tactile sensors and extensive data analysis with line-oriented algorithms, are more comprehensively sampled by optical sensors and precisely represented by areal parameters.

Table 1 shows a comparison of evaluation results of an automotive gear sample from three different instruments with both line- and area-oriented evaluations. The three evaluations are presented in a random sequence as A, B, and C, which are based on, respectively: 1. tactile measurements with line-oriented evaluations from a commercial software; 2. tactile measurements with areal evaluations; and 3. optical measurements with areal evaluations. 6 deviation parameters are evaluated in each case.

For the slope, crowning, and single pitch deviations, the maximum difference across the three cases is 3.1 μm, while the measurement uncertainty of these parameters in the given experimental condition is typically not less than 3 μm. Therefore, the optical measurements and areal evaluations offers effective results which are comparable to the standard methods. The range of difference for twist is 3.9 μm. In the line-oriented evaluation, the average of profile and helix twists is listed as the holistic twist, which is sensitive to the measurement diameter of the profiles.

TABLE 1. Comparison of evaluation results from three experiments with different instruments and evaluation methods (numbers are in μm)

PARAMETERS	EVALUATIONS		
	A	B	C
PROFILE SLOPE DEVIATION	-1.4	0.8	-2.0
PROFILE CROWNING	4.3	5.7	7.2
HELIX SLOPE DEVIATION	-1.1	-2.2	0.9
HELIX CROWNING	9.0	9.0	9.4
TWIST	24.4	20.5	21.6
SINGLE PITCH DEVIATION	1.1	2.0	2.2

Figure 4 illustrates the evaluation of a gear flank with tip and root triangular relief modifications. The point cloud consists of the plumb line distances from the sampled points to the nominal three-dimensional gear model. The center (non-modified) region and the triangular relief regions are approximated, respectively. The amount of measured root triangular relief (symbolized by f_{CEfC}^{A}) is defined to be the maximum distance between the center plane and the root triangular relief plane in the plumb line direction within the evaluation range (at the profile control diameter). The transition line is computed at the intersection of the center and the relief planes. Thus, the length of the relief and alignment of the transition area could be evaluated. Similarly, the measured tip triangular relief f_{CEaC}^{A} is defined.

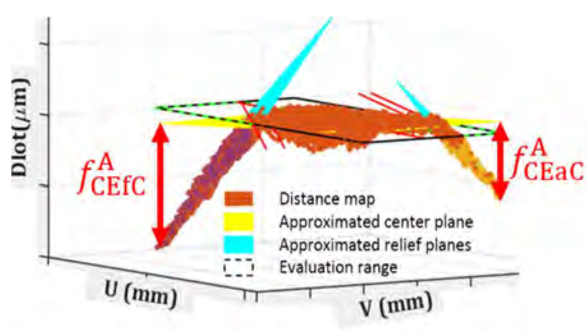

FIGURE 4. Areal evaluations of gear flank with triangular relief modification

EVALUATION TIME

Some efforts have been made to reduce the measurement time and evaluation time. So far, the evaluation starts after all the gear flanks are measured. An alternative approach is to evaluate the gear parameters flank by flank. After one flank measurement is finished and parallel to the measurement of the next flank, the previously captured flank data is evaluated. This can reduce the evaluation time significantly. Another proposed alternative is to partially measure the flanks around a target flank by adjusting the generation area appropriately as shown in Figure 5.

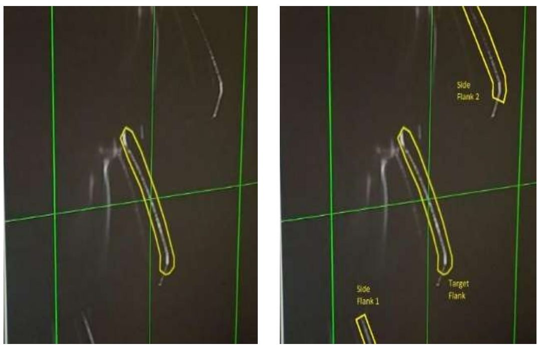

FIGURE 5. Partial measurement of side flanks

CONCLUSION AND FUTURE WORK

Fast optical measurement coupled with areal evaluation method provides a substantial data for gear inspection to meet the pressing need to fast holistic evaluation of commercial gears, especially in today's automotive industry where the main manufacturing processes of mid-size automotive gears take short time period. Developing new methods to remove the current obstacles in optical inspection when using triangulation sensors, in terms of reduction in large form deviation, elimination of multiple light reflections, and improvement in evaluation time, improve the quality of manufactured gears by reducing measurement uncertainty while simultaneously save the production time. Comparing the evaluation results of tactile measurements with line-oriented evaluations, tactile measurements with areal evaluations, and optical measurements with areal evaluations, the maximum difference among the results is within the measurement uncertainty. Therefore, the results verify the effectiveness of the adopted laser triangulation sensor, areal parameters, and algorithms. There are still more open research opportunities on the measurement uncertainty, filtering of the sensor signal, the development of peak detection algorithm, and the improvement of the evaluation process.

ACKNOWLEDGEMENTS

In accomplishing this work, the authors gratefully acknowledge the helpful contributions and support of Nikon Metrology at Brighton-Mi, USA, Centre for Precision Metrology (CPM) at UNC Charlotte-USA, Reishauer at Wallisellen-Switzerland, Hexagon-Leitz at Wetzlar-Germany, Liebherr at Kempten-Germany, Siemens Energy at Charlotte-USA.

REFERENCES

[1] F. Gert Goch, Kang Ni, Yue Peng, Anke Guenther, "Future gear metrology based on areal measurements and improved holistic evaluations" 2017 CIRP Annals - Manufacturing Technology 66: pg 469–474.

[2] Cincinnati Automation, laser Measurement Product Brochure, Yumpu, 2020. Accessed on Jul. 9, 2020. [Online]. Available: https://www.yumpu.com/en/document/read/11746393/laser-measurement-product-brochure-cincinnati-automation

[3] Vision Spectra, A 3D Triangulation Vision System, Photonics, May 15, 2017. Accessed on Jul. 10, 2020. [Online]. Available: https://www.photonics.com/Articles/Configuring_a_3D_Triangulation_Vision_System/a62061