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Development of Novel Device to Measure Thickness of Contact Strip and Horn of Pantographs

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Abstract

We have developed a highly accurate method for measuring the thickness of N700S flexible-type contact strip and horn. We confirmed that the method has sufficient accuracy up to a relatively high speed (70km/h) compared to conventional one. As a result, measurement devices can be installed at high-frequency measurement locations, such as rolling stock entrance at the station on main lines, leading to a reduction in the number of installed units.

Keywords: 3D profile measurement, optical cutting method, data analysis, rolling stock, pantograph, inspection labor saving.

1 Introduction

Rolling stock is inspected by checking the amount of remaining consumables (e.g., lubricating oil level) and visual condition (e.g., presence of dents) to ensure the safety of the rolling stock. Currently, rolling stock safety is ensured at the timing of periodic inspections. However, if non-contact inspection equipment could be installed at stations and other locations to automatically inspect rolling stock each time it enters a station, the frequency of inspections would be dramatically increased and the inspection labor would be reduced even further. In particular, the pantograph contact strips and horns (Figure 1) on the roof of the train are consumable parts that contact the overhead wires during running and wear out, so automatic inspection is required.

Non-contact measurement methods include ultrasonic and optical methods. However, it is known that the measurement accuracy of ultrasonic measurement is affected by wind and other factors due to the characteristics of the importance of air vibration propagation[1,2]. On the other hand, focusing on the optical cutting method, which applies light as a non-contact measurement method, it is possible to make stable measurements by using a high-performance camera and a computer capable of high-speed processing. In recent years, with the progress of devices, examples of 3D measurements using the optical cutting method have been observed[3]. This technique has the potential to inspect rolling stock equipment without being affected by disturbances such as wind. However, depending on the shape of the measurement object, the measurement accuracy of the edge of the object will be lower when the passing speed is high.

Therefore, in this development, we will develop a system that acquires 3D profile data of contact strips and horns accurately and automatically monitors the remaining thickness and abnormal wear, etc. even at a speed of 70 km/h when the train enters the station, using the optical cutting method.

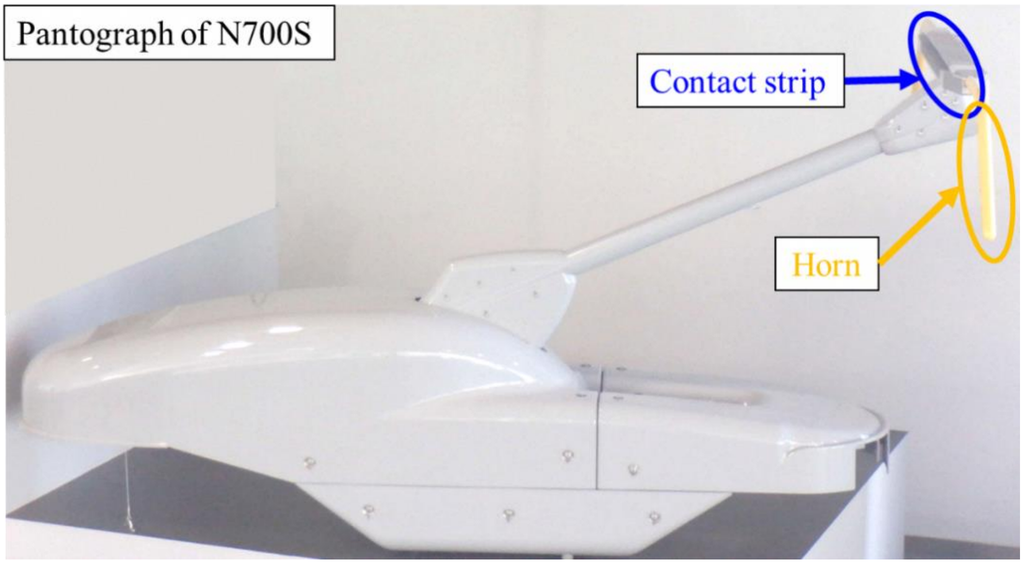


Figure 1: Contact strips and horns of our N700S Shinkansen cars.

2 Methods

2.1 Problems in measuring the thickness of contact strip

In the measurement of 3D profiles using the optical cutting method, a laser is irradiated so that the direction of the laser line is perpendicular to the direction of the object to be measured, and the 3D sensor acquires the shape data of the laser line at regular intervals. By accumulating this data, a 3D profile of the object is formed (Figure 2).

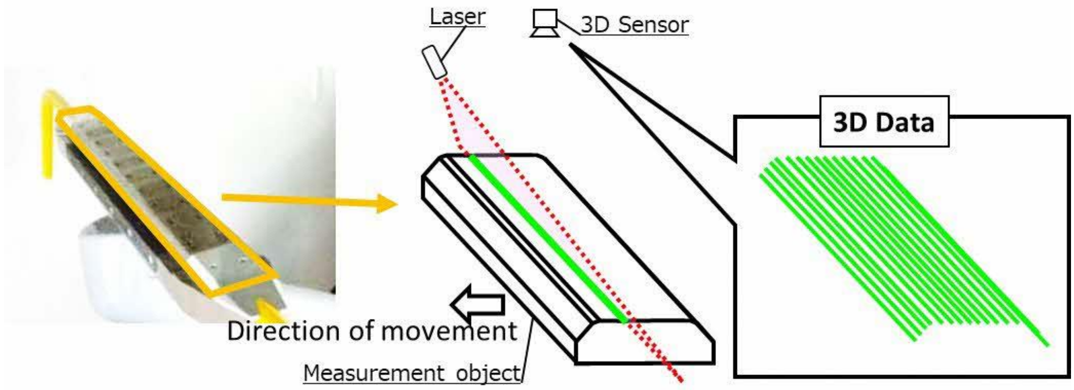


Figure 2: Image of measurement by general optical cutting method.

In order to measure the remaining thickness of the contact strip from the 3D profile data, it is necessary to measure the distance from the reference point. In the case of the flexible-type contact strip used in our N700S Shinkansen cars, the contact strip edge, which is almost unaffected by wear, is suitable as a reference point because the flexible-type contact strip is designed to move up and down (Figure 3).

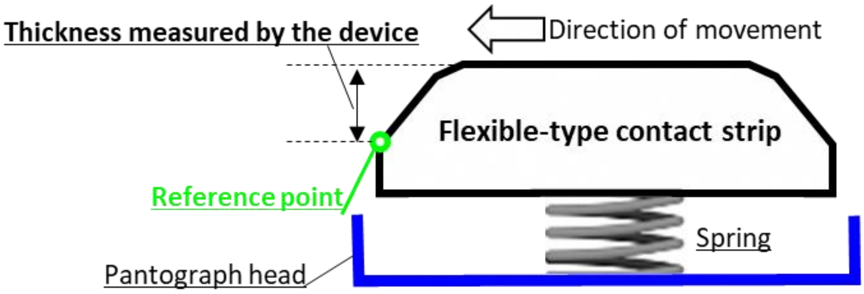


Figure 3: Structure of flexure-type contact strip.

To measure the contact strip thickness based on the edge of the contact strip, the thickness shown in Figure 4 (1) is measured. However, because the device measures at a constant cycle, it cannot accurately measure the edge of the contact strip and measures it as shown in Figure 4 (2), causing the edge of the contact strip to pass through the laser line between measurements, resulting in a measurement error.

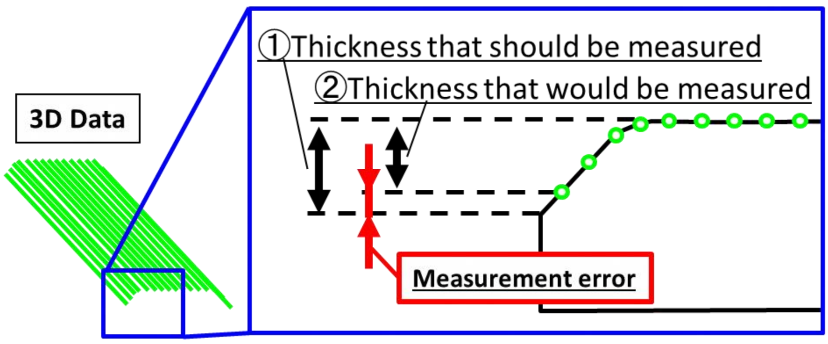


Figure 4: Mechanism for measurement error occurrence.

The measurement error is larger when the object passes through the 3D sensor at a higher speed and with a longer sampling period, and smaller when the object passed through the 3D sensor at a slower speed and with a shorter sampling period. Since the measurement error includes the measurement error that occurs at the contact strip edge as described above and the measurement error due to the resolution of the 3D sensor, the following formula can be calculated.

Using Parameters

- Sampling frequency of 3D sensor : f (Hz)
- Passing speed of contact strip : v (km/h)
- Angle between laser optical axis and 3D sensor direction axis : θ (rad)
- 3D Sensor Resolution : dy(mm/px)
- Measurement error occurring at the edge of contact strip : E_e
- Measurement error due to 3D sensor resolution : E_e

Measurement error E, which is the sum of the measurement error occurring at the edge of the contact strip and the measurement error due to the resolution of the 3D sensor.

$$\mathrm{E} = E_e + E_r = \frac{v/3.6\times10^3}{f} + d_y \times \tan^{-1}\theta \quad \text{.................................} \ (1)$$

The calculated accuracy for each speed was obtained by setting the sampling frequency of the 3D sensor to the maximum sensor performance for contact strip measurement (15,000 Hz) and the resolution of the 3D sensor to the highest sensor performance for contact strip measurement (0.01 mm/pixel) (Table 1). When this system is introduced into actual operation, we would like to achieve an accuracy of ±0.5 mm or less, but at the speed of station entry (70 km/h), the measurement accuracy is ±1.32 mm, resulting in a large error.

Speed	**10km/h**	**70km/h**	**150km/h**	**285km/h**
Measurement accuracy	±0.21mm	±1.32mm	±2.81mm	±5.31mm

Table 1: Calculated accuracy per speed.

When this system is introduced into actual operation, we would like to achieve an accuracy of ±0.5 mm or less, but the measurement accuracy is ±1.32 mm at the speed at station entry (70 km/h), resulting in a large error. Therefore, it is necessary to consider a measurement method that can measure with higher accuracy even at the speed of entering the station (70 km/h).

2.2 Study of a method that enables highly accurate measurement at a passing speed of 70 km/h

As described in Chapter 2, in the general 3D profile measurement method using the optical cutting method, the laser beam is irradiated so that the direction of the laser line is perpendicular to the direction of the object to be measured, which causes an error. This is because the edge of the contact strip passes through the laser line during the interval between measurements of the 3D sensor, making it impossible to accurately measure the edge of the contact strip.

Therefore, in this development, the laser line is irradiated at an angle so that the laser line always intersects the edge of the contact strip (Figure 5). This enables measurement of the edge of the contact strip without fail, thus ensuring the necessary measurement accuracy even at a speed of 70 km/h.

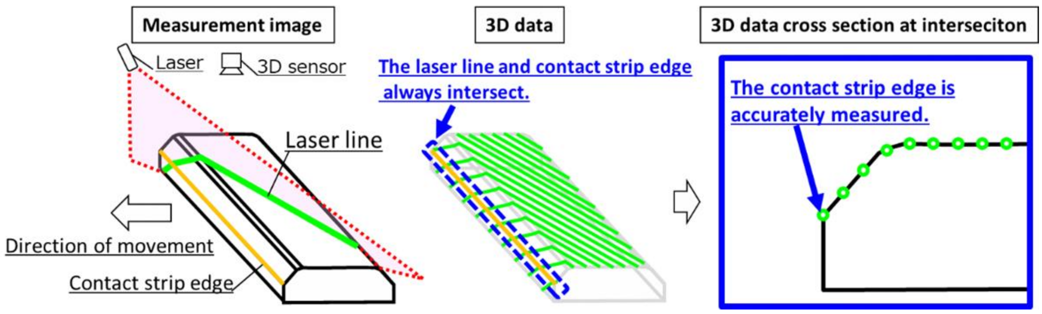


Figure 5: Image of measurement with laser line irradiated at an angle.

This measurement method makes it possible to accurately measure the contact strip edge, so the measurement error is only due to the measurement error caused by the resolution of the 3D sensor, so the measurement error can be calculated with Ee = 0 in Eq. (1). As in the calculation of Table 1, the calculated accuracy for each speed was obtained by setting the sampling frequency of the 3D sensor to the maximum value (15,000 Hz) and the resolution of the 3D sensor to the highest resolution (0.01 mm/pixel) (Table 2).

Speed	10km/h	70km/h	150km/h	285km/h
Measurement accuracy	±0.02mm	±0.02mm	±0.02mm	±0.02mm

Table 1: Calculated accuracy per speed.

The measurement accuracy was ±0.02 mm without speed effect, and it was expected to be accurate enough even at the entering station speed (70 km/h). Therefore, it was decided that the laser line would be measured at an angle.

The shape of the height data of the contact strip cross section was checked in a bench test at our facility under the condition that the laser line was actually irradiated at an angle. Then, a surface that differed from the true shape was confirmed at the edge (Figure 6). As described in Chapter 2, data at the edge of a flexible-type contact strip is important for measuring the remaining thickness of the contact strip. Therefore, it is necessary to have a method to suppress the effects that occur at the edge and to ascertain the accurate height of the edge.

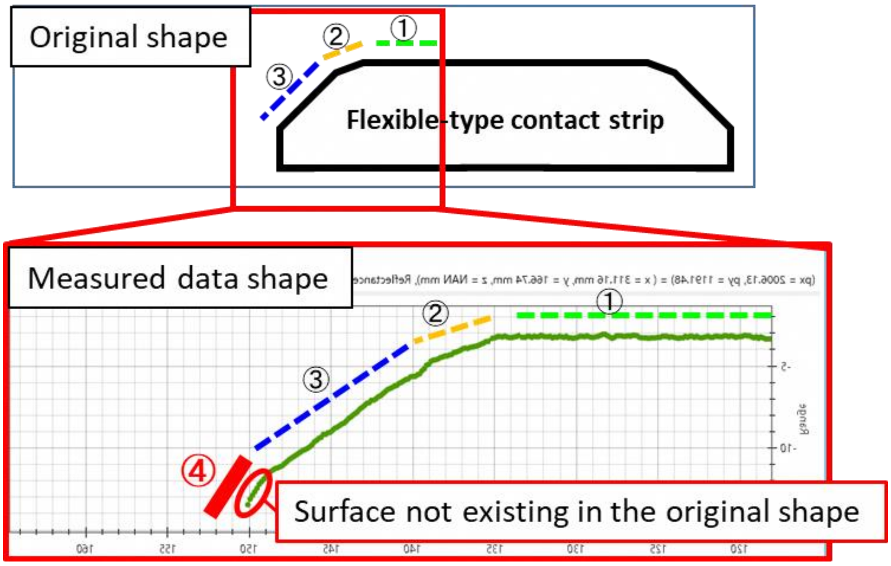


Figure 6: Occurrence of surfaces that differ from the original shape.

2.3 Mechanism of generation of surfaces that differ from the original shape

In the measurement of 3D profile data using the optical cutting method, the surface that differs from the original shape at the edge was probably generated by mechanism as shown in Figure 6 (4).

In the optical cutting method, a laser is irradiated at an angle to the measurement direction of the 3D sensor, and the position information of the laser recognized by the 3D sensor is used to convert into height information (Figure 7). Therefore, the laser position recognized by the 3D sensor is important in the height calculation.

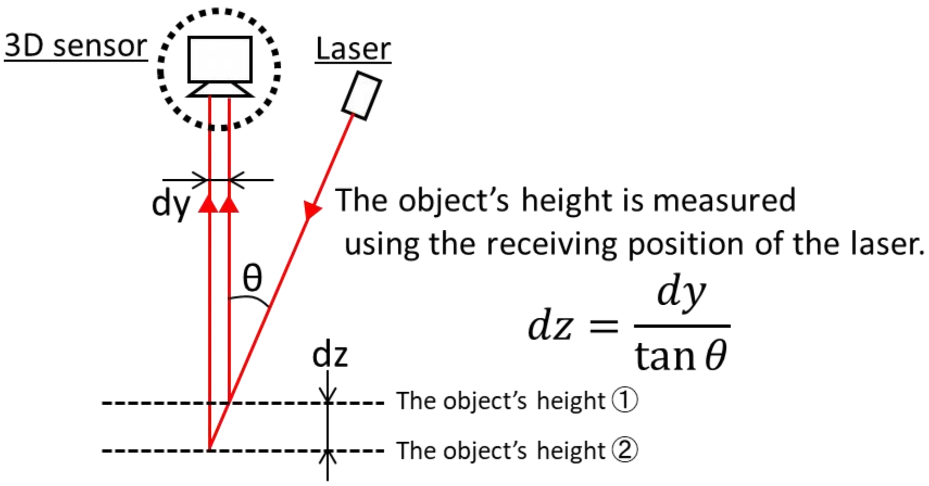


Figure 7: Height calculation method by optical cutting method.

When detecting the laser position from the laser recognized by the 3D sensor, the center of gravity in a constant width range based on the maximum peak value of intensity is recognized as the laser irradiation position (Figure 8).

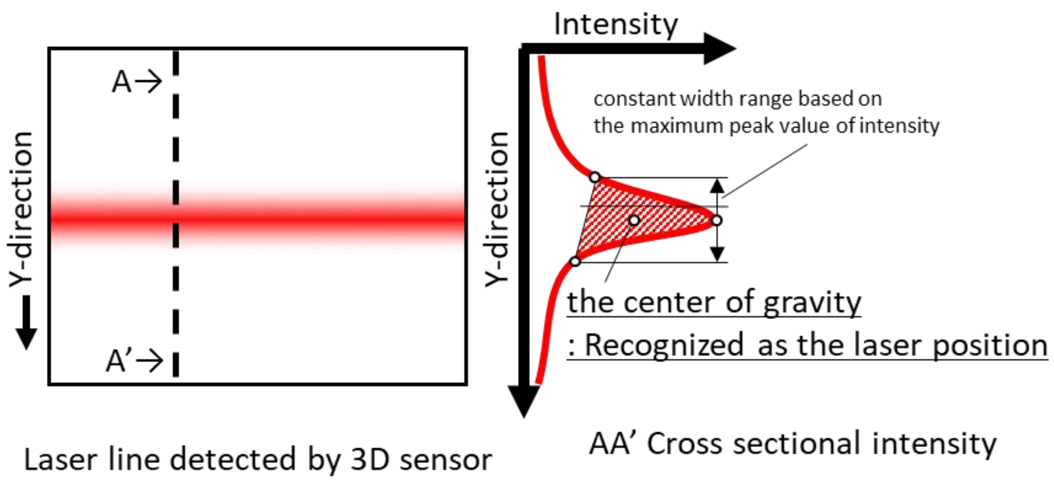


Figure 8: Laser position detection method in 3D sensor.

In other words, the 3D sensor recognizes the center of gravity as the laser position based on the distribution of detected laser intensity. Therefore, to accurately measure the height of the measurement object (contact strip), the whole laser thickness must be irradiated to the measurement object (contact strip). The laser width is the range where laser intensity distribution exceeds the detection threshold set by the 3D sensor, which can be checked on the monitor connected to the 3D sensor.

On the other hand, as shown in Figure 9, when the edge of the contact strip is within the laser width range, the height data obtained is not accurate because the whole laser width is not irradiated. As a result, data different from the original shape is obtained, as shown in Figure 6.

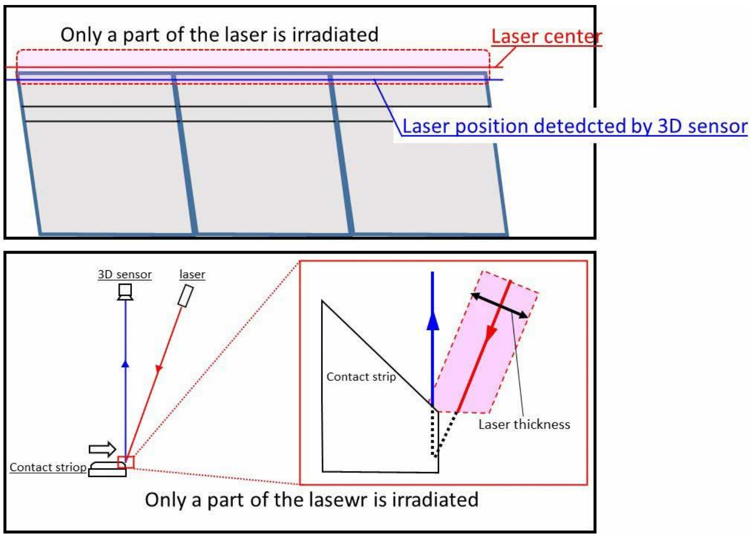


Figure 9: Mechanism of data generation at the edge.

The actual position of the edge of the contact strip is half of the laser thickness from the point where the edge of the contact strip comes within the laser irradiation range. Based on the above characteristics, we have considered the following compensation method to calculate the exact height of the edge of the contact strip.

2.4 Compensation method for errors occurring at the edge of contact strip

<u>Step1 : Deletion of data within the affected area of laser thickness</u>

As shown in Chapter 2.3, the error occurs at the edge of the contact strip when the edge of the contact strip is within the range of the laser width, so the range of the error is the range of the laser width (Figure 10). Therefore, by deleting the data in the laser width range (the left 3 data framed in Fig. 10) from the whole acquired data, only the data not affected by the laser width can be left.

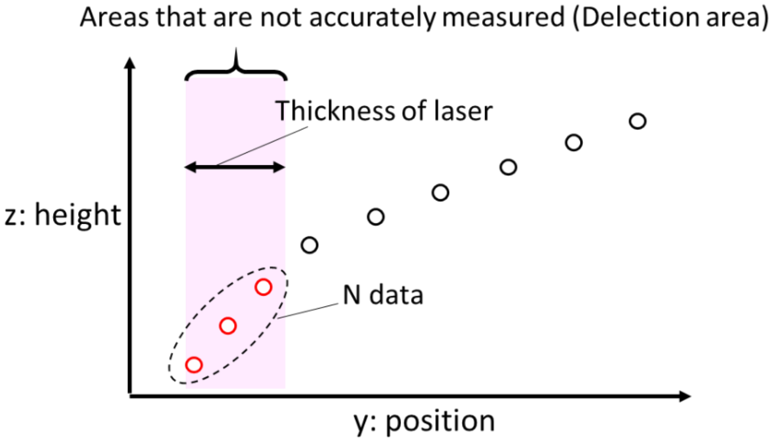


Figure 10: Range of data affected by laser thickness.

Assuming that N data affected by the laser thickness are occurred from the data edge (the leftmost data in Figure 13), N can be calculated as follows.

Using Parameters

- Sampling frequency of 3D sensor : f (Hz)
- Passing speed of contact strip : v (km/h)
- Laser thickness : T (mm)

Number of data affected by laser thickness N

$$\mathrm{N} = \frac{T \times 10^{-3}}{v/3.6} \times f \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

In this way, we can exclude the area affected by the laser thickness by deleting N data from the data edge.

<u>Step2 : Estimated height of contact strip edge</u>

Next, we estimate the height of the edge that could not be measured accurately. The height when the edge of the contact strip is at the laser center can be estimated by drawing an approximate line using the data left over from Step 1, and calculating the height at the position where the edge of the contact strip has moved by half of the laser thickness from the position where the edge of the strip is about to enter the laser irradiation range.

From the approximate line of the contact strip edge data, the laser thickness is estimated as shown in Figure 11.

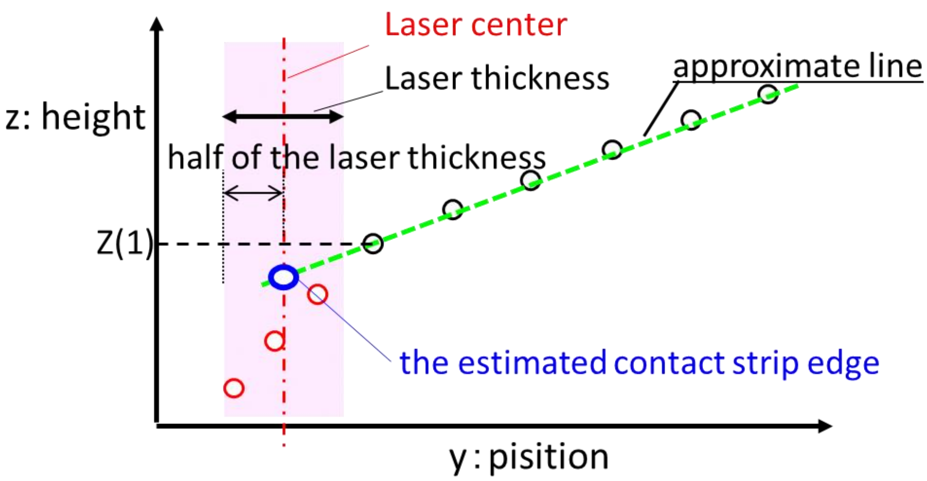


Figure 11: Method of compensating for laser thickness effects.

Assuming that the estimated contact strip edge height is Z_B (mm), Z_B can be calculated as follows

Using Parameters

- Laser thickness : T(mm)
- n-th data height : Z(n) (mm)
- Tilt with multiple data at the edge : dz/dy

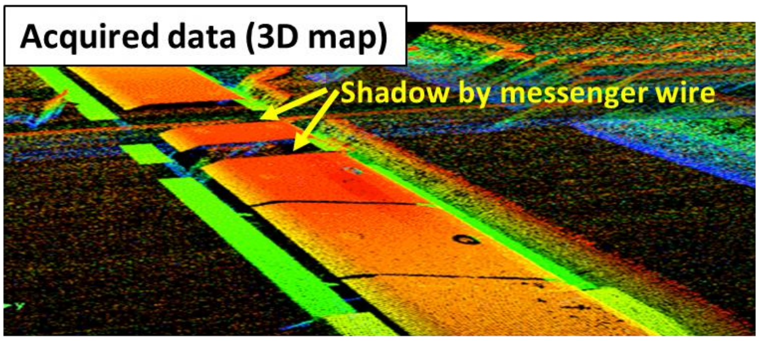
Estimated contact strip edge height Z_B

$$Z_B = Z(1) - \frac{dz}{dy} \times \left(N \cdot \frac{v/3.6}{f \times 10^{-3}} - \frac{T}{2} \right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

In this way, the edge height of the object to be measured can be estimated.

3 Results

The measurement accuracy was confirmed by actually moving the pantograph at a speed of 70 km/h using a test line in our research facility. Figure 12 shows the measurement results.



Comparison to actual size (measured value – actual value)

Maximum error	Mean error	standard deviation
-0.226 mm	-0.130 mm	0.073 mm

※N＝9

Figure 12: Results of measuring the remaining contact strip thickness at a speed of 70 km/h.

From the 3D map of the acquired data (Figure 12), it was confirmed that the entire surface of the contact strip could be measured successfully without missing any measurements, even at a speed of 70 km/h. We selected nine locations from the acquired data, calculated the difference in height between the edge of the contact strip and the top surface of the strip in the cross section, and compared it to the actual thickness of the contact strip. The results show that even at a speed of 70 km/h, the measurement accuracy is very high. However, this evaluation was made using only a portion of the data because the calculation was done manually. In the future, we will develop software that can evaluate measurement accuracy using the entire acquired data.

4 Conclusions and Contributions

In order to accurately measure the shape of the contact strip edge even at an entry station speed at 70 km/h, a method was devised to irradiate the laser line at an angle to the moving direction of the measurement object. When we checked the data obtained by this method, we found that the edge of the contact strip had a surface that was different from the true shape. We considered that this was caused by the influence of the laser width, and investigated a data correction method based on the assumed mechanism of occurrence. By applying correction to the edges of the acquired data, it was expected that highly accurate measurement would be possible even at a speed of 70 km/h. The results of this study showed that the data was accurate even at a speed of 70 km/h or lower. This would enable measurement at speeds of 70 km/h or lower, even at locations where vehicles frequently pass by, such as stations, etc., and furthermore, would significantly reduce the number of devices installed.

This report is the result of manual calculation of a part of the measurement data, but in the future, we will develop software that automatically measures the thickness and detects abnormal wear from the acquired data so that the entire acquired data can be evaluated.

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