

Application of Non-contact Measurement Technology to Precision Parts

Shigeru TAKAMURA*

ABSTRACT

A non-contact measurement system has been used for the precision analysis of parts in 3D shape evaluation employing CAD data. In recent years, there have been attempts to utilize non-contact measurement systems to respond to demands for 3D shape evaluations of precision parts such as gears. However, there are various optical issues with conventional optical non-contact measurement systems. These issues had to be addressed for application to precision parts, necessitating the development of a new measurement system.

The sensor testing were conducted using a variety of optical sensors to clarify the specific issues arising in the measurement of precision parts with non-contact measurement systems, enabling the optimum optical sensors to be selected. The newly developed system employs two sensors, which enables the achievement of the level of accuracy required for 3D shape evaluation of parts. A multi-axis mechanism which compensates for the weak points of the optical sensors completes the new system.

This paper will demonstrate examples of the use of data measured by the developed measurement system.

1. Introduction

Present-day automobiles are precision machines that demand high performance and high quality. The parts that support these demands also require highly accurate shape measurements. Measurement values of guaranteed accuracy can be obtained with certainty by using a Coordinate Measuring Machine (CMM). The CMM is an effective tool that is equipped with a variety of functions for measuring geometric dimensions. Using it to measure complex surface shapes, however, involves following numerous procedures, from initial setup to the measurement operation itself, so it is a challenge to obtain numerous factors of shape information in a short amount of time using this method.

The advantage of non-contact 3D measurement is that it can obtain large amounts of information in a short period of time in the form of point cloud data. Though this method has been in use for

many years, it must be used correctly in order to obtain highly accurate measurement values by taking advantage of the strengths of this method.

This paper introduces the current state of non-contact measurement technology using optical sensors and the application of that technology.

2. Determining the Measurement Accuracy Required for Precision Parts

Figure 1 classifies measurement systems that are suitable to measurement needs according to their measurement accuracy and measurement range, which are derived from the properties of non-contact sensors and the measurement performance. As indicated by the area enclosed by the dotted line in the figure, however, the

* Tochigi R&D Center

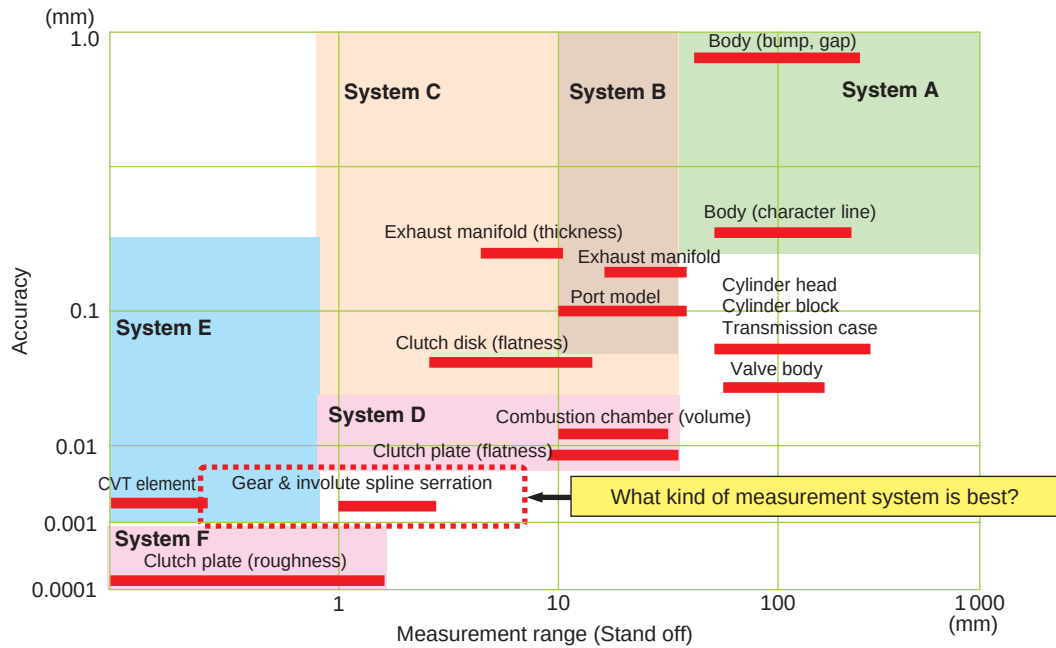


Fig. 1 Classification of non-contact measurement systems

shape measurement of gears and other such precision parts requires a measurement range of 1 – 10 mm and accuracy of about 0.005 mm. There was no appropriate measurement system to meet these requirements.

3. Issues in Conventional Optical Non-contact 3D Measurement

Conventional non-contact measurement systems involve the following kinds of issues:

- (1) Their measurement accuracy is insufficient for precision-machined parts.
- (2) They can only measure objects that have been coated with powder.
 - Accurate measurements of glossy areas cannot be obtained because of halation error and the reflection of environmental light.
 - Accurate measurements of black or dark-colored areas cannot be obtained because the light illuminating the object is absorbed and therefore cannot be detected by the sensor.
- (3) It is a challenge to measure narrow and deep sections where the light does not reach.

Even though attempts to measure an object are made from several directions, detection is a challenge because the light does not reach all the way into deep indentations.

Figure 2 shows parts involving these issues.

Research and development of a non-contact measurement system was initiated in order to address these issues. Gears, which are precision-machined parts, were chosen as the automobile parts to work with.

4. Issues with Gear Parts

Due to their characteristic shape (Fig. 3), gear parts can be expected to present challenging issues. These issues were organized into the following categories:



Fig. 2 Parts with the issues

- (1) Tooth shape: There are shadowed portions because of the irregular shape, and measurements cannot be obtained in areas where light does not reach.
- (2) Part surface: Practically the entire surface is a machined or ground surface, and these kinds of glossy surfaces reflect light.
- (3) Bottom shape: The measuring light causes multiple reflections from the curved surfaces (R sections) of the material, resulting in measurement errors.

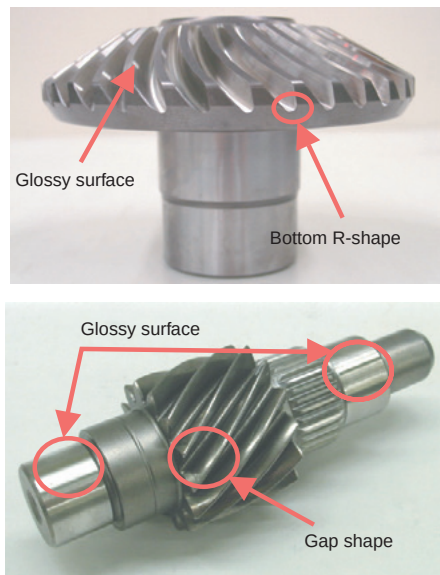


Fig. 3 Shape and surface of gear parts

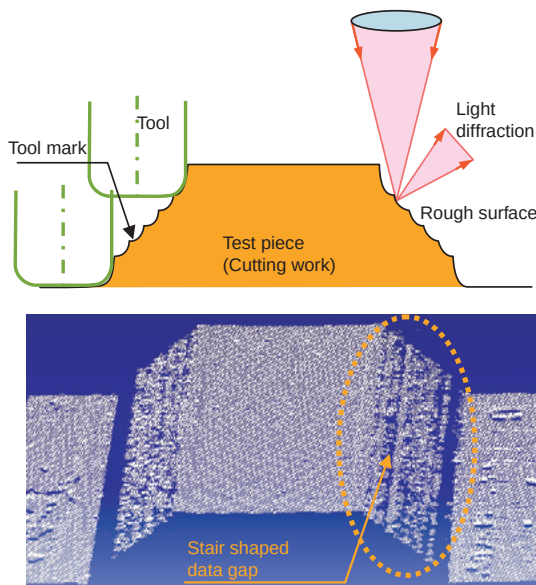


Fig. 4 Data gap caused by optical properties

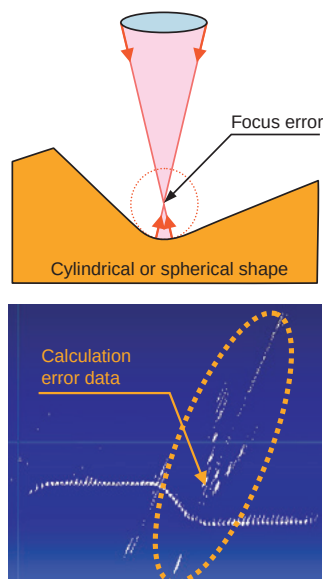


Fig. 5 Data error caused by optical properties

A test piece was fabricated and tests were carried out to verify the measurement values obtained when conducting shape measurements of gear parts.

Figure 4 illustrates how minute irregularities like tool marks in the surface shape cause full reflection from parts of the surface, according to its angle to the measuring light. As a result, stair-shaped gaps in the measurement values thus appear along the tool marks.

Figure 5 shows how cylindrical and spherical surfaces that are glossy result in the measuring light focusing at a distance from the shaped surface. The measurement therefore returns values for a location that are not correct.

In either case, this is a phenomenon that results because of the glossy measurement surface. The conventional method would be to cover the glossy surface with anti-reflective powder. The dispersion in thickness of the powder coating would be added to the precision part, however, so the measurement values would not match the actual object.

When the measured part is later used in testing with actual machines, the residue of powder particles on sliding surfaces and other areas affect the performance. Just like destructive inspection, this makes further use of the part unlikely after measurement.

5. Optical Non-contact Sensors Suited to Use with Precision Parts

Actual gear parts were used to carry out tests with a variety of optical non-contact sensors. The characteristics of the three sensor types that yielded valid results are described below (Fig. 6).

(1) Conoscopic coaxial laser sensor⁽¹⁾

- Strengths: If measurement is carried out in a direction perpendicular to the part surface, measurement values can be obtained with few errors, even from parts with glossy areas.
- Weaknesses: Measurement requires a scanning operation, and shape measurement is time consuming.

(2) Confocal multi-beam sensor⁽²⁾

- Strengths: Measurement in the optical axis direction provides high resolution, and perpendicular to the axis of the light provides highly accurate measurement values (resolution: $0.2 \sigma \mu\text{m}$).
- Weaknesses: The region that can be measured in a single shot is quite limited, so shape measurements are time consuming. (6 mm × 6 mm)

(3) Pattern projection 3D sensor⁽³⁾

- Strengths: The area measured in a single shot is quite extensive, so measurement values can be obtained for a wide area at once. (30 mm × 40 mm)
- Weaknesses: No pattern is projected for areas that are shadowed, so no measurement values are obtained for them.

The light is reflected off of glossy surfaces without projecting a pattern, so no measurement values are obtained.

6. Development of a Non-contact Measurement System

The above test results showed that making good use of sensor strengths would require a mechanism capable of maintaining the proper sensor attitude, relative to the work shape.

Gear parts are evaluated by taking the rotational axis as the standard. Shape data measured by a sensor unit, therefore, does not provide sufficient information to calculate the geometrical basic dimension. Consequently, it is necessary to have a system with a mechanism that can obtain measurement data on the same coordinate system, even for the reference cylinder surface and datum end face used to calculate the geometrical basic dimension. Given the need for use in gear strength analysis, and considering shape reproducibility in the software used for analysis, the tolerance requirement for the measurement values must be about $5\text{ }\mu\text{m}$. It was decided to develop a new measurement system that would satisfy these requirements.

Sensors (1) and (2) were selected for mounting onto the instrument because of their advantages with regard to accuracy, glossy surfaces, and irregular shapes. Sensor (3) was not selected because multiple reflections occurred in the projected pattern between opposing gear teeth, causing measurement errors.

The measuring device was made multi-axial to enable reproduction of many different sensor attitudes. The unit was equipped with two types of sensors, and the specifications call for a movable 5-axis configuration. This measurement system was developed jointly with Opton Co., Ltd.

In order to obtain shape measurement data with a conventional contact measurement system, first the geometrical basic dimension is measured and the work coordinate system is calibrated. Then trace measurements are carried out.

There are various trace measurement methods. If the starting point and ending point are designated, the measuring system can conduct an auto-scan while computing an estimated shape; another method involves providing the system with a reference shape as nominal data before measurement. Both methods require huge amounts of time and effort, and neither is practical. The advantage of the developed measurement system is the ability to obtain precise shape measurement data simply and conveniently, without

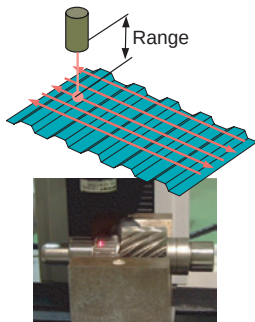
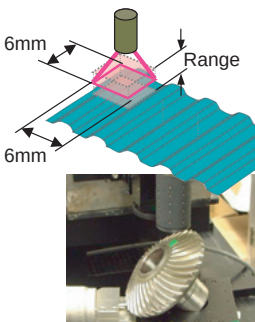
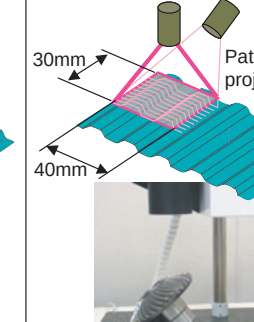
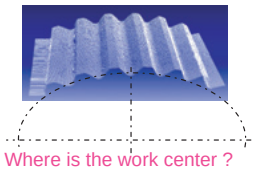
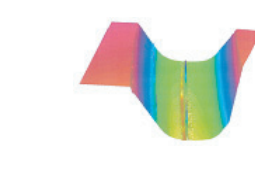
	(1) Conoscopic coaxial laser sensor	(2) Confocal multi-beam sensor	(3) Pattern projection 3D sensor
Type of optical 3D sensor			
Measurement data	 Where is the work center ?		 Where is the work center ?

Fig. 6 Types of optical measurement sensor

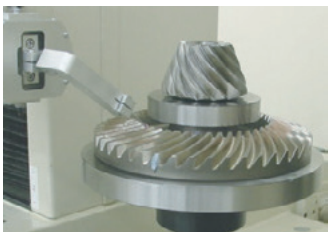
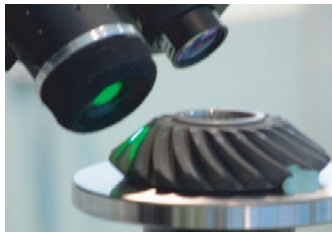
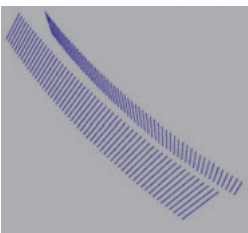
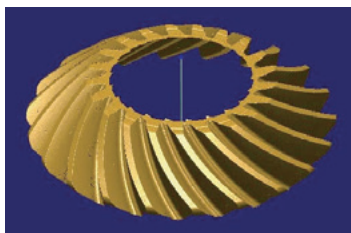
	Conventional system	Newly developed system
Measurement system	 Contact measurement system	 Non-contact measurement system
Measurement data	 Grid point data	 High-density point cloud data

Fig. 7 Conventional and newly developed measurement systems

employing such procedures. Figure 7 shows a comparison of a conventional contact measurement system and the newly developed system.

7. Accuracy of Actual Measurements

The measurement accuracy of the developed measurement system was verified by comparing its measurements with those of a conventional contact measurement system. The gear tooth measurements from a contact gear measurement system and the gear tooth shape measurements obtained by non-contact 3D measurement were superimposed on the same reference shape, and their measurement accuracy was verified in terms of the differences between the data. The procedure was to generate the nominal data line, created for gear tooth measurement purposes, on the 3D model created with point cloud data from the non-contact measurement. The probe of the contact gear measurement system was then traced over this data line, and the measurements were obtained (Fig. 8).

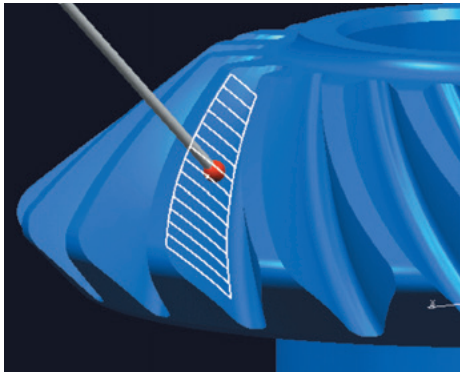


Fig. 8 Nominal data line generated on reverse actual model

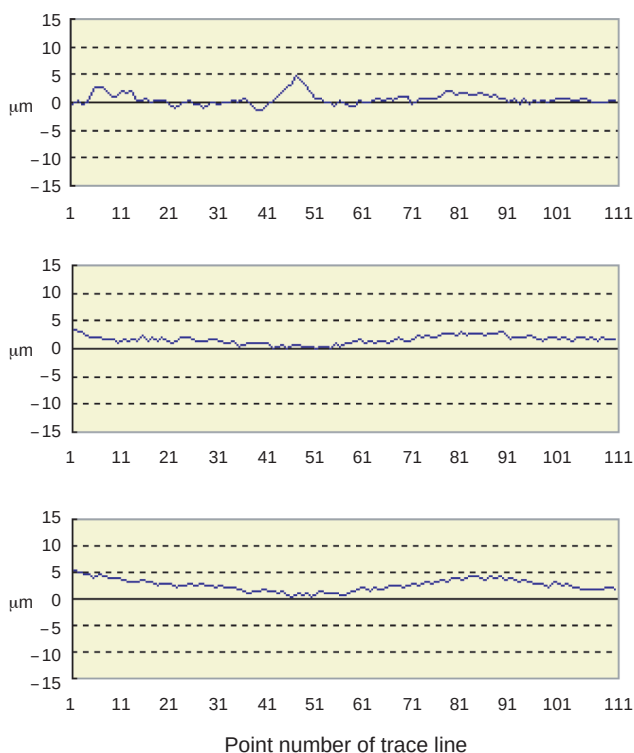


Fig. 9 Difference between measurement data

The differences between these measurement values and the original point cloud in the normal direction of the gear teeth surface were then identified and found to be within 5 μm . The differences were plotted on each tooth height trace line, and the resulting graphs of the tooth shapes are shown in Fig. 9.

8. Application Case Example

The highly accurate, high-density measurement data obtained through non-contact 3D measurement includes an enormous quantity of information about the part features. It is thought that this information will have numerous useful applications.

Here, the point cloud data from the measurement of gear parts were used to generate a 3D model (actual model) that accurately represents the part shape. This was subjected to CAE analysis, and the design specifications were then examined in a trial study. This case is shown in Fig. 10.

The development of automobiles involves the fabrication of large numbers of prototype vehicles of various types, which are subjected to running tests. In the initial stages of development, parts alone are fabricated and subjected to specification studies, without fabricating prototype vehicles. The ability to estimate at this stage whether the performance of a part will pass or fail may help to reduce the number of tests performed on a prototype vehicle. As a result, development time and cost reductions could also be expected.

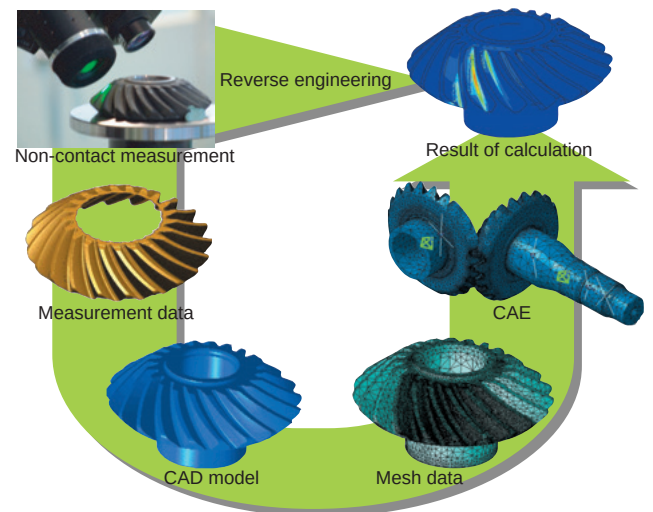


Fig. 10 Reverse engineering

9. Conclusion

The above practical application to precision parts measurement demonstrated the applicability of non-contact 3D measurement. The results achieved and issues for the future are summarized below.

- (1) This method can be used to non-destructively measure objects, leaving them undamaged. Consequently, the method can be used in the quality control and analysis of precision parts, procedures which were previously not possible using contact measurement methods.
- (2) The high density and high volume of measurement values

make it possible to perform shape evaluation that takes the surface as its measurement unit. Thus the method can deal with quality discrepancies that could not be adequately evaluated or analyzed previously by points and lines.

- (3) The developed measurement system makes it possible to measure parts such as gears that have complex shapes presenting a measurement challenge. Also, the measurement system should be applicable to other precision parts apart from gears, as well.
- (4) Recent 3D CAD analysis is able to handle polygon data generated from measurement point cloud data, and measurement results can therefore also be used in CAM/CAE analysis by reverse engineering.
- (5) The accuracy of actual measurement values is still far from adequate for evaluating the contact of gear teeth and other such matters. Therefore, efforts to increase the accuracy of the system will be continued.

Current non-contact measurement technology has been in a period of transition. It appears likely, however, that this technology will be applied in a variety of different fields in the times ahead, and new developments in this technology can be expected to emerge. It is hoped that this paper will be of some help in bringing this about.

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■ Authors ■



Shigeru TAKAMURA