OpreX Battery Web Gauge ES-5

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We first released an online thickness gauge for sheet manufacturing processes in 1962, and have been contributing to improving the quality and productivity of sheet products such as papers and films while advancing sheet manufacturing measurement and control technology up to the present day. In recent years, the shift to electric vehicles has led to booming investment in manufacturing plants for secondary batteries, including lithium-ion batteries. Our products are in wide use, including the WEBFREX NV online thickness gauge, which measures the thickness of separator sheets used in secondary batteries, and the WEBFREX3ES online thickness gauge, which measures the amount of coating in the battery electrode sheets.

With the expanding secondary battery market, in 2023 we released the frame QC1F16 for WEBFREX NV online thickness gauge used for films that is compatible with the laws and regulations of various countries and the Internet of Things, making a major contribution to the measurement of separator sheet thickness. Various issues have arisen in measuring the coating amount of electrode sheets, such as reducing the environmental impact, improving safety, and raising efficiency. Therefore, we have developed the new OpreX Battery Web Gauge ES-5 as a successor to the WEBFREX3ES to address these issues. This article introduces this new measurement technology.

INTRODUCTION

Online thickness gauges for battery electrode sheets play an important role in measuring the amount of coating in the battery electrode sheets and contribute to improving product quality. Uniformity of positive and negative electrode slurry application has a significant impact on quality and yield. Moreover, poor coating quality can lead to serious accidents, such as battery ignition during use. Yokogawa launched the WEBFREX3ES online thickness gauge for battery electrode sheets in 2010 based on expertise in online sheet quality management and measurement technology for paper and film manufacturing processes developed over 50 years[(1)]. Since its release, the WEBFREX3ES has been widely adopted at lithium-ion battery manufacturing sites for coat weight measurement, contributing to quality and cost improvements. The strength of Yokogawa's thickness gauges lies in the expertise accumulated over many years in operational monitoring and improvement at manufacturing

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sites. This expertise continues to be utilized in production environments today.

In recent years, growing interest in renewable energy and efforts toward a decarbonized society have driven the adoption of electric vehicles and energy storage systems for realizing a more sustainable society. Lithium-ion and other secondary batteries are essential to these developments, and the production volume of secondary batteries is expected to continue growing at least until 2030. In particular, the construction of new lithium-ion battery factories is anticipated, especially in China and Europe. As a result, there is now a need for online thickness gauges for battery electrode sheets to provide not only cost and quality improvements but also new value in terms of reducing environmental impacts, ensuring safety, and enhancing production efficiency through digital transformation (DX).

OVERVIEW OF THE OpreX BATTERY WEB GAUGE ES-5

The OpreX Battery Web Gauge ES-5 (hereinafter "ES-5") is a system for measuring, monitoring, and controlling the amount of coating in the battery electrode sheets. It consists of a frame with a sensor for measuring the coat weight and a measurement operator station (OPS) for system operation and monitoring. The measurement OPS can connect up to two substations via a switching hub, and by using an optional profile stack server, it enables the storage and management of a large volume of profiles. Additionally, for integration with external systems, ES-5 supports input/output with MELSEC sequencer and output to OPC Data Access (OPC DA) clients. Figure 1 shows an example of the system configuration.

The ES-5 can accommodate up to five frames on a single coating line. As shown in Figure 2, Frame #1 measures before coating, Frame #2 measures immediately after surface coating, Frame #3 measures after surface drying, Frame #4 measures immediately after backside coating, and Frame #5 measures after backside drying, determining the basis weight (area mass) at each stage. The coat weight of the sheet is calculated from the difference in measured basis weight at each frame. To calculate the coat weight accurately, it is important to align the measurement points before and after coating. The ES-5 utilizes a synchronized measurement function to measure the same spot on the conveyed sheet at each frame, enabling precise calculation of the coat weight.

Frame and Control Box

As shown in Figure 3, the frame consists of the frame itself, which is equipped with a dedicated sensor that scans across the entire width of the sheet, and a control box that houses the control circuitry.

The frame is available in a short length with a maximum sheet measurement width of 800 mm and a long length with a maximum sheet measurement width of 1,600 mm. The measured data are transmitted from the control box to the measurement OPS via a dedicated measurement network.

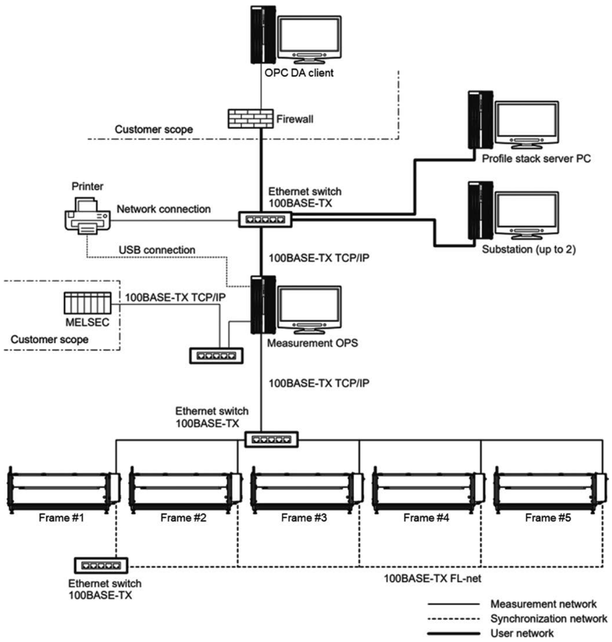

Figure 1 Example system configuration

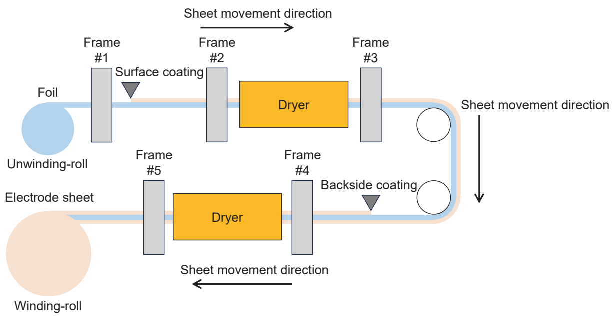

Figure 2 Frame installation locations

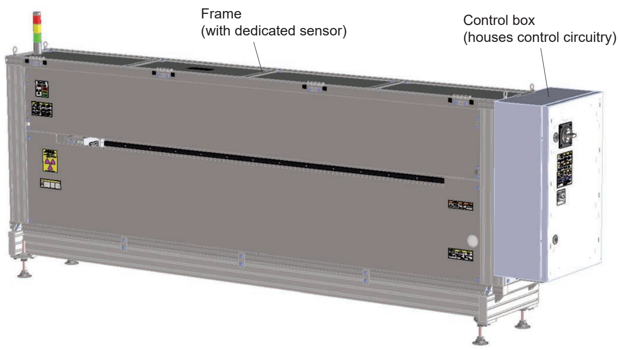

Figure 3 Appearance of frame and control box

Sensor

The sensor employs a transmission-type measurement method using beta-rays, enabling accurate measurement regardless of the sheet material or coating substance. As shown in Figure 4, the sensor consists of an upper head, which houses the detector, and a lower head, which contains the radiation source. Both heads scan simultaneously within the frame. The sheet passes between the upper and lower heads, enabling non-contact basis weight measurement.

Figure 4 Appearance of sensor

FEATURES OF THE OpreX BATTERY WEB GAUGE ES-5

The secondary battery market faces the following challenges:

- Reduction of CO_2 emissions in the supply chain
- Monitoring and improvement of manufacturing quality to prevent and mitigate fire accidents
- Enhancement of production efficiency

The ES-5 addresses these challenges by providing value in three key areas.

Reduction of Environmental Impact

The ES-5 features a redesigned structure, replacing the conventional robust welded construction to a design based on a single base plate (for details, see the section "Design based on a base plate" below). This enables a more compact and lightweight system compared with the conventional frame (Table 1). In addition to reducing the raw materials used for the frame, the packaging for export can be switched from conventional wooden crates to cardboard packaging, contributing to the reduction of packaging waste.

The control box can be installed flexibly, either on the opposite side of the frame or separately. This design supports the creation of a more compact production line by optimizing space utilization. Additionally, compared with conventional frames, the ES-5 significantly reduces both power and air consumption (Table 1), contributing to lower CO_2 emissions in the factory.

A standard aluminum frame is used for the device structure to ensure rigidity. Since it is not welded, the unit can be easily disassembled, reused, or disposed of when no longer in use.

In these ways, the ES-5 contributes to reducing environmental impact at every stage, from manufacturing and transportation to operation and disposal.

Table 1 Comparison of conventional and new frames

Comparison items	Conventional frame (WEBFREX3ES)	New frame (ES-5)
Size	Width 2,460 mm Height 1,280 mm Depth 425 mm	Width 2,454 mm Height 1,006 mm Depth 380 mm[1]
Weight	Approx. 470 kg	Approx. 140 kg
Power consumption	0.8 kVA	0.25 kVA
Air consumption	8 N-m^3/h	0.1 N-m^3/h

[1] 360 mm without control box

Safe and Secure Battery Manufacturing

The ES-5 also features a redesigned sensor, reducing the beta-ray irradiation window slit width compared with conventional sensors and allowing for finer measurement pitch selection (Table 2). This enables high-precision measurement of coating edges and other areas important for quality control. The new sensor is also lighter (Table 2), enabling faster scanning speeds and reducing the risk of missing variations in quality. Additionally, while being more compact and lightweight, the sensor reduces effective radiation levels around the product compared with previous models, facilitating a smaller radiation-controlled area. Furthermore, the measurement range has been expanded to a maximum of 2,000 g/m^2 (Table 2), which enables measurement of a wider variety of materials and thicknesses, thereby supporting the development and production of next-generation batteries.

New features include barometric pressure correction in addition to the conventional temperature correction (for details, see the section "Temperature and barometric pressure correction" below), enabling measurements better adapted to environmental changes and extending the AUTCAL (automatic calibration) interval. Furthermore, a new profile noise reduction filter (for details, see the section "Renewal of profile noise reduction filter" below) shortens the time required for profile stabilization after startup. These new features allow for increased measurement time compared to conventional models, reducing material loss and supporting stable factory operation.

Table 2 Comparison of conventional and new sensors

Comparison items	Conventional sensor (WEBFREX3ES)	New sensor (ES-5)
Beta-ray irradiation window	15 mm dia.	Min. slit width: 5 mm
Minimum measurement pitch	1 mm	0.5 mm[2]
Upper head weight (detector side)	Approx. 12.1 kg	Approx. 2.7 kg
Lower head weight (source side)	Approx. 15.4 kg	Approx. 4.1 kg
Maximum scanning speed	30 m/min	36 m/min[3]
Maximum measuring range	1,200 g/m^2	2,000 g/m^2 [4]

[2] Applicable to sheet widths of 800 mm or less
[3] Applicable to measurement pitches of 2 mm or more
[4] Applicable to a slit width of 10 mm

DX in Battery Production

The ES-5 is compatible with Yokogawa's proprietary coating automation control software, which helps shorten the convergence time to optimal product quality and improve yield, thereby enhancing production efficiency. Additionally, the system offers a highly flexible operation and monitoring interface, enabling the proposal of a monitoring environment that meets the user's needs.

The ES-5 platform incorporates Yokogawa's Collaborative Information (CI) Server, an integrated information server. This provides the following advantages:

- Allows for monitoring and control from any location or device through remote operation.
- Supports not only local optimization for individual plants but also overall optimization across multiple plants and sites.
- Integrates with information systems, data analysis applications, and the like, contributing to improved production efficiency and quality enhancement.

Figure 5 illustrates the CI Server integration.

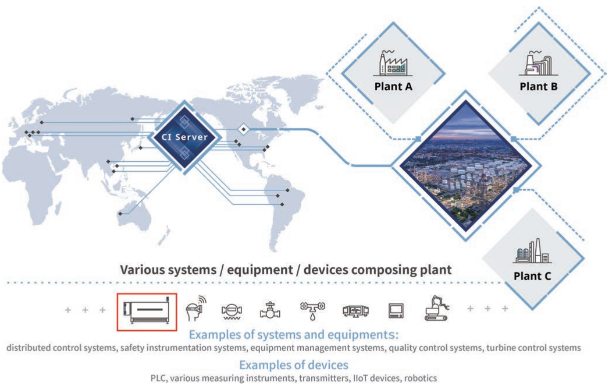

Figure 5 Diagram of CI Server integration

INTRODUCTION TO THE NEW FEATURES AND TECHNOLOGIES IN THE ES-5

This section introduces the main new features and technologies added or modified in the ES-5 compared to previous models.

Design Based on a Base Plate

As shown in Figure 6, the ES-5 features a redesigned structure, replacing the conventional O frame with a single base plate that includes an opening for the electrode sheet. Components are mounted on this base plate, providing the following advantages:

- The need for robust welding is eliminated, enabling significant size and weight reduction of the equipment.
- Since components are mounted on the same surface of the base plate, the relative positions of the upper and lower rails remain unchanged, enabling stable measurement even when exposed to temperature variations from dryers and other equipment.
- Even if the factory installation surface is not perfectly level when the frame is installed, the relative positions of the upper and lower rails remain unchanged, enabling stable measurement by aligning the pass line (sheet transport height).
- Positioning pins on the base plate enable precise mounting of components without parallel alignment of the upper and lower rails or adjustments to motor-driven components.

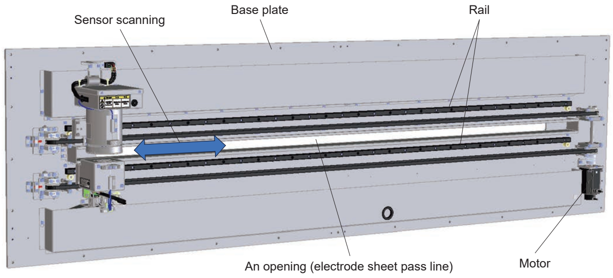

Figure 6 Appearance of base plate

Temperature and Barometric Pressure Correction

A thickness measurement system measures the basis weight without contacting the sheet by detecting the attenuation of radiation. Since air is also present between the upper and lower heads in addition to the sheet, the radiation is attenuated by the weight of the air layer as well. If the basis weight of the air layer remains the same as during AUTCAL, its effect on the measurement value is negligible. However, if the air layer density changes, an offset occurs in the measurement values.

Conventional thickness gauges measure the temperature within the gap between the upper and lower heads and compensate for air density based on temperature alone. To maintain measurement accuracy, regular AUTCAL calibration is required approximately every 2 h. In contrast, the ES-5 incorporates barometric pressure correction in addition to temperature correction, facilitating an extended interval between AUTCAL calibrations compared with conventional systems.

Figure 7 shows the measured barometric pressure as a gray line, the basis weight before temperature and pressure correction as a blue line, and the basis weight after correction as an orange line. The left vertical axis shows basis weight, the right vertical axis shows barometric pressure, and the horizontal axis shows measurement time. Before applying temperature and pressure correction, the basis weight fluctuates in response to changes in barometric pressure. However, after correction, stability is maintained within ±0.1 g/m^2 for at least 2 weeks. This increases equipment operating times and contributes to stable factory operations.

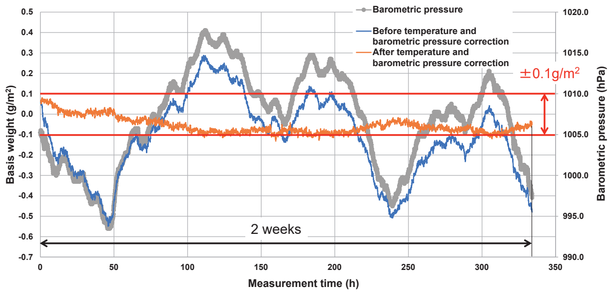

Figure 7 Effect of temperature and barometric pressure correction

Renewal of Profile Noise Reduction Filter

In the measurement of thickness and basis weight using radiation, statistical fluctuations in the radiation source's emission over time introduce noise into the profile. Conventional thickness gauges reduce this noise by smoothing measurement points over multiple scans in the machine direction (MD), which is the direction of electrode sheet conveyance. However, achieving a stable profile requires multiple scans, a process that wastes electrode sheet material.

The ES-5 adds a new smoothing process in the cross direction (CD)—the width direction of the electrode sheet—followed by smoothing in the MD to achieve high-speed profile stabilization. As a result, waste of the electrode sheet material is reduced compared with conventional methods. Additionally, in CD smoothing, a threshold can be set to distinguish between noise and significant sudden changes in values. This allows abnormal coating conditions to be more easily detected and recorded.

In Figure 8, the yellow line represents the profile from the first scan, the red line represents the profile from the 22nd scan using the conventional correction method that performs smoothing in the MD direction, and the blue line represents the profile from the 5th scan using the new correction method that performs smoothing in both the CD and MD directions. The vertical axis shows the basis weight of the sheet, while the horizontal axis shows the measurement point across a sheet width of 1,600 mm, with a measurement pitch of 1 mm. In the CD direction, smoothing is performed using a moving average over 15 segments. In the MD direction, smoothing is applied using a smoothing factor (SMF) of 0.1. Here, SMF is a coefficient used to smooth each measurement point, and MD smoothing is performed using the following formula:

Calculated value for each measurement point
= Current measurement × SMF
+ Previous calculated value using SMF × (1 − SMF)

While the standard deviation (σ) of the profile at the 22nd scan is 0.19% with the conventional correction method, the new correction method achieves a standard deviation (σ) of 0.18% at the 5th scan, enabling faster profile stabilization. This improvement reduces electrode sheet material loss and contributes to stable factory operation.

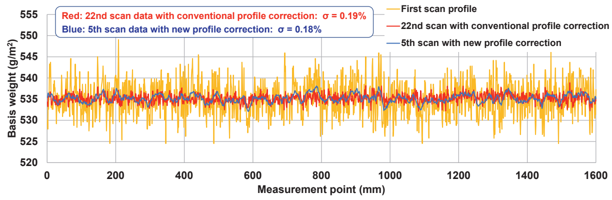

Figure 8 Effect of new profile noise reduction filter

CONCLUSION

The newly developed ES-5 is a device specialized for measuring the thickness of battery electrode sheets. To meet market demands, it has been completely redesigned from the frame to the sensor and system, integrating the core technologies Yokogawa that has built over time. With the ES-5, Yokogawa aims to deliver even greater value, contributing to the continued growth of the secondary battery market and the realization of a more sustainable society.

REFERENCE

(1) Takaaki Kishino, Yoshihiko Hagiwara, et al., "WEBFREX3ES Dedicated Coat Weight Measurement System for Battery Electrode Sheets," Yokogawa Technical Report English Edition, Vol. 62, No. 1, 2019, pp. 9-14