A High-precision IR Moisture Sensor for the B/M9000VP System

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The production of paper, especially for cardboard and tissue, is increasing in emerging countries, and control systems for paper machinery are required for improving sensing performance for efficient production. To satisfy this demand, Yokogawa has developed a new IR moisture sensor for the B/M9000 VP system.

With various new technologies incorporated, this sensor measures moistures accurately in various applications. The new technologies include the industry-first semiconductor light source, the innovative optical system, and the single-cell detector for truly simultaneous measurement of single spot. This paper describes the background of the development, its new technologies, and the performance of the sensor.

INTRODUCTION

Demand for paper for corrugated cardboard and sanitary paper such as tissue paper and their production volumes are rapidly increasing in emerging countries as a result of rapid industrialization and improved living standards. Consequently, paper manufacturing equipment is being enhanced, thus investment in measurement and control systems used for paper machines and coating machines for quality control is also being stimulated. (Hereafter, such a system is referred to as a "B/M system," where B/M stands for basis weight and moisture.)

To increase competitiveness in this market, Yokogawa has developed an innovative moisture sensor different from conventional ones which apply the optical filter method. Figure 1 shows an external view of the light source side head of the new moisture sensor, and Table 1 lists the major specifications. Basis weight is the weight of paper per unit area and is expressed in g/m^2. Moisture content is the ratio of water weight to weight of dry paper and is expressed in %M.

The size of the new moisture sensor is reduced to less than half of existing ones, and achieves excellent measurement stability in a wide measurement range of basis weight from low range, e.g. tissue paper, to high range, e.g. paper for corrugated cardboard.

Figure 1 External view of the moisture sensor

Table 1 Specifications of moisture meters

Item	Conventional moisture sensor	New moisture sensor
Light source	Halogen lamp	Near infrared emitting semiconductor device
Photo detector	PbS photodiode	InGaAs PIN photodiode
Wavelength discrimination	Turret rotation	Direct control Lock-in amplifier
Measurable range of basis weight	Craft 80 to 400 g/m^2 Liner for corrugated cardboard 50 to 200 g/m^2	Tissue, craft 8 to 850 g/m^2 Liner for corrugated cardboard 40 to 500 g/m^2
Mean value repeatability	±0.1%M	±0.005%M

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CONVENTIONAL MOISTURE MEASUREMENT METHOD

Measurement Principle

Conventional moisture sensors determine the moisture content by calculation using absorbance at three wavelengths; one sensitive to water, one sensitive to cellulose, and one sensitive to neither water nor cellulose for reference.

Figure 2 shows a typical absorbance in the near infrared region. Strong absorptions of water and cellulose are seen at wavelengths of 1.94 µm (M light) and 2.1 µm (C light) respectively. Light with a wavelength of 1.7 µm (Ra light) is used as the reference.

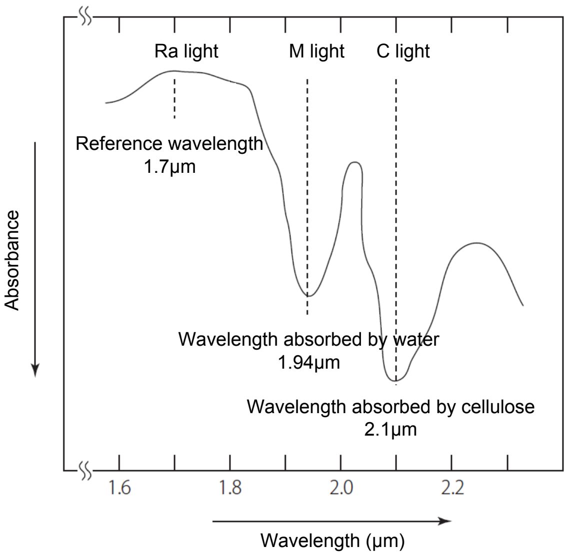

Figure 2 Typical absorbance in the near infrared region

Configuration

Conventional moisture sensors use a halogen lamp which emits a broad spectrum from visible light to far infrared light and optical band-pass filters (BPF) which selectively transmit any one of the above three wavelengths.

The light beam is irradiated onto one side of the paper, and the transmitted light is detected by a detector on the other side. Three BPFs are switched mechanically to measure the transmittance of each wavelength.

Problems

Paper for corrugated cardboard, for which demand is growing, has a high basis weight and is usually made from recycled paper in which impurities such as carbon are contained. The transmittance of infrared light by such paper tends to be low, and measurement with a high signal-to-noise ratio (S/N ratio) is difficult.

For this reason, conventional moisture sensors use higher power halogen lamps to secure accurate measurement. However, in this method which selects desired wavelengths by filtering the black-body radiation, the ratio of effective light radiation energy to input energy is low, and thus a large amount of energy is wasted as heat.

In addition, to obtain a higher S/N ratio, the beam diameter must be enlarged, which restricts spatial resolution.

Even more problems in this method arise from rotation of the filter wheel. Because multiple required wavelengths are extracted by the filter wheel rotation, irradiation time of each wavelength is shifted. This makes simultaneous multiple measurement on the same spot impossible. Necessity of frequent maintenance due to wear of the rotating mechanism is also a problem.

THE NEW MOISTURE SENSOR

Features

Yokogawa has successfully developed an innovative moisture sensor that can resolve all the problems above. Features of the new moisture sensor are as follows.

- ■ Feature 1: High precision and high stability
  - Simultaneous irradiation of multiple lights with different wavelengths enable the simultaneous multiple measurement on the same spot, improving measurement accuracy.
  - Newly developed reflector optics reduce the measurement fluctuation caused by fluctuation of the sample position, down to 1/8 of the conventional one.
  - A narrowed beam diameter improves spatial resolution of the measurement.
  - Damage to samples caused by light irradiation is reduced, improving repeatability during long-time or repeated measurement.
  - A newly developed highly airtight container for standard samples ensures accurate control of measured values.
- ■ Feature 2: Wide measurement range
  - Combining homogenization optics and multi-reflection optics improves the efficiency for light utilization, achieving a wide measurement range from tissue (8 g/m^2) to paper board (500 g/m^2).
  - Direct control of a semiconductor light source and detection by a digital lock-in amplifier achieves a 10,000 times higher S/N ratio than that of conventional sensors.
- ■ Feature 3: High reliability and long-life operation
  - The life of a newly developed semiconductor light source is more than three times that of halogen lamps.
  - Elimination of moving elements such as a filter rotation mechanism ensures stable measurement over a long period.
  - A self-detection function for an open failure or a short-circuit failure and a function for monitoring and detecting a decline in light intensity for each light source improve maintainability.

Light Source and Optical System

This moisture sensor applies an originally developed semiconductor light source, instead of commonly used halogen lamps. This light source emits only the wavelengths required for moisture measurement, and this is a module integrating three light sources for different wavelengths of: 1.7 µm, 1.9 µm, and 2.1 µm.

The output power is about 0.02 W, which is less than one thousandth of that of halogen lamps, typically 50 W. There is no damage to paper because the output power is so weak, and the irradiated light includes no wavelengths other than those required for the measurement. Unlike halogen lamps, the output light intensity of semiconductor devices can be electronically changed at high speed. The intensity of each wavelength is controlled independently.

Figure 3 illustrates the optical system. With a newly developed optical component applying a light pipe, the spatial distribution of radiation intensity from the light source is homogenized. This light pipe is a tubular, reflector-type element whose circumference is covered by a material with a higher reflectance unlike the usual light pipes, so as not to be affected by absorption by transparent glass material. This called a light pipe tube reflector.

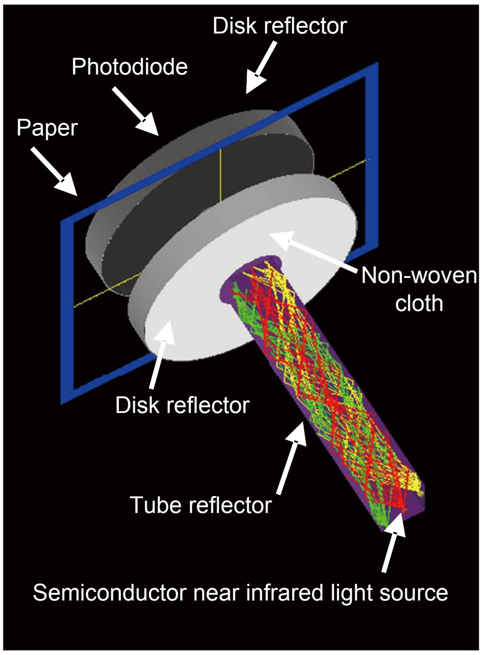

Figure 3 Optical system of the new moisture sensor

At the exit of the tube reflector, a pair of dish-shaped reflective optical components are arranged with a paper sample between them. This dish-shaped reflective optical component is called a disc reflector. Owing to these disc reflectors, the irradiation light goes back and forth through the paper multiple times.

Photo Detector and Detecting Electronics

A detecting unit is on the opposite side of the paper. The photo detector is an InGaAs PIN photodiode which is highly sensitive to infrared. The photodiode is cooled and its temperature is stabilized by a two-tier Peltier chip to secure a high S/N ratio.

A single photodiode receives the measuring light with multiple wavelengths, and a signal of each wavelength is extracted from the composite signal, and its intensity is amplified by a digital lock-in amplifier, and then the absorbance of each wavelength is calculated. A 2-phase lock-in amplifier is used, because it does not require synchronization between the oscillator and receiver and thus eliminates the troublesome need for synchronization. Furthermore, a narrow bandwidth of the lock-in amplifier remarkably reduces disturbance from other frequencies and crosstalk. As a result, this sensor has an approximately 10,000 times higher S/N ratio than conventional ones. The use of a single detecting component also makes truly simultaneous multiple measurement on the same spot possible.

Measurement Range

As stated above, higher basis weight causes higher scattering and absorption of incident light, and thus the amount of light that reaches the detector decreases exponentially, which lowers the S/N ratio and increases dispersion of measured values.

Successful measurement of paper with high basis weight depends on how much high S/N ratio for the detection is secured. Figure 4 shows the dispersion of measured values for different basis weights. Four curves indicate the case of the normal range type and wide range type of a conventional

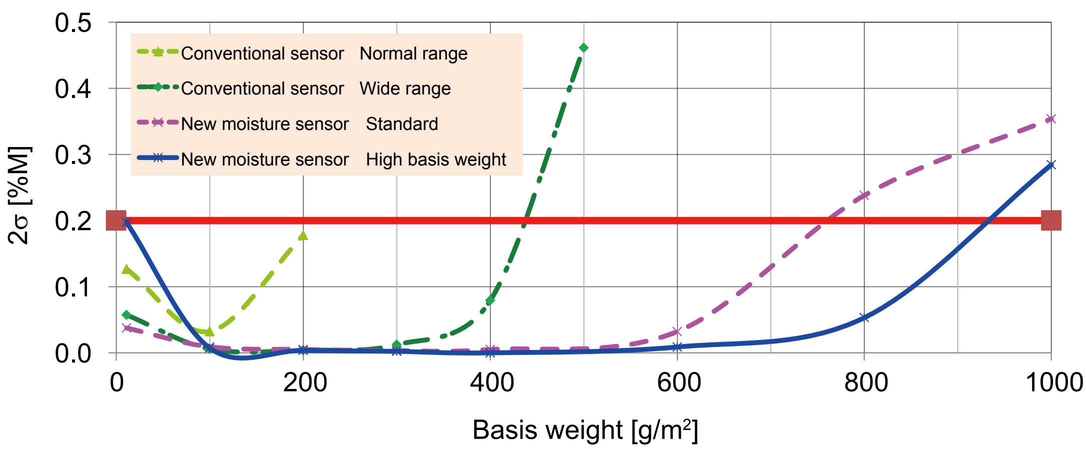

Figure 4 Dispersion of measured values for different basis weights

sensor, and the standard type and high basis weight type of the new sensor, respectively.

In the measurement by the new moisture sensor, 2σ of the measure values keeps within 0.2%M for a wide range of basis weight, from 10-100 g/m^2 equivalent to that of tissue paper etc. to 900 g/m^2 equivalent to that of paper for corrugated cardboard etc. A single new moisture sensor can cover the range, which conventionally needs two different types of sensors.

Improving Measurement Accuracy

It is difficult to verify the measurement accuracy of a moisture sensor because the moisture weight in paper cannot be measured accurately while keeping the conditions consistent at which a moisture sensor has measured.

Only a few seconds exposure to the room atmosphere changes moisture content by 0.1 to 0.2%M. Although moisture weight can be measured concurrently with the measurement with a moisture sensor, it is not easy to obtain reliable results because of conditions in the equipment, uneven dryness in the sample, and so forth.

A moisture sensor itself can also affect the sample condition, which makes it more difficult to verify the certainty of the indicated values, and the repeatability and stability of the measurement.

Yokogawa has developed a sample container with over 10 times higher air tightness than existing ones. By measuring the stable moisture sample, the measurement accuracy is drastically improved.

Figure 5 shows the results of measurement using the highly airtight sample container. This graph plots moisture content in %M obtained by actually measuring the weight of water in a paper against an intermediate value INX in the moisture sensor to determine the moisture content. The graph includes the measurement results of six different types of paper including kitchen paper and paper for paper bags. If the INX has a strong positive correlation with moisture content, the plot should fit in a curve of a low-degree polynomial even if different brand samples are used for plotting. This polynomial serves as a calibration curve for the moisture meter. The moisture content obtained by measuring the weight of water deviates from the calibration curve by less than 0.2%M over the practically important range of less than 10%M. Even in the region of 10%M or higher, the deviation is within 1%M. This shows the polynomial is well fitted to the actually measured moisture content.

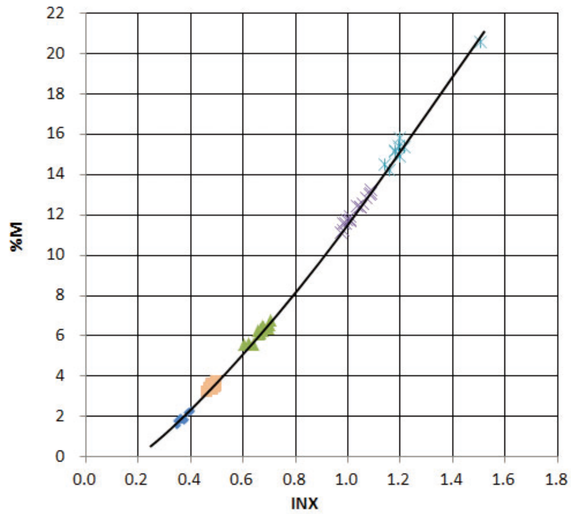

Figure 5 Measurement results using the highly airtight sample container

CONCLUSION

This paper describes the measurement principles of an online moisture sensor and the features of the newly developed moisture sensor, including the semiconductor near infrared light source and the optical system.

The moisture sensor is the most crucial sensor in a B/M system. The new moisture sensor described in this paper has remarkably improved performance and can be applied to a wide range of paper specification, from tissue with low basis weight, for which demand is rapidly increasing, to cardboard with high basis weight. This improvement has drastically boosted the competitiveness of our B/M9000VP system, a measurement and control system for paper machines and coating machines, in overseas markets.

Yokogawa will keep improving the moisture sensor by expanding the measurable range, developing a standard sample with long-term stable characteristics, applying the technologies described in this paper to basis weight measurement, and so forth.