

DEVELOPMENT OF A DYNAMIC TRACK MEASURING DEVICE FOR GAUGE AND TWIST TO REDUCE DERAILMENT ACCIDENTS

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ABSTRACT

The track measuring car is very expensive, so static measurement is being carried out not only at regional railway operators but also at major railway operators when it comes to lines in the yard. However, the device for static measurement is lightweight, so it is not possible to obtain dynamic track irregularities due to the wheel load and lateral force during a vehicle running. Therefore, in such a section of the line, a derailment accident may occur when dynamic track irregularity is large due to deterioration of track materials. From the above, with the aim of further reducing derailment accidents, we are developing a low cost measuring device for measuring gauge and twist affecting the driving safety of the vehicle which can be easily mounted on a motor car. This device measures the relative displacement between the device and the rail by the two-dimensional laser sensor and can display the rail profile of the measurement position during data processing. Therefore, when large measurement values are seen, it is possible to grasp whether there is a significant track irregularity at the site or an error at the time of measurement. In addition, we developed a mounting method using the traction coupler of track motor car or bolts for installing the guard iron of passenger vehicles, and carried out the running test at a speed of up to 40km/h to confirm the measuring performance. As a result of calculating the reproducibility (standard deviation of the difference between the two measured values) using measurement data of various speeds, it is confirmed that this device has measurement accuracy equivalent to that of the existing track measuring car. In this paper, we report the outline of the measuring device and the results of running tests conducted to confirm its performance.

Keywords: dynamic track measuring device, gauge, twist, reproducibility, the wide gauge derailment, the flange climb derailment.

1 INTRODUCTION

Types of derailment accidents caused by track condition include the wide gauge derailment due to gauge expanding [1] and the flange climb derailment due to large twist in the curve section [2]–[4]. These derailment accidents in Japan are caused by the dynamically increasing track irregularities due to the wheel load and the lateral force acting on the track when the vehicle running in the section where the track materials are deteriorated. Therefore, it is necessary to measure dynamic track irregularity during running of the vehicle and maintain track based on the result to prevent a derailment accident related to such a track condition. On the other hand, the track measuring car like Dr. Yellow [5] used for dynamic measurement of track irregularity is very expensive, so it is difficult for regional railway operators with poor management status to introduce it. Although they measure track irregularity using a trolley-type measuring device or the like, the device that measures a static track irregularity is lightweight and can't obtain dynamic track irregularity during running of the vehicle.

Therefore, in order to further reduce the derailment accident causing the track condition, we developed a measuring device that can be installed in a vehicle and can measure dynamic irregularity of gauge and twist which are greatly affecting the deterioration of the running safety of the vehicle. In this paper, we outline the developed measuring device and the result of running test.



2 OUTLINE OF A TRACK MEASURING DEVICE FOR GAUGE AND TWIST

Outline of derailment accident caused by track condition is shown in Fig. 1. As shown in Fig. 1(a), the wide gauge derailment is a phenomenon in which wheels fall to the inside of the gauge, and it is often caused by a decrease in rail fastening force due to wooden sleeper corrosion or the like. As shown in Fig. 1(b), the flange climb derailment is a phenomenon in which wheels ride on rails and derail. One of the factors is that as the vehicle runs on the track with a loose sleeper due to deterioration of ballast, track irregularity of twist increases and wheel load is decreases. In this chapter, the outline of the developed device which can measure track irregularity of gauge and twist will be explained.

2.1 Composition of a track measuring device for gauge and twist

The composition of the developed device is shown in Fig. 2. This device consists of a sensor unit, a pulse converter, a controller and PC for measuring. A sensor unit incorporates a two-dimensional laser sensor composed of a laser and a camera and an angle sensor. The size of a sensor unit is 860mm in width, 160mm in height, 230mm in depth, and weight is approximately 10kg, which is smaller and lighter than a sensor unit of a typical track measuring car.

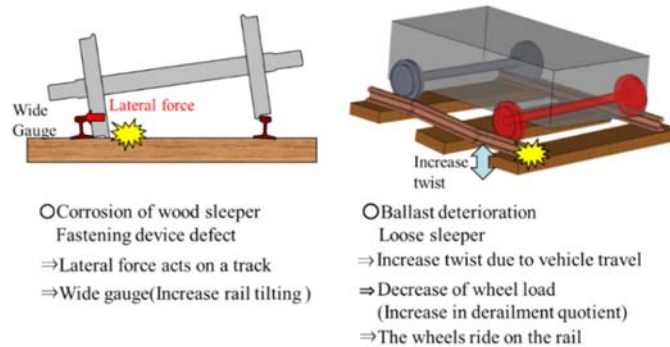


Figure 1: Derailment accident caused by track condition. (a) The wide gauge derailment; (b) The flange climb derailment.

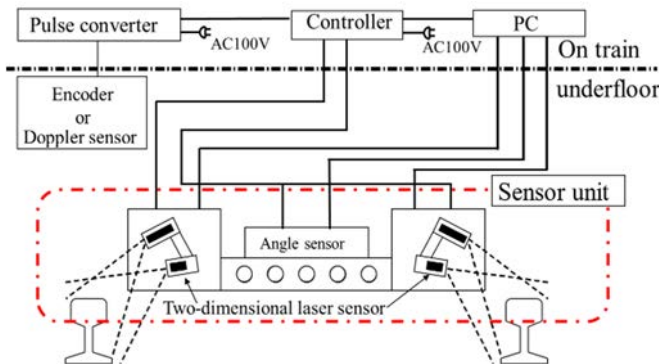


Figure 2: Composition of the developed measuring device.

The pulse converter receives the pulse signal of the encoder and calculates speed and measurement distance. The controller supplies power to each sensor and controls the sensor.

2.2 Outline of the developed measuring device

2.2.1 Measurement method of gauge and twist

Our device measures the relative displacement from both ends of the device to the top surface and the side surface of the rail with a two-dimensional laser sensor and measures the inclination of the device with respect to the upper surface of the rail with an angle sensor.

Irregularity of gauge is calculated from the relative displacement to the side of the rail. The measurement position on the side of the rail can be selected with a distance of 14mm or 16mm from the top of the rail head so that it can correspond to the definition of each railway operator.

Irregularity of twist is calculated from the cross level measured with the device. Cross level is calculated by (1) from the relative displacement to the rail head top surface and the inclination of the device with respect to the rail top surface

$$S = 1067 \tan \left(\tan^{-1} \left(\frac{z_r - z_l}{1067} \right) - \varphi \right), \quad (1)$$

where S is cross level, z_l and z_r are the relative displacement to the top of the rail of the left and right rails, and φ is the roll angle. The interval of cross level used for calculating twist can be selected from 2.0m, 2.5m, and 5.0m so as to correspond to the definition of each railway operator.

2.2.2 Output of measurement result

Fig. 3 shows the output screen of the PC as the measurement result of our device. In the output screen, the measurement positions of track irregularity, measured values of gauge, cross level and twist are shown in the table.

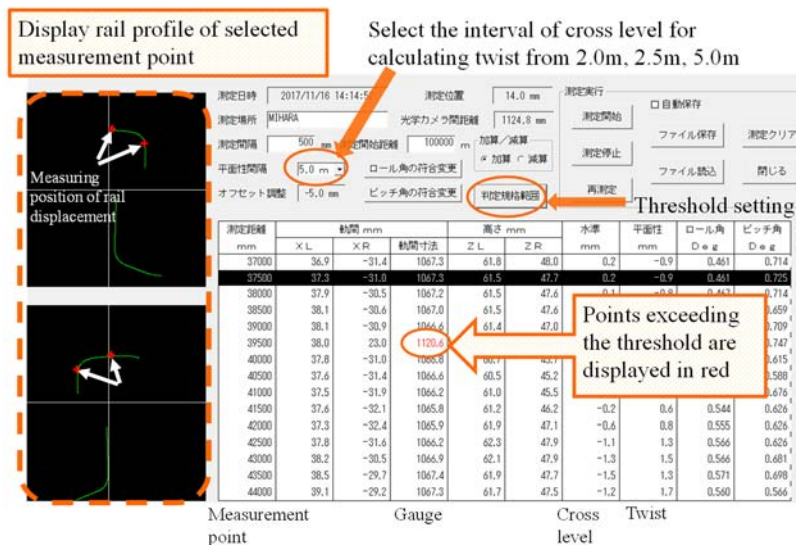


Figure 3: Output screen of the PC as the measurement result of the device.

For each measured value, it is displayed in red if it exceeds a preset threshold (for example reference value). Also, when we select the measurement position we want to check with the mouse cursor, we can know the rail profile of that position and the measurement position of the rail displacement. When we check abnormal measured values, we can grasp whether there is a significant track irregularity at the site or an error at the time of measurement.

2.3 Performance evaluation method of measuring device of track irregularity in Japan

The track measuring device requires high measurement accuracy. We will show the verification method of the measurement accuracy of the track measuring device (including the case where the track measuring device is mounted) commonly used in Japan. We evaluate the accuracy of a measuring device in the following order (1) to (5).

1. Repeat the same section repeatedly with a measuring device. At this time, the measuring section is set to include a straight line and a curve (preferably including the minimum curve radius in the route).
2. In the measurement section, we set the evaluation section to perform accuracy verification. When setting up the evaluation section, we take care not to include the part where the track dynamically deforms due to the force acting on the track while the vehicle is running. In addition, set a section of at least 1km or more for both straight lines and curved lines (curves are not necessarily one curve).
3. For the longitudinal level and the alignment, in consideration of the characteristics of the transfer function of the track measuring device, band-pass filter processing with a wavelength of 6m to 80m is performed. For cross level, drift components are eliminated by high pass filter processing or the like. For gauge and twist, do not perform filter processing and evaluate with measured values.
4. For the two measured data, compare the position of the waveform and subtract it. In this case, we will perform location verification using cross-correlation method as needed.
5. For the data obtained by subtraction, divide the evaluation section into fixed intervals (generally 200m), calculate the standard deviation.

Table 1 shows the repeatability accuracy required for track inspection car used in Japan. We define this standard deviation as repeatability and check whether the values in Table 1 are satisfied. The method of evaluating the measurement performance of the measuring device of track irregularity is also presented in the EN standard [6], [7]. From the above, we also evaluate the measurement performance of our device by the same method.

Table 1: Required repeatability accuracy for track measuring device.

Kind of track irregularity	Shinkansen	Conventional line
Longitudinal level	0.3mm	0.5mm
Alignment	0.3mm	0.5mm
Gauge	0.3mm	0.5mm
Cross level(cant)	0.5mm	1.0mm
Twist	0.5mm	1.0mm



3 CONSIDERATION ON A METHOD OF INSTALLING A DEVICE IN A VEHICLE

We examined methods to install our device in the vehicle to measure the dynamic track irregularity with our device. Here, we will describe the method of installing our device in a motor car, and a bogie for a commercial vehicle.

We decided to install our device using a traction device, which is considered to be a structure common to many motor cars. Fig. 4(a) shows the installation position of the sensor unit in the motor car. This part used for installing the sensor unit is about 22kg. In the case of this method, the distance from the wheel position to the measuring position by laser is 1.15m. The attachment and detachment of the sensor unit can be carried out by one person, and the time required takes about 30 minutes.

Next, we decided to use guard iron mounting parts in order to install our device in commercial vehicles without making significant improvement of a bogie. Fig. 4(b) shows the installation position of the sensor unit on bogie for a commercial vehicle. In this installation method, the distance from the wheel position to the measuring position by laser is 0.95m. That is, it can be measured at a position close to the wheel as compared with installing on the motor car. The work of attaching the sensor unit was about 1.5 hours.

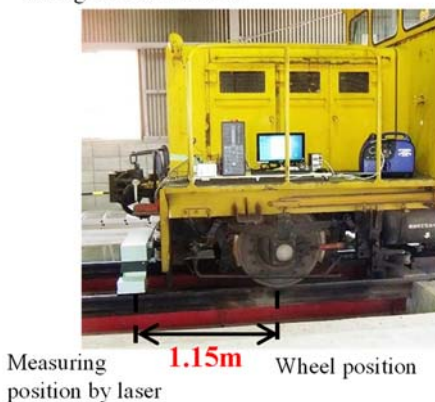
4 VERIFICATION OF MEASUREMENT ACCURACY BY RUNNING TEST

4.1 The running test with motor car

We verified the measuring performance of gauge by running test of the motor car with a curve of about 400m in radius and about 30mm in cant. The landscape of running test is shown in Fig. 5. In a section of the running test, we removed the rail fastening system for up to four sleeper, measured the displacement of the rail in the lateral direction when passing through the motor car, and compared it with the gauge measured by our device.

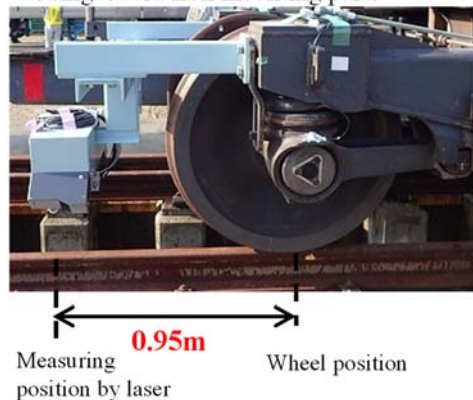
Fig. 6 shows the measurement result of irregularity of gauge. The measurement result of our device was approximately overlapped except for the section where the rail fastening

•Using traction device



(a)

•Using Guard iron mounting parts



(b)

Figure 4: Output screen of the PC as the measurement result of the device. (a) Installation method on motor car; (b) Installation method on bogie for a commercial vehicle.

system was removed, and the repeatability of the gauge was 0.20mm. From the above, it was confirmed that gauge can be measured with high accuracy like the existing measuring device. Next, the measurement result of irregularity of gauge in the rail fastening system removal section is shown in Fig. 7. The irregularity of gauge measured in the section where the four-sleeper rail fastening systems were removed was 0.49mm larger than the state of all rail fastening systems.

Fig. 8 shows the result of measuring the displacement of the rail in the lateral direction called dynamic irregularity of gauge when passing through the motor car. As described above, the sensor unit of our device is mounted at a distance of 1.15m from the wheel of the motor car. When the motor car runs at a speed of 10km/h, the sensor unit passes the position of the wheel after 0.43 seconds. Therefore, since it is considered that the displacement of the rail in the left-right direction becomes the maximum when passing through the wheel, the expansion amount of the gauge can be obtained from the displacement in the left-right direction after 0.43 seconds. As a result, the expansion amount of the gauge was 0.77mm at test condition that the rail fastening device was removed and 0.15mm at all the conditions of the rail fastening device, and the difference was 0.62mm.

This result is about the same as the increment of gauge measured by our device. From this, it can be found that our device can measure dynamic irregularity of gauge. On the other hand, we found that it is desirable to mount our device closer to the wheel to measure the dynamic irregularity of gauge when passing through the wheel. That is, regarding the mounting position of the device, it is necessary to consider the structure of the vehicle in the future.



Figure 5: Motor car running test.

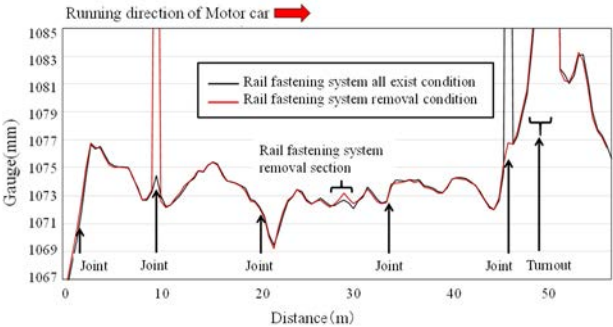


Figure 6: Measurement result of irregularity of gauge.

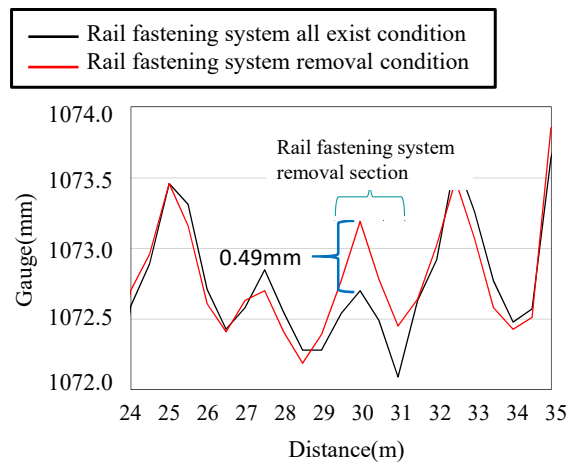


Figure 7: Measurement result of gauge at rail fastening system removal section.

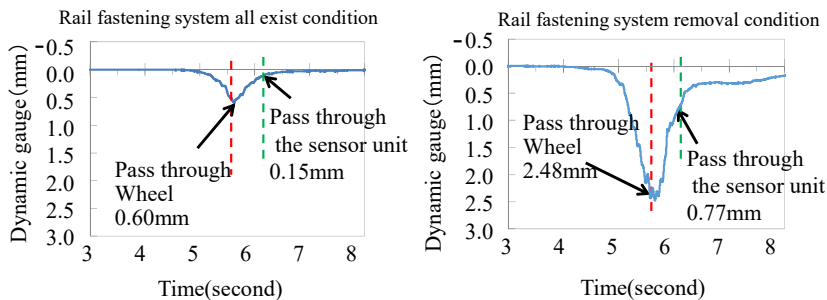


Figure 8: Result of dynamic gauge (the displacement of the rail in the lateral direction).

4.2 The running test with commercial vehicle

We have verified the measuring performance of gauge and twist by running test with commercial vehicles on a line with minimum curve radius of 120m, maximum can't of 107mm (gauge = 1067mm), maximum gradient of 50%. The running speed of the vehicle was 10 to 40km/h. The landscape of running test is shown in Fig. 9.

Fig. 10 shows the measurement results of gauge, cross level and twist with speed of 10km/h and 40km/h. In this figure, the measurement data of both are almost overlapping except for the level crossing and the turnout where the rail could not be detected by our device. This result is the same even at speeds of 20km/h and 30km/h, and it can be found that our device can measure irregularity of gauge and cross level even if the running speed is different.

We divided the measurement data every 200m and calculated the repeatability. The results are shown in Table 2. As a result, except for the section including level crossing and turnout, the repeatability of gauge was 0.3mm or less, the repeatability of 5m twist was mostly 1.0mm or less. Therefore, we found that the track irregularity can be measured with the same accuracy as the existing track measuring device.

Next, in the section where the radius of 120m and the steep gradient of 50% and vertical curve coexist, the measured values of our device and the measured values of the trolley type measuring device were compared. Fig. 11 shows the results of data. As a result, even under such severe linear conditions, the cross level of the device does not drift and is similar to the measurement value by trolley type measuring device. Therefore, we confirmed that irregularity of cross level and twist can be measured with sufficient accuracy even in the section where the curve and the gradient or the vertical curve coexist.

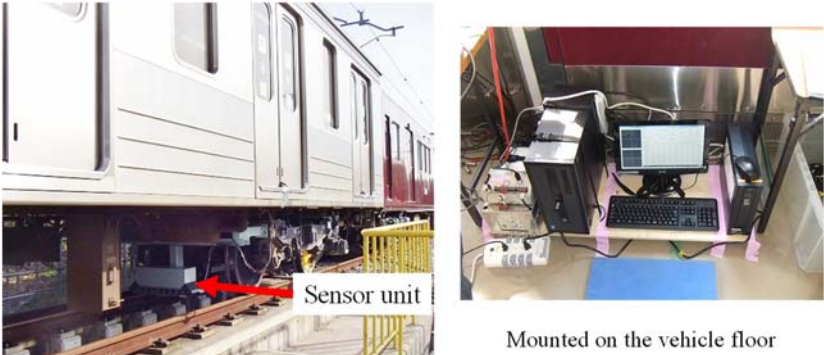


Figure 9: Commercial vehicle running test.

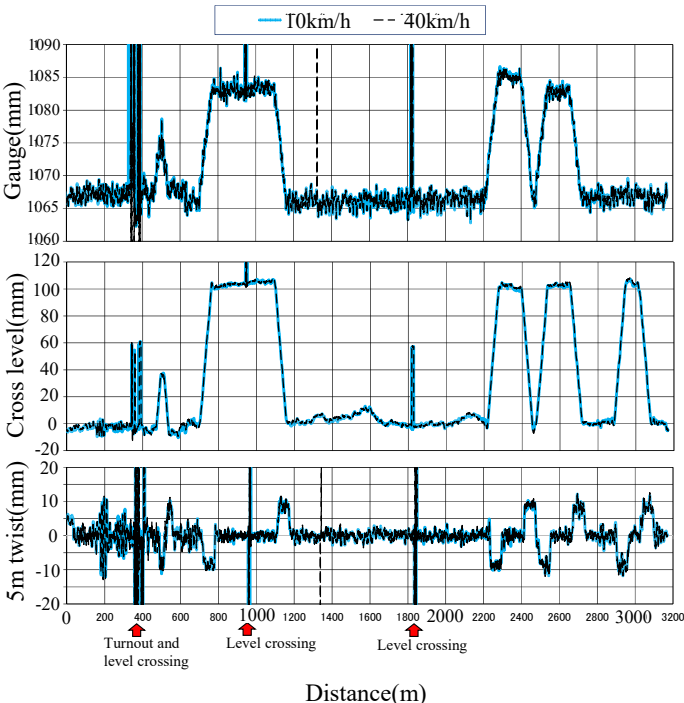


Figure 10: Result of dynamic gauge (the displacement of the rail in the lateral direction).

Table 2: Repeatability of gauge and twist. (a) Gauge; (b) Twist.

Distance		Speed of comparison data(km/h)						Speed of comparison data(km/h)						Error
から	まで	10-20	10-30	10-40	20-30	20-40	30-40	10-20	10-30	10-40	20-30	20-40	30-40	
0m	200m	0.12	1.51	0.23	1.50	0.13	1.50	0.74	1.73	0.87	1.78	0.98	1.85	Error(30km/h)
200m	400m	9.82	5.87	10.92	11.01	9.78	10.79	14.68	13.20	18.59	18.18	16.47	18.97	Turnout, Level crossing
400m	600m	0.16	0.13	0.27	0.18	0.17	0.29	0.92	0.95	1.08	1.08	0.99	1.13	
600m	800m	0.12	0.08	0.21	0.13	0.12	0.21	0.67	0.52	0.75	0.69	0.71	0.66	
800m	1k000m	5.09	4.01	5.38	4.94	3.64	4.24	13.15	9.89	15.31	14.01	11.38	14.69	Level crossing
1k000m	1k200m	0.13	0.09	0.14	0.11	0.08	0.13	0.49	0.54	0.55	0.47	0.50	0.50	
1k200m	1k400m	0.12	0.06	2.51	0.14	2.51	2.51	0.42	0.52	1.62	0.47	1.59	1.62	Error(40km/h)
1k400m	1k600m	0.10	0.07	0.11	0.14	0.06	0.14	0.47	0.43	0.50	0.42	0.49	0.47	
1k600m	1k800m	0.10	0.07	0.10	0.14	0.06	0.13	0.42	0.40	0.45	0.39	0.45	0.39	
1k800m	2k000m	4.88	2.88	5.45	4.94	3.58	5.47	9.02	6.16	10.51	9.64	7.46	10.56	Level crossing
2k000m	2k200m	0.10	0.17	0.09	0.22	0.07	0.20	0.35	0.63	0.52	0.63	0.48	0.68	
2k200m	2k400m	0.15	0.13	0.17	0.18	0.18	0.16	0.79	0.79	0.87	0.77	0.74	0.78	
2k400m	2k600m	0.19	0.10	0.13	0.18	0.16	0.11	0.58	0.72	0.69	0.71	0.63	0.65	
2k600m	2k800m	0.17	0.09	0.10	0.17	0.17	0.11	0.59	0.59	0.53	0.68	0.64	0.61	
2k800m	3k000m	0.15	0.07	0.08	0.15	0.15	0.08	0.41	0.46	0.54	0.50	0.59	0.53	
3k000m	3k200m	0.14	0.05	0.06	0.13	0.13	0.06	0.49	0.47	0.48	0.49	0.51	0.48	
average		0.13	0.09	0.14	0.16	0.12	0.15	0.56	0.59	0.65	0.61	0.64	0.63	

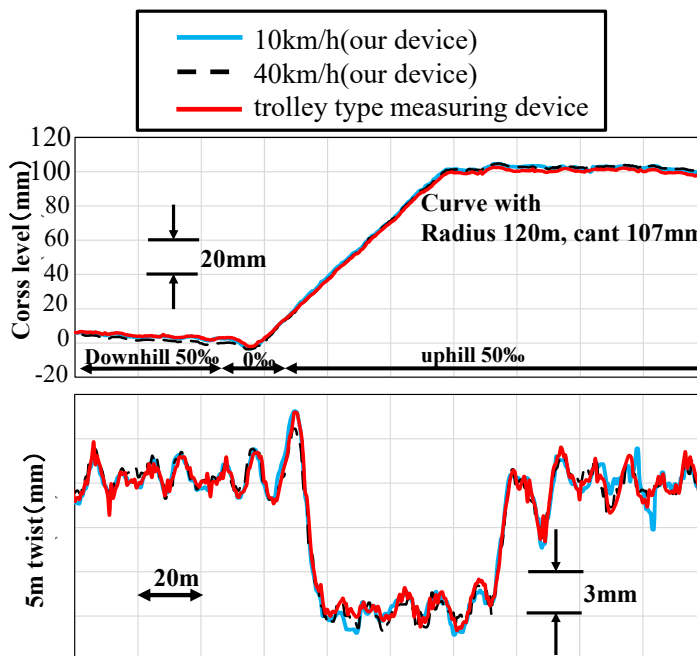


Figure 11: Measurement results of coexistence section of curve, gradient, and vertical curve.

5 CONCLUSION

We developed a device that can measure dynamic irregularity of gauge and twist which have a large influence on the running safety of the vehicle with the aim of further reducing the derailment accident causing the track condition. As a result of calculating the repeatability of the measurement data by carrying the running test with our device mounted on a vehicle, repeatability of gauge was 0.3mm or less and repeatability of 5m twist was 1.0mm or less. From the above, it was confirmed that the measurement accuracy of our device is equivalent to that of existing track measuring device.

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