EdgeEye: an Online Coating Position Gauge for Battery Electrode Sheets

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From the viewpoint of safety and productivity, it is very important to control coating positions of battery electrodes in the coating process of rechargeable battery electrode sheets. Conventionally, the coating positions were measured after the drying process. However, early feedback of position data to the coating process is required to improve productivity. In addition, to make rechargeable batteries much safer, the coating positions need to be controlled more accurately. To meet such market needs, Yokogawa has developed the EdgeEye, an online coating position gauge for battery electrode sheets. This device—dedicated for measuring the coating positions, which can calibrate measurements by using a built-in scale traceable to the national standard—accurately measures the coating positions immediately after the coating process. This paper describes the specifications, configuration and features of EdgeEye.

INTRODUCTION

In accordance with growing attention to efforts toward low carbon societies and renewable energy, rechargeable lithium ion batteries are expected to be a key component constituting the core of future large scale storage battery technology. Investment in this field, mainly by battery manufacturers, is increasing.

Yokogawa commercialized the WEBFREX3ES in 2010, which accurately measures coating amounts (basis weight) for battery electrodes in their manufacturing lines. It has successfully won a top market share in Japan.

EdgeEye, a newly developed online coating position gauge for battery electrode sheets, measures the distance from the edge of the foil, which serves as a substrate for the electrodes, to each coating position; the width of each coated portion; and the position gap between the coated portions on the front and back sides of the foil. The EdgeEye has achieved real-time and online measurement of coating positions, which is one of the most important requirements for a battery electrode coating process. This position gauge enables users to enhance safety and performance of battery electrodes and reduce their production costs. Figure 1 shows the appearance of the measuring part of EdgeEye, and Table 1 gives its major specifications. Know-how accumulated during field use of the WEBFREX3ES, an online thickness gauge, has been incorporated into EdgeEye specifications, making the system easy to use at actual production sites.

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Figure 1 Appearance of the measuring part of EdgeEye

Table 1 Major specifications

Measurable width	800, 1200, 1450 mm
Visual field of a camera	55 (width direction) x 35 (flow direction) mm
Number of cameras	2 to 8 (standard)
Measurement value calculation interval	1 s
Repeatability	0.05 mm or less with 2σ probability
Synchronized measurement	Number of sensor units: Max. 2 Synchronous accuracy: ± 33 ms
I/O	Contact input: 6 points Contact output: 8 points Sheet speed input: Analog or pulse input
Installation angle	0 – 360 degrees

ISSUES CONCERNING BATTERY ELECTRODE COATING

In rechargeable lithium ion batteries, the positive and negative electrode sheets (metal sheets coated by electrode material) are stacked in multiple layers with plastic films called separators put between them, and then they are stored in a container filled with electrolyte. Metal oxide containing lithium ions is used for the positive electrodes, and carbon materials are used for the negative electrodes. The reactions when charging or discharging basically consist only of movements of lithium ions. More precisely: when charging, lithium ions are pulled from the positive electrode and move to the negative electrode; and when discharging, lithium ions are released from the negative electrode and move towards the positive electrode.

Regarding rechargeable lithium ion batteries, problematic cases of excess heat production or catching fire are sometimes reported, and an internal short circuit caused by uneven electrode areas is pointed out as one of the possible causes in such cases. When charging or discharging, lithium ions move between the positive and negative electrodes through the separator. In this process, if the widths of the electrode material coating for each electrode are uneven, ion exchange does not occur uniformly, and lithium ions are extracted as metal onto the negative electrode. This extracted lithium metal may cause penetration of the separator, reaching the positive electrode, and thus causing a short circuit between the positive and negative electrodes, which may produce heat and cause a fire. In order to prevent such accidents, the negative electrode is coated slightly wider than the positive electrode. However, too wide a coating requires more high cost electrode material, and reduces the space efficiency of the battery. Thus, controlling the coating position and width is an important factor which impacts on both the safety and productivity of the rechargeable lithium ion batteries.

PROBLEMS WITH THE EXISTING METHOD

Conventionally, to detect defects in coating, a defect inspection apparatus was often installed in a battery electrode coating line, and it would also be used for coating position measurement. However, the following are problems with this method:

■ Problem 1: Calibration accuracy

Defect inspection apparatus usually use a line sensor in which picture elements are located linearly. Because a target is transported continuously, two-dimensional area data can be obtained by combining the brightness signals measured by a line sensor in chronological order, even though the measured data is one-dimensional. When using a line sensor, there is a problem that measurement results cannot be accurately calibrated by using a scale. As a scale cannot be transported with a target, it must be located with a target within the visual field of a line sensor for inspection in a stationary state. Furthermore, because a line sensor can obtain only one-dimensional data, information regarding causes such as dirt, blurs, stains or scrapes of a scale directly resulting in measurement error cannot be corrected or removed.

For these reasons, values measured by a line sensor are usually adjusted for by measuring the rolled metal sheets after a coating process, thus taking a lot of time for the calibration.

■ Problem 2: Effect of path line fluctuation

The height to which a metal sheet coated with electrode material is transported for inspection is called the path line. The path line may fluctuate due to electrode material transportation, and a fluctuation of the distance between the path line and the cameras causes an error in the coating position measurement. Because a defect inspection apparatus usually covers the entire width with a small number of cameras (1 or 2), the angle of the visual field of the cameras for inspection needs to be wide. For example, when a line sensor covering a visual field of 90 degrees is used, a measurement error of 1 mm is produced if the path line fluctuates 1 mm. Although measurement is conducted at a place guided by a roller where the path line fluctuation is small, a fluctuation of several hundred μm cannot be avoided, resulting in a measurement error of several hundred μm.

EdgeEye

System configuration

The system configuration for both sides measurement is shown in Figure 2. Devices shown in the dotted line are not required for single side measurement.

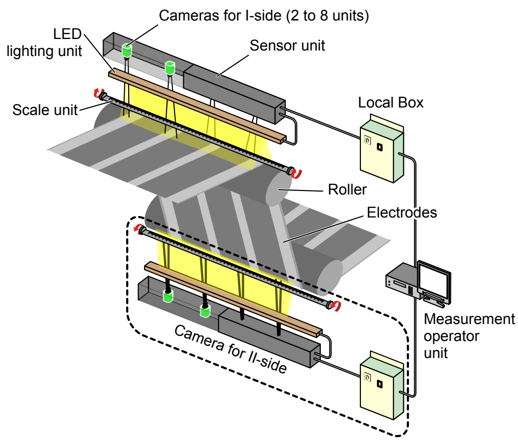

Figure 2 System configuration for both sides measurement

The measuring part of the EdgeEye, consisting of a sensor unit, an LED lighting unit and a scale unit, are usually located near the roller in a coating machine. As shown in the center of Figure 2, the measuring parts for the I-side (front side) and II-side (back side) are respectively placed near the different rollers in opposite directions. The cameras are set so that their light beams intersect at right angles with the rotational axes of the rollers.

The sensor unit includes 2 to 8 cameras, and is fixed at a position where they can take pictures of the images of the foil edges and coating positions.

The LED lighting unit is a light source with multiple LEDs arranged at regular intervals, and it illuminates the measurement target area to provide sufficient brightness.

The scale unit is mounted where the electrodes pass through. When the scale is turned to contact with the roller while the sheet transportation is suspended, the divisions of the scale come into the visual field of each camera, and thus the imaging positions and magnification ratios of each camera can be calibrated. The scale unit is flipped up while the sheet is flowing, so as not to interfere with the travel of the electrodes.

A local box is connected to each measuring part. The local box contains a power supply unit, external contact input/output terminals, etc., and is connected with the sensor unit and the LED lighting unit. It also includes a function for relaying communications between the sensor unit and the measurement operator unit.

The measurement operator unit calculates the distances from the foil edge to each coating position by using image processing based on the images taken by each camera, and it displays the calculated measurement values, widths of each coated portion, and the position gaps between the coated portions on the front and back sides on its operation screens. Users can adjust positions on a sheet onto which an electrode material is coated while viewing the values displayed on the operational screens. The measurement values can be associated with the sheet length by using the coating signals and sheet speed signals from the coating machine. Alarms can be created on the basis of tolerance or standard values. Figure 3 shows an example of an operational screen. This screen can display two arbitrary panels at its top and bottom. Figure 3 is an example displaying a longitudinal trend display panel showing variations in the flow direction at the top and a multiple digital values display panel at the bottom.

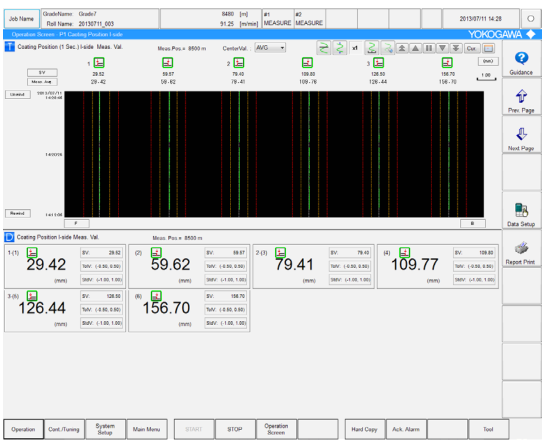

Figure 3 Operational screen example

Features

Major features of EdgeEye are as follows:

■ Feature 1: High calibration accuracy achieved by the scale

The EdgeEye uses cameras as area sensors in which picture elements are arranged two-dimensionally, making it possible to acquire two-dimensional brightness information. Even if the scale is subject to disturbances for measurement such as dirt, blurs, stains or scrapes, these can be removed by image processing using two-dimensional brightness information. This makes a calibration error small enough against the required accuracy.

Furthermore, the scale equipped in the scale unit is calibrated by a calibration service provider certified by the Japan Calibration Service System (JCSS), and its traceability to a national standard is secured.

■ Feature 2: Reducing effect by path line fluctuation

The angle of the visual field of the camera is about 8 degrees, only one-tenth of that of a line sensor of 90 degrees. Thus, even if a path line fluctuates several hundred μm, this causes only a measurement error of approximately 0.02 mm, smaller than that of a line sensor by more than one digit.

■ Feature 3: Measuring immediately after a coating process

Based on the experience in the WEBFREX3ES, the units have been designed compact enough to be easily put in narrow spaces in a coating machine. Because the measuring part is installed using the guide rollers of the coating machine, it can be flexibly installed at any angle from 0 to 360 degrees. This enables measurement immediately after coating in a coating machine.

High precision measurement

To achieve high precision measurement, repeatability of 0.05 mm or less with 2σ probability, the following functions were developed:

■ Function 1: Correction algorithm

The following correction algorithms were developed for real-time corrections:

- Distortion correction: Lenses usually have a distortion aberration of 0.1 to 1%, and magnification ratio differs depending on the positions of the image sensor. Data for correcting the distortion is prepared by taking an image of an accurate lattice chart prior to shipment from the factory, and it is saved as data peculiar to each camera to be used for the correction.
- On Roll Correction: Because electrodes on a sheet are measured while the sheet is in contact with the surface of a roller, the measurement targets are located on a cylindrical surface. When a camera takes an image of a cylindrical surface, distances to various points of the surface differ from each other within its visual field, resulting in differences in magnification ratios. Data for correcting the magnification ratio depending on the distance is prepared prior to shipment from the factory, and it is saved as data peculiar to each camera to be used for the correction.
- Temperature correction: The measurement accuracy is affected by the differences between the coefficients of linear expansion of the materials used for fixing cameras and that used for the scale. The measurement

is compensated in real time based on the difference between a temperature measured by a temperature sensor and a temperature obtained in calibration, and by using coefficients of the linear expansion of the materials.

- Function 2: Foil edge reference

Coating positions are measured by using the foil edge as a reference. Thus, even if the foil flutters, the coating position can be measured accurately. Because the roller is made of a polished metal and its reflection coefficient is close to that of the metal foil, it may be erroneously detected as a part of the metal foil. However, a new algorithm stably detecting the foil edge has been developed to prevent such an erroneous detection.

- Function 3: Synchronized measurement of the front and back sides

The timings to make images by all the cameras for the I-side (front side) and II-side (back side) are synchronized by using the sheet speed and the accurate path length, which is the distance between the measurement points of the I-side and II-side. Thus, coating conditions at the same positions on both sides of an electrode can be measured, and so a position gap between the coated portions on the front and back sides of an electrode can be measured.

MEASUREMENT EXAMPLES

Figure 4 shows measurement results for 16 hours of continuous operation using a pseudo sample sheet containing a single strip of electrodes in the longitudinal direction, and it shows the deviation from the set point of the width. Although the deviation is increasing during a certain interval, it is because of a temperature fluctuation in the range of 1.5 °C, due to a problem with air conditioning at night. Even if its interval is included, the repeatability does not exceed 0.01 mm with 1σ probability, thus achieving a high precision measurement.

Figure 5 shows the results of coating the width measurement of a pseudo sample sheet containing a single strip of electrodes in the longitudinal direction while the brightness is changed by moving the LED lighting unit up and down. The average brightness signal value from the image sensor corresponding to the position of the foil edge is used as the brightness. In this image sensor, the brightness signal is expressed by 10 bits. In this measurement, the brightness is varied from 450 to 1023 by moving the LED lighting unit. The measurement error is ±0.007 mm, achieving stable measurement less susceptible to brightness.

The repeatability is 0.05 mm or less with 2σ probability even if the effects of variation in measurement, brightness fluctuation and so on are taken into account. Highly precise and stable measurement results are obtained.

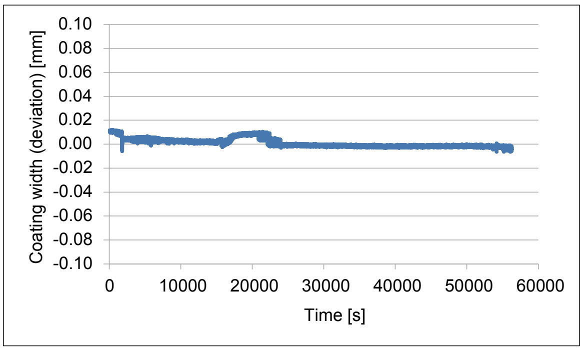

Figure 4 Pseudo sample continuous measurement results

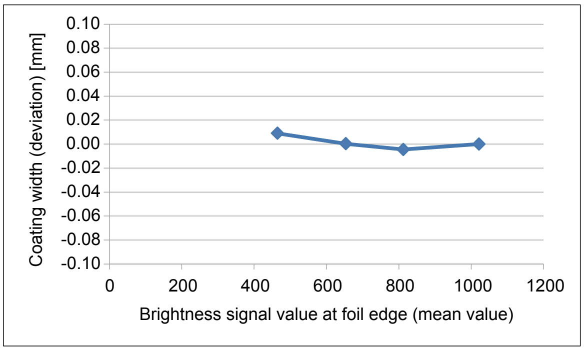

Figure 5 Error due to brightness fluctuation

CONCLUSION

The newly developed EdgeEye has the following features: the coating position can be calibrated by using a scale traceable to the national standard; the measuring part can be installed inside of a coating machine; and it can accurately measure coating positions immediately after a coating process. These features enable accurate feedback to a coating process at an early stage, to prevent waste of materials. Yokogawa has been receiving favorable reports from EdgeEye customers that they are enjoying better quality with less materials loss thanks to its introduction.

Production of rechargeable batteries is expected to drastically increase after 2015. Yokogawa hopes that the WEBFREX3ES online thickness gauge and the EdgeEye online coating position gauge for battery electrodes will contribute to improving quality in production across customer sites.

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