New Technologies of OCS Inspection System, CATENARY EYE

Seiji Tabayashi

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Abstract

After the first delivery of our Overhead Catenary System (OCS) inspection system called "CATENARY EYE," various new measuring functions have been developed for this system. As a result, our OCS inspection system currently available has a variety of functions and is contributing to the maintenance and management of electric railway catenary systems for many railway operating companies domestically and abroad.

In addition to its conventional measuring functions, CATENARY EYE has developed new functions such as, "evaluation and diagnostic technologies for high-speed railway dynamic interaction performance" and "construction clearance limit measurement technologies," that are introduced in this paper. The "evaluation and diagnostic technologies for high-speed railway dynamic interaction performance" is a function to evaluate the dynamic interaction performance between the catenary and pantograph. This function is used to evaluate the correlation between the contact force and the amount of arcs generated as a result of contact loss based on statistical analysis. The construction clearance limit measurement function has been developed to avoid interference between train cars and other stationary objects such as surrounding track-side facilities and trees. Unlike the conventional method using a laser system, this technology is based on a simplified measuring approach by use of image analysis.

1 Preface

It has been 18 years since our first Overhead Catenary System (OCS) inspection system, "CATENARY EYE," was delivered to Kyushu Railway Company (JR Kyushu), in Japan. After our first supply, this equipment also was delivered to many other railway companies. We offer four (4) classes of OCS inspection systems which railway companies can select from for a suitable system based on the train service scale and the preferred inspection system operating method.

When Class 1 is selected, it is possible to make catenary inspection in the middle of a train's commercial service by using equipment installed on a high-speed inspection train car or a Shinkansen train car, and/or overseas high-speed rail train car. Dynamic measurement is possible by a current collecting pantograph.

For Class 2, two cases of usage can be considered. Equipment installed on a commercial train vehicle may be used for conventional JR or private railways when the vehicle is used as an out-of-service train car without passengers. In the other case, it is also possible to use this equipment in a passenger train car. Dynamic measurement can be carried out by means of a current collecting pantograph.

For Class 3, equipment may be installed on a dedicated test train vehicle. Compared with a commercial vehicle, there are less restrictions in terms of installation space. For this reason, many measuring functions are available. Dynamic measurement can be carried out by means of a current collecting pantograph.

For Class 4, equipment is installed on a dedicated inspection train vehicle such as a road-rail vehicle or a dedicated maintenance service train car. The both vehicles run at a low speed. Static measurement is carried out without using a current collecting pantograph. Measurements are limited to the basic items only. Since the inspection equipment is made compact, detachable inspection device for vehicle is also possible.

All the aforementioned classes of equipment are based on image processing technologies and common analytical software is adopted. This paper introduces the features of CATENARY EYE developed and its adoption as a new technology.

2 Evaluation of Current Collecting Pantograph and Diagnostic Technologies

2.1 Purpose

In order to maintain the stable operation of electric railways, repair and maintenance works in various fields are required. As one of such examples, there are two kinds of work: ① maintenance and repair work of catenary systems and ② diagnostic work for catenary conditions. Such work is indispensable to maintain good condition of the catenaries. Work of the former is conducted on a daily basis at the repair facilities of railway operating companies. The former work is performed based on the diagnostic results of the latter work. Technologies for evaluation and diagnosis on current collecting pantograph are used mainly for the measurement of contact force between the catenary and pantograph and that of the arcs generated when the pantograph is detached from the contact wire. The acquired data are used as the basis for contact loss measurement. The method of measurement is based on the IEC Standard for current collection system. This is an international standard.

For the evaluation of current collecting performance, a statistical processing approach is applied to the measured result of contact force and contact loss. **Fig. 1** shows an outlined evaluation approach for current collecting performance. There is a strong correlation between contact force and contact loss. Such a situation is shown in **Fig. 2**. These techniques are applicable to Class 1 and Class 2 of CATENARY EYE.

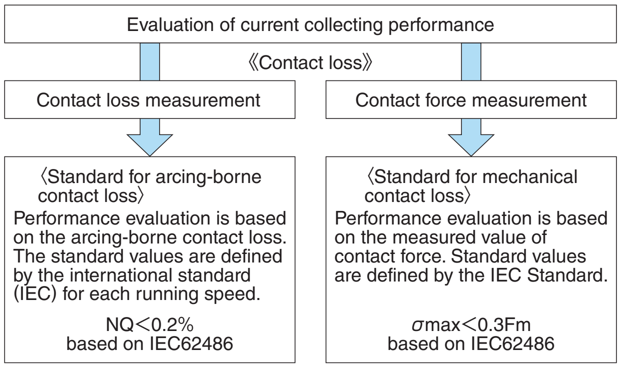

Fig. 1 Outlined Evaluation Approach for Current Collecting Performance

The target items for current collecting performance control are the arcing-borne contact loss and mechanical contact loss. Both are defined by the IEC Standard.

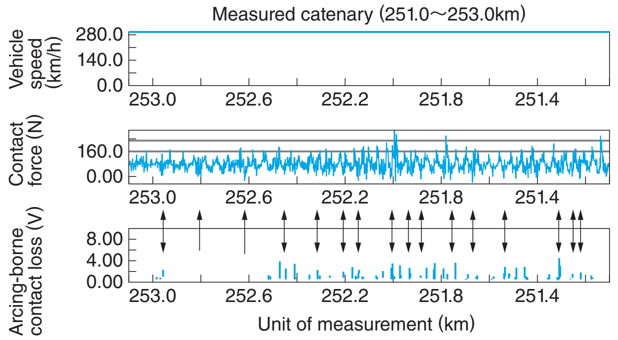

Fig. 2 Result of Contact Force Measurement

Charts of contact force are shown, measured for one block (unit of one catenary). The points where the contact force is zero or below are applicable to the places where contact loss is caused.

2.2 Technical Systems

(1) Measurement of contact force

Two sets of Line Sensor (LS) cameras are used to observe the behavior of vertical movement of a pantograph in non-contact mode. Based on the amount of vertical motion, reaction force of the internal spring in, and inertial force of, the pantograph head are calculated by image processing. In addition, according to the velocity of the running car, force of the pantograph uplifted by the aero dynamic force is calculated. These three forces are synthesized to determine an output of contact force. Since the behavior of the pantograph yields a vertical motion, the upward force is defined as a positive (+) force and the downward force is defined as a negative (−) force. Where the contact force is zero or below, the push-up force is considered to be lost between the pantograph and catenary. In such a case, contact loss by arcing is caused by the air gap generated at that time.

(2) Measurement of contact loss

An Ultraviolet (UV) sensor is used to detect the wavelength band that is peculiar to ultraviolet rays contained in arc light. The arc light continuing for 1 millisecond or longer is measured as an arcing duration. Maximum duration and contact loss rate are determined and used for the evaluation of current collecting performance. Since sunlight contains

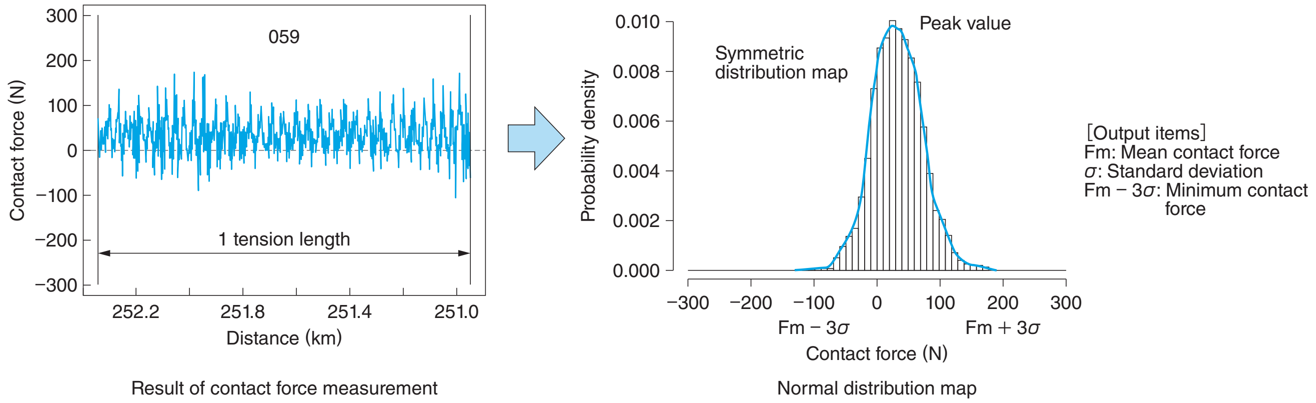

Fig. 3 Normal Distribution of Contact Force

This is a normalized distribution chart of contact force for one block. The peak values appear symmetrically on the right and left at each point. One block: a unit of length of a single catenary line amounting to approximately 1.5km.

ultraviolet rays of the same wavelength band, their energy level is weak and identification of the arc light can be based on the intensity of ultraviolet rays.

(3) Evaluation of current collecting performance

As an evaluation approach for current collecting performance, a statistic technology of normal distribution is adopted in order to grasp the condition of the overall catenary system from raw waveforms acquired from measurements. This is an approach in line with the International Standard (IEC). Based on values of measured contact force in the unit of catenary block, mean value of contact force (Fm), standard deviation (σ), and statistical maximum/minimum contact force ($Fm \pm 3\sigma$) are determined. These statistic numerals can be used as the evaluation values to assess the catenary system. By examining their variation grade, a standard can be established to identify how good the quality of the catenary facilities is.

Fig. 3 shows a normal distribution of contact force. When minimum contact force ($Fm - 3\sigma$) and contact loss rate are plotted on the normal distribution diagram, the result can suggest a possible correlation. Judging from the normal distribution diagram, it is possible to determine a regression line where the contact loss rate becomes larger as the minimum contact force gets smaller. According to the result obtained, it is then possible to determine an evaluation value to the catenary system to be used to assess the condition of the current collection. Fig. 4 shows an analytical diagram for contact loss regression.

Fig. 5 shows the contact loss rate caused in the catenary system as a whole. In this analytical example, catenary sections can be seen where the contact loss rate for indicating the current collecting performance is far larger than the standard value of

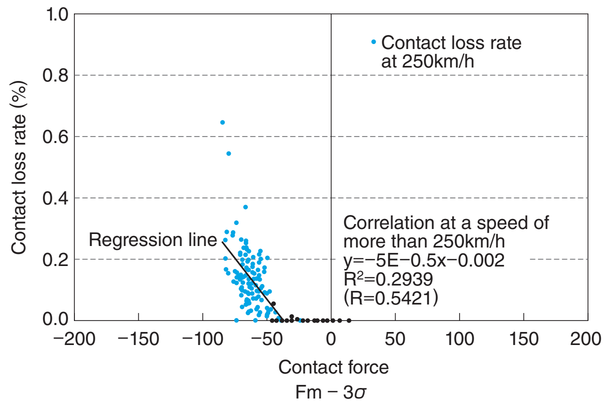

Fig. 4 Analytical Diagram for Contact Loss Regression

Correlation between contact loss and statistical minimum value of contact force is shown. Correlation values can be obtained based on the regression analysis. As the minimum contact force goes on below zero, the relationship with contact loss rate can be grasped in the form of regression line.

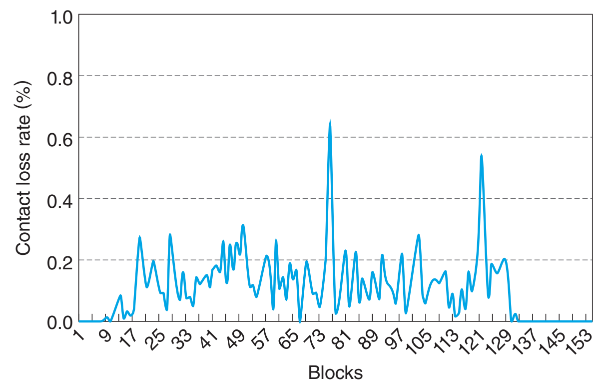

Fig. 5 Contact Loss Rate

The contact loss rate per block for 155 blocks is shown.

0.2%. These values are recorded as the management target in terms of the evaluation of current collecting performance. They are reviewed at the time of the catenary maintenance work. Based on the result, a maintenance engineer in charge at the railway operating firm will investigate the possible causes at each maintenance site. There are check items specified for the on-site investigation. We plan to show a sample in a future paper.

2.3 Expected Effects

Catenary systems come in a facility configuration that extends over a long distance and the maintenance requires a considerable cost, hence, a saving of maintenance cost is desired. When an evaluation of current collecting performance is statistically analyzed by this approach, the maintenance department can grasp and understand the result accurately and quickly. This approach is, therefore, very useful in maintaining good quality of catenary systems. There are four seasons in Japan and changes in ambient temperatures are substantial. In such circumstances, the conditions of catenaries also change significantly. By making continuous measurement and statistical analysis, it is expected that such big data will offer the metrics for better facility management.

3 Technologies for Construction Clearance Limit Measurement

3.1 Purpose

When operating commercial train cars, it is necessary to measure the construction clearance limit periodically in order to avoid train car collisions with various stationary facilities, adjacent houses and buildings, trees, and such surrounding structures along the railway tracks. In the case of conventional approaches, many laser units were installed in a special train vehicle, like a clearance limit measurement train car. In some cases, measuring instruments are brought to the measuring rail site and measurement is done manually. In the former cases, both methods are the point-based measurement and are not a reliable method for recognizing as the fixed structure by visual (graphical) recognition.

Our new technology employs a triangulation method for measuring the objects located alongside the track. We use the track images taken by the two cameras installed at the front of the vehicle. This is

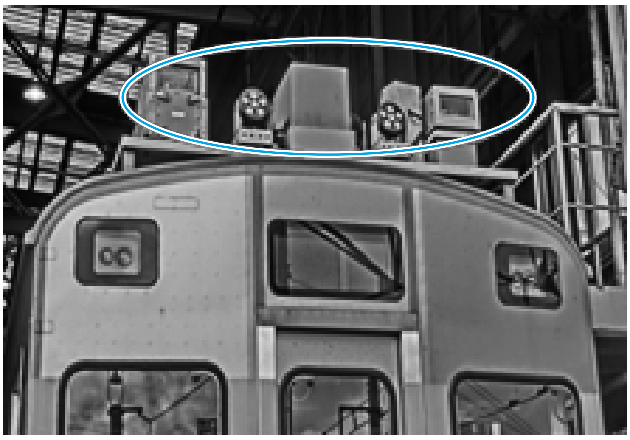

Fig. 6 Appearance of Clearance Limit Measuring Equipment

This is an actual example of equipment. Two cameras and a lighting set are installed at the front end of the measurement train vehicle. The said measurement is conducted while doing the catenary inspection.

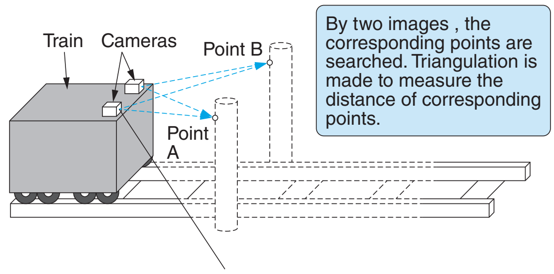

Fig. 7 Conceptual Diagram of Clearance Limit Triangulation

By using the images by two cameras, the system conducts a triangulation measurement.

not the point-based measurement, but the continuous measurement on the plane. Fig. 6 shows an appearance of clearance limit measuring equipment and Fig. 7 shows a conceptual diagram of clearance limit triangulation.

In the actual measurement, the accumulated data after the completion of taking an image are transferred to a PC unit on the ground and the PC carries out an automatic analysis offline. Maintenance personnel check the situation of the maintenance site. The inspection is done while observing the record of the violating spots and the related images. The function of clearance limit inspection is available mainly with Class 3 and Class 4 of CATENARY EYE.

3.2 Technical Systems

(1) Track image monitoring

Two sets of two-dimensional cameras are

Table 1	Configuration and Various Factors of Clearance Limit Measuring Equipment

Necessary units and the specification necessary for clearance limit measurement are shown.

Camera (lens)	2 units	2.4Mpixel Measuring frequency 30fps
Optical converter sets	2 sets	Optical line between camera and vehicle-top PC
Round lighting	2 units	KWM70
On-board PC	1 unit	Optical converter, image board, external disk, OS-related software
Measurement sensor	1 unit	Laser Doppler type
UPS	1 unit	1kVA (AC100V)
Arrangement jigs	1 set	Calibration, etc.

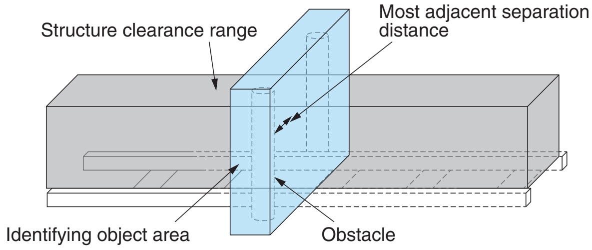

Fig. 8 Outlined Diagram of Objective Area for Clearance Limit Measurement

Since the images taken at the constant frequency are used, the measuring region is set up according to the sampling pitch for the measuring object range.

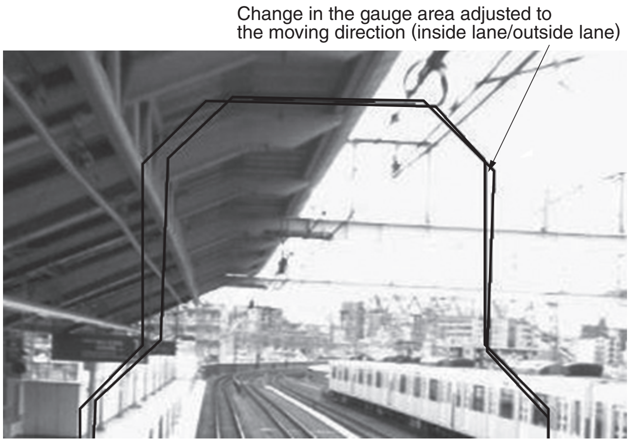

Fig. 9 Virtual Gauge for Clearance Limit Measurement

The virtual gauge for structure clearance measurement is not constantly maintained. In the curve, the scope of the gauge expands, assuming the possible tilting and centrifugal force of the vehicle. Another virtual gauge in a different size is used during the station-passing or station-to-station-passing period.

installed to take images of the track in the forward direction (including surrounding scene) for a specified period. Image monitoring is generally carried out in the daytime. Considering the case of traveling through a tunnel or under highway/railway bridge, a lighting device is installed. **Table 1** shows the configuration and various factors of clearance limit measuring equipment.

(2) Gauge for clearance limit measurement

For clearance limit measurement, a gauge is superimposed in the track center so that the distance from surrounding structures can be measured. In the case of a monitoring system, the measuring position from the camera is predetermined and an virtual gauge is put on the center position of the track. A designed margin is given to the measuring area where the virtual gauge is put in the image so that all measurement can be accomplished. **Fig. 8** shows an outlined diagram of an objective area for clearance limit measurement. The virtual clearance limit measuring gauge is required to make dimensional expand according to the track curving condition. This is because a running train tilts along a track curve due to the effect of centrifugal force. As such, the virtual gauge setting must be changed dynamically at the curve. For this purpose, the curvature of the curving section and the track cant are continuously measured so that the system can put the virtual gauge in accurate position in the image. The method of track detection is described in (3) below. According to the method shown in **Fig. 9**, values of both the inside and outside of the curve are expressed in the same image for the clearance limit measurement.

(3) Track detection system

When the clearance limit is detected by image processing, the most important technology is the track recognition. In order to place the virtual clearance limit gauge on the track center in the image, the track itself must be detected correctly. Recognition of the track by our detection system is carried out by using the following features:

(a) Compared with surrounding structures, the upper part of the track is viewed differently.

(b) Regarding the track width, in the case of a conventional track, it is 1067mm.

(c) The track does not have the big change. Track positions are continuously connected and the curvature can be determined based on the positional relationship.

Based on the above-mentioned conditions, a geometric model corresponding to the track curvature is established and this geometric model is compared with the screen image of the track so that the

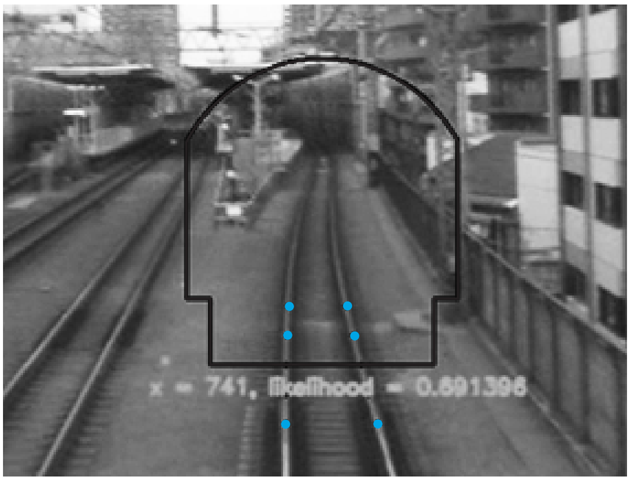

Fig. 10 Image of Track Recognition and Virtual Clearance Limit Gauge Showing

The track position and the curve are determined by image processing. Reproduced data are indicated by a blue point in the track position. This is an image with an virtual gauge.

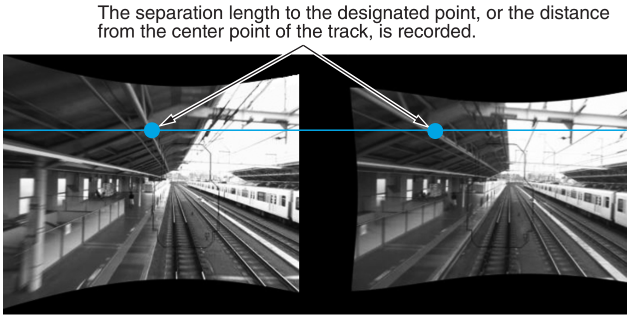

Fig. 11 Manual Clearance Limit Measurement

While the right and left images are displayed, when we click the mouse on the left-side image and then click the same point on the right-side image located on the blue guideline, the length of the separation distance is measured.

curvature of the matched shape is regarded as the track curvature. Fig. 10 shows an image of track recognition and an virtual clearance limit gauge showing.

(4) Detection and measurement of railway facilities

After the completion of preliminary arrangements described above, various railway facilities and structures included in images from the two cameras are detected and measured. For detection, the system assesses each object based on the principle as long as something is there, and the object in the image is captured by two cameras. Furthermore, in order to obtain the distance to the object and the spatial position over the track, the principle of triangulation is used to measure the spatial position accurately. Based on the result of measurement and the mutual separation distance between the measured spatial position and virtual gauge, judgment is made if there is any contact within the gauge. In some cases within the space of an image, there may be some unrecognizable object due to the "look-like" effect by sunlight or an effect of a background image. In such cases of an unrecognizable object, these objects are removed from data as unconnected object like objects in the sky, considering its possible size. In this manner, error detection rate is minimized.

(5) Manual measurement

In addition to the functions of this system by image taking, data analysis, and data outputting are performed automatically, functions for manual measurements are also available. With manual functions, the person can make a direct measurement to inspect the measured result by referring to the related image. In a case when a position for fixed-point measurement is predetermined, such a fixed-point measurement can be carried out with the use of an individual measurement feature. For railway facility detection described in (4) above, everything contained in the image can be an inspection object. For this reason, various matters like snow and trees are detected as an object. Confirmation of objects can be made by displaying the said image. Fig. 11 shows manual clearance limit measurement.

3.3 Expected Effects

The same level of inspections and measurements conducted by conventional equipment can be realized by using lightweight equipment with two cameras. This immediately leads to a saving the cost for the system introduction. In addition, monitoring can be done at a regular car running speed. Such a feature implies that track inspection can be finished in a short time and that measurements are possible in the daytime. In other words, late-night work can be converted into a daytime shift. In consideration of a decrease in employees who are engaged in maintenance work in railway yards, the role of our new system offers significant labor-saving.

4 Postscript

This paper introduced our new technologies for the OCS inspection system, CATENARY EYE.

Technologies for the evaluation of current collecting performance and catenary diagnosis are one of many essential technologies in evaluating the good condition level of catenary facilities. This system can be also used for overseas markets, especially for overseas railway operating companies who introduced the catenary systems compliant to the IEC Standard. In addition, railway operating companies in Japan also show the trend of accepting IEC Standard for catenary system. Given such a business climate, we expect that our system will contribute to rail facility maintenance. Our strategy to make CATENARY EYE, from a simple catenary inspection device to the same with a diagnostic function, is expected to greatly help and save costs for the catenary repair and maintenance. Technologies for construction clearance limit measurement is a very unique area in the field of catenary inspection. As a new function of an image processing technology application, we would like to add this function on our CATENARY EYE product lineups offerings.