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STUDY OF CONFIGURATION OF OVERHEAD CONTACT LINE IMAGING DEVICE FOR SHINKANSEN

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Abstract

Overhead contact line (OCL) is installed over long distances, so that a lot of maintenance worker is required for its maintenance. To reduce OCL maintenance works such as walking patrols and close-distance inspections, it is strongly desired to automate part of the inspection of OCL, especially anomaly detection of OCL fittings which are installed in large quantities. To automate OCL inspection, it is efficient to inspect OCL by analysing these anomalies in OCL images obtained from imaging device installed on the running vehicle instead of visual inspection by maintenance workers. In this paper, we proposed an imaging device configuration using two monochrome line scan cameras with tilt-shift lens and near-infrared LED lights to acquire OCL images in Shinkansen speed range up to 360km/h. To enable frequent inspection, the proposed device configuration was considered with mounting on the roof of a commercial train. The imaging range was set to be -400 mm to +400 mm in stagger and 4800 mm to 7000 mm in height from rail level as the installed range of OCL for Shinkansen, taking account into the car-body tilting system. The image obtain frequency of the device was set to the maximum of 40 kHz which corresponded to the resolution of 2.1 mm in the travelling direction at a running speed of 300 km/h. Hence, the device can acquire OCL images with an image quality that enables the auto detection of anomalies of OCL fittings. We prototyped a device according to the proposed configuration to verify its performance in bench tests. As a result, it was confirmed that the proposed device configuration ensured a depth of zone that covered the installed range of OCL. In addition, it was also confirmed that the device could obtain images of a rotating disk simulating 300 km/h running with 2.1 mm resolution and without subject blur.

Keywords: OCL, maintenance, OCL fittings, shinkansen

1 Introduction

Overhead contact line (OCL), which supplies electric power to EMU or electric locomotives, is installed over long distances. To keep operation of train transportation safely and stably, a lot of work is required for OCL maintenance such as walking patrols and close-distance inspections. We have been engaged in research and development to automate inspection of OCL by applying image processing and have developed a contactless measurement device for OCL for conventional lines [1]. We propose an imaging device configuration to realise image inspection of OCL for high-speed train, the Shinkansen. Specifically, the proposed device configuration used two monochrome line scan cameras with tilt-shift lens and near-infrared LED lights to obtain OCL images in Shinkansen speed range up to 360 km/h. Furthermore, the imaging performance at speeds up to 360 km/h was confirmed by bench tests.

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2 Study of configuration of OCL imaging device

2.1 Requirement of the device

We studied the device configuration installed on a roof of a Shinkansen train to continuously obtains images of the OCL using monochrome line scan cameras. The device configuration is similar to the contactless measurement device for OCL for conventional lines. The line scan frequency must be high and the exposure time per line must be quite short to obtain images with a resolution (about 2 mm in the direction of travelling) that enables anomalies in OCL fittings to be detected even under high running speed. In addition, the lighting must be bright enough to obtain OCL images clearly in tunnel section or nighttime, small enough to be mounted on the roof of Shinkansen vehicle. In Japan, since the Shinkansen runs through urban and residential areas, so it is strongly required to ensure that the lighting does not disturb the environment of these areas such as light dazzling.

2.2 Configuration of the device

Based on the requirements described in section 2.1, we determined the device configuration and imaging range shown in Figure 1. Furthermore, based on the same requirements, the line scan frequency was set to the maximum of 40 kHz to ensure the resolution of 2.1 mm in the direction of travel at a running speed of 300 km/h, and a fixed exposure time of 22 us. Four LED lights emitting near-infrared telecentric beam which mitigates light dazzling and concentrates light beam were set both sides. The resolution of the line scan camera was 8k for conventional lines with visible light. However, the sensitivity of camera is generally low in the near-infrared wavelength band. Therefore, the resolution of the line scan camera for Shinkansen was lowered to 4k from 8k to increase the area per pixel of the photosensitive element.

If a wide-angle fisheye lens with a deep depth of field is used for 4k line scan cameras instead of 8k line scan cameras, the resolution in the line direction of the line scan camera decreases due to the wide imaging range. For this reason, the imaging range for Shinkansen was reduced from that for conventional lines, so that only the longitudinal area around the contact wires as shown in Figure 1 is included in the imaging range. The imaging range was from 4800mm to 7000 mm height from rail-level. In recent years, the car-body tilting system has been introduced to Shinkansen vehicles. Therefore, the imaging range was expanded from within ±300 mm to within ±400 mm in the deflection direction so that the OCL does not deviate from the imaging range even when the car body is tilted. In order to ensure depth of field without the use of a fisheye lens, we proposed a configuration that uses a tilt-shift lens which sets the focal plane in the vertical direction using the shine-proof principle [2, 3].

When the minimum distance between the camera and the imaging range is reduced, the depth of field narrows. It is necessary to increase the distance between the camera and the OCL to be obtained as much as possible. Therefore, the distance between two cameras was set to 2600 mm.

We prototyped the device shown in Figure 2. The device also has laser range scanners to measure 3D position of the wires of OCL. The 3D position data of the wires support detecting wires from the obtained image and anomaly detection of the OCL fittings.

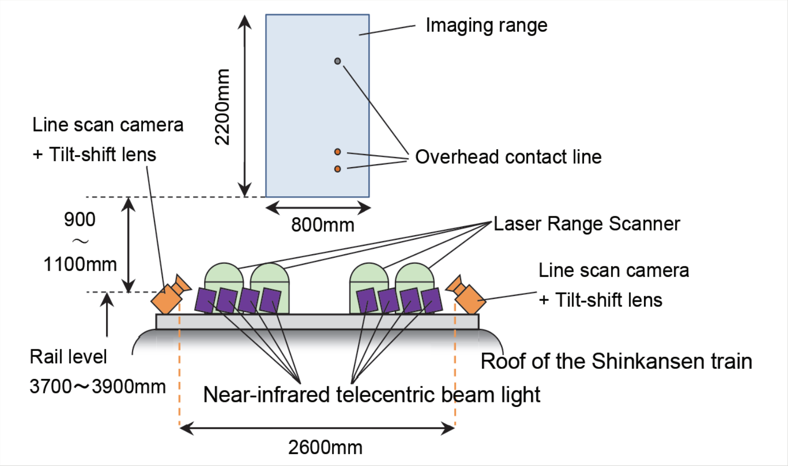


Figure 1 Camera configuration and imaging range

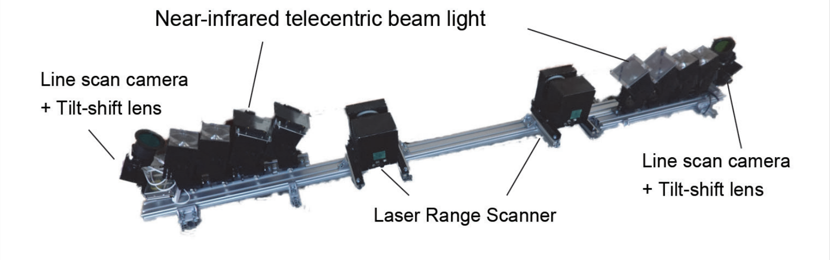


Figure 2 Prototyped OCL imaging device for Shinkansen

2.3 Discussion of F-number of lens

For the proposed configuration, the authors examined the depth of field and lens aperture (F-number) settings required to obtain OCL of the Shinkansen to confirm whether that depth of field depending on F-number satisfy imaging range in a bench test. The configuration of the bench test is shown in Figure 3. The line scan camera and four LED lights were installed on a slide rail, and the line scan camera was manually slided parallel to the wall surface to obtain images of markers on the wall surface. The distance between the line scan camera and the wall surface was varied from 800 mm to 1700 mm in increments of 100 mm. This corresponds to a OCL stagger of -500 mm to 400 mm when the distance between the cameras is 2600 mm. The obtained images were confirmed to visually check whether each image is focused. Since the purpose of this test was to check the depth of field, the exposure time was set long enough to obtain a clearer image. The depth of field is greatly affected by the F-number of the lens; a larger F-number provides a greater depth of field, but the obtained image is darker. Considering this balance, the F-number was set to 8.0. The focus was set by adjusting the tilt so that the entire wall marker was in focus. After adjusting the focus at a stagger of -400 mm, fine-tuned the focus again at a stagger of 400 mm. A portion of the obtained image is shown in Figure 4. As shown in Figure 4, the image at a stagger of -500 mm was out of focus and the letters on the marker were blurred. On the other hand, images with little blurring at a stagger of -400 mm to 400 mm were obtained. As a result, it was confirmed that the depth of field satisfying the imaging range could be secured with the F8.0 configuration.

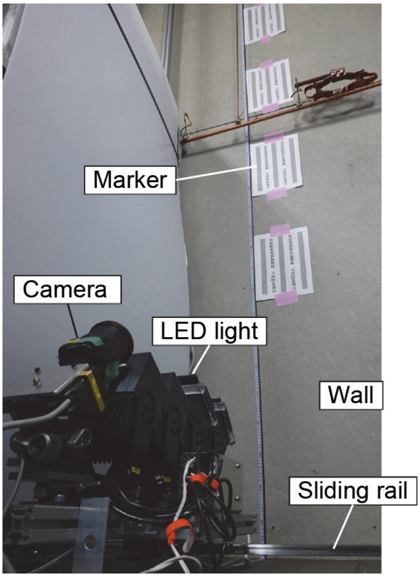


Figure 3 Experimental configuration of depth of field confirmation

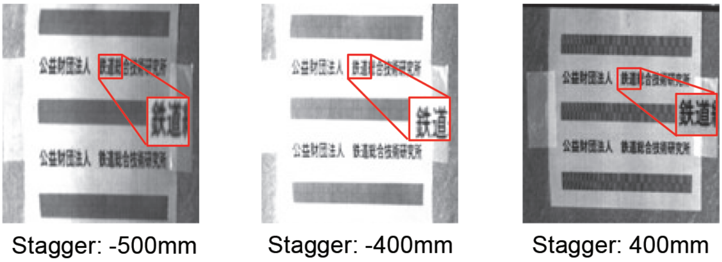

Stagger: -500mm
Stagger: -400mm
Stagger: 400mm

Figure 4 Obtained image of depth of field test

3 High-speed imaging test

We confirmed high-speed imaging tests using the High-Speed Test Facility for Pantograph/OCL Systems (HiPaC) at Railway Technical Research Institute. Figure 5 shows the test configuration. Images of a rotary disk of the HiPaC rotated at high-speed were obtained by a line scan camera. The rotary disk rotated while being vibrated with an amplitude of ±5 mm up and down and ±150 mm left and right to simulate the sag and zigzag between the span length of the support points. Since the camera was equipped with a bandpass filter for near-infrared light, the test was conducted with the lighting of the test chamber on.
We evaluated the high-speed imaging performance by visual checking the letters “RTRI” (width: about 112 mm) written on the disk to check for object blurring. The scan frequency of the camera was controlled in proportion to the speed of the disk up to a speed of 300 km/h (40 kHz at 300 km/h rotation) and was set to be constant at 40 kHz at higher speeds.
The sag was set to one cycle per one span, and the zigzag was set to one cycle per two spans, so that the vibration was linked to the disk rotation speed, and span length was 50 m.

Figure 6 shows the results of the images taken when the disk rotating speed was 60 km/h, 300 km/h, and 360 km/h. Comparing the images taken at 60 km/h and 300 km/h, the letters “RTRI” were obtained without any blurring in either case and almost the same pixel width about 53 to 54 pixels. The same pixel width indicates that the images were obtained with same resolution of 2.1 mm. It was also confirmed that the same image could be obtained at a rotating speed of 360 km/h without any blurring of the object.
In conclusion, we have confirmed that the proposed device configuration can obtain images without subject blur regardless of the speed range, even when the height and stagger of the OCL fluctuate at high speeds.

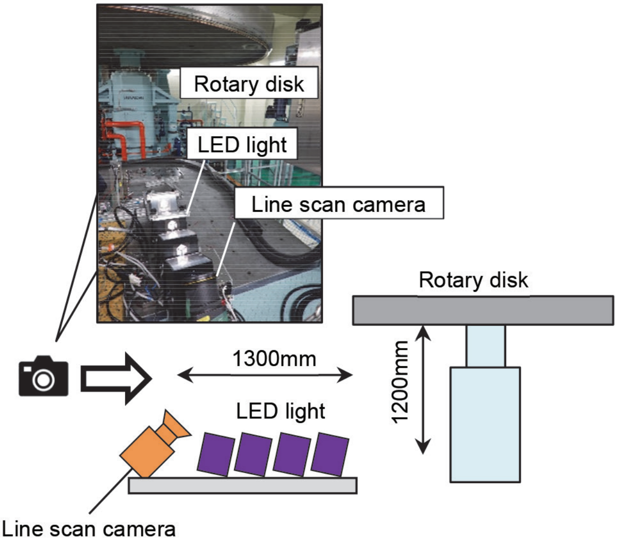
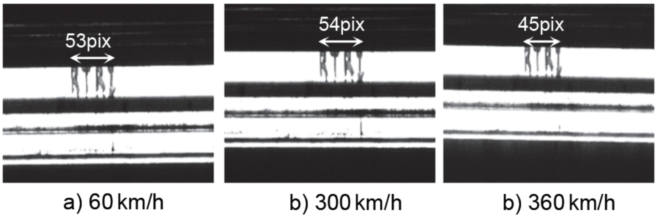


Figure 5 Experimental configuration of high-speed test.



a) 60 km/h b) 300 km/h b) 360 km/h

Figure 6 Obtained image of high-speed test.

4 Conclusion

In this paper, we proposed a device configuration by which continuous images of OCL for the Shinkansen could obtained and confirmed its high-speed imaging performance. As a result, it was confirmed that the device configuration with a tilt-shift lens can obtain images of a rotating disk simulating a 360 km/h travel without blurring the subject with a depth of field corresponding to the range of the OCL of the Shinkansen.

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