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近红外技术在纸张水分率测量中的应用

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摘　要：为了解决纸张水分率指标的在线测量问题，研究了基于近红外光谱分析的水分率测量技术，阐述了介质对光谱吸收的基本原理，分析了该原理应用于纸张水分率测量时存在的问题，探索了采用两条谱线（测量谱线和参考谱线）的方法实现水分率在线检测的关键技术，设计规划并实验研究了相应的测量方案，论述了方案中各功能模块的作用. 基于光谱法和干燥称重法的水分率对比测量实验表明，基于光谱法的测量准确度可控制在 0.5％以内. 因此该方法可实现在线检测且满足准确度要求.

关键词：近红外光谱；水分率；纸张；在线检测
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Application of Near Infrared Techniques in Paper Moisture Parameter Measurement

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Abstract: In order to solve the online inspection problem of paper moisture rate technical specification, the moisture rate measuring technique based on the near infrared spectroscopic analysis is researched. The basic theory on the spectral absorption of medium is expatiated and the problems applying the theory to the moisture rate measurement are also analyzed. The key technique that can realize the moisture rate on-line inspection by means of two near infrared spectral lines (measuring spectral line and the reference line) is explored in detail. The measurement project is designed and the role of the main functional module in the project is discussed. The corresponding experimental research showed that, the precision of moisture rate measurement based on near infrared spectroscopic method is less than0. 5%. It is higher than measuring precision of the dry method and the method can be applied to on-line inspection in paper－making process.

Key words: Near infrared spectral; Moisture rate; Paper; On-line inspection

0 Introduction

In the 21st century, with the development of culture, scientific research, education and information industry, papermaking industry is closely relate to national daily life, industrial and agricultural production, and became one of the ten pillars of the national economy[1-2]. A number of parameters need to detect in the paper production process such as moisture ratio. Generally, dry weighing technique is used to measure moisture ratio to guide the adjustment of the parameters based on results. Dry weighing technique is the most commonly used with very high precision. However, this measurement is offline and can not adjust and control in real-time[3-4]. Paper moisture

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rate on-line measurement methods mainly include microwave method and near infrared method. The microwave method universally is used in the situation in which requirement to the measurement accuracy is not high, and the near infrared more used in the situation in which requirement to the measurement accuracy is high precision[5-6]. The method that the paper moisture rate is online measured by means of near infrared technology, is to use the characteristics that a certain specific near infrared spectrum obviously is absorbed by moisture of paper. But it is very difficult avoiding the influence of other factors to the spectrum absorption, if the principle is directly applied to the paper moisture rate measurement. An online detection technique of moisture ratio based on Infrared Spectroscopy is presented in this paper, which has important significance for improving the product quality of the papermaking industry.

1 Measurement based on the spectral analysis

1.1 The basic principle of measurement on moisture

The basic principle based on spectral analysis is Lambert-Beer law. Lambert-Beer law can be proposed that an absorption ratio of incident light absorbed by a medium in cuvette is proportional to the thichness of the medium traversed, but is independent of the intensity of incident light[7]. The law is the basic laws of light absorption, applies to all electromagnetic radiation, and all of the light absorbing material. Beer-Lambert law is photometric, colorimetric assay and the quantitative basis of the photoelectric colorimeter.

In other words, a bunch of parallel monochromatic light through an absorbing medium, because the media has absorbed part of the light intensity of the transmitted light should weaken. The larger the concentration of the absorbing medium, the larger the dielectric thickness, the intensity degree of weakening has become more significant. The general Beer-Lambert law is usually written as

$$A=\ln\frac{I_0}{I}=\varepsilon\cdot c\cdot L \tag{1}$$

where A is the measured absorbance, I_0 is the incident light intensity, I is the emitted light intensity, ε is a wavelength-dependent absorptive coefficient, L is the path length, and c is the analytic concentration, when working in concentration units of morality.

The absorption coefficient ε and the optical path (paper thickness) L are constants applied to the paper moisture measurement for the specified type of paper, according to the measured absorbance A can determine the absorption of optical media (paper) concentration.

1.2 Paper moisture rate measurement based on spectral analysis

The absorbance A is not only relating to paper moisture ratio, but also with the paper material parameters, so it must be remove the impact of the paper material and other parameters on the absorbance.

Lambert-Beer law reflects the absorption of analyte[8], if multiple independently components are present in a sample when the medium contains multiple of each other absorbance, the total absorbance at a given wavelength is the sum due to all absorbers, this rule is called the Absorbance additive property. According to this feature, we select two monochromatic light λ_1 and λ_2 within a band which absorption coefficient of the paper moisture paper are quite difference, while the other components of paper are substantially constant. Using this property, we can determine the paper moisture ratio.

In our study, the spectral range is at 0.78～2.526 μm[9]. As shown in Fig. 1, curve C_1 is transmissivity of real paper moisture ratio and C_2 is other components in paper[10].

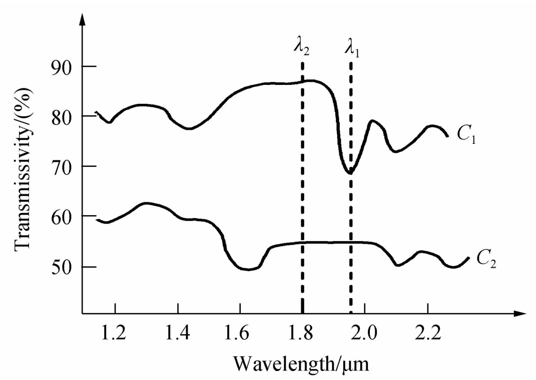

Fig. 1 Transmission rate curve of different medium

In terms of Lambert-Beer law, λ_1 is measure wavelength, λ_2 is reference wavelength, and the paper absorbency A_1 and A_2 at the two wavelengths can be obtained

$$A_1=\ln\frac{I_0(\lambda_1)}{I(\lambda_1)}=\varepsilon_{(\lambda_1)}\cdot c\cdot L \tag{2}$$

$$A_2=\ln\frac{I_0(\lambda_2)}{I(\lambda_2)}=\varepsilon_{(\lambda_2)}\cdot c\cdot L \tag{3}$$

Using Eq. (2) and Eq. (3), we can get

$$\ln I_0(\lambda_1)-\ln I(\lambda_1)=\varepsilon_{(\lambda_1)}\cdot c\cdot L \tag{4}$$

$$\ln I_0(\lambda_2)-\ln I(\lambda_2)=\varepsilon_{(\lambda_2)}\cdot c\cdot L \tag{5}$$

Intensity of light at the spectral range of

1.0～2.2 μm is approximated constant, so $I_0(\lambda_1)$ and $I_0(\lambda_2)$ is approximately equal, from Eq. (4) and Eq. (5). Thus we can get the difference of Eq. (5) and Eq. (4) as

$$\ln\frac{I(\lambda_1)}{I(\lambda_2)}=(\varepsilon_{(\lambda_2)}-\varepsilon_{(\lambda_1)})\cdot c\cdot L \tag{6}$$

For a specific paper, $\varepsilon(\lambda_1)$, $\varepsilon(\lambda_2)$, and L are constants, so Eq. (6) can be written as

$$\ln\frac{I(\lambda_1)}{I(\lambda_2)}=K\cdot c \tag{7}$$

where, $K=(\varepsilon_{(\lambda_2)}-\varepsilon_{(\lambda_1)})\cdot L$.

The constant K of different paper can be determined by calibration in practice. If we get the intensity of light $I(\lambda_1)$ and $I(\lambda_2)$ after passing through the paper, the concentration of c can be obtained. That is the paper moisture ratio.

2 Paper moisture on-line measurement scheme

In order to implement this measurement system based on NIR absorption, a system block diagram is shown in Fig. 2.

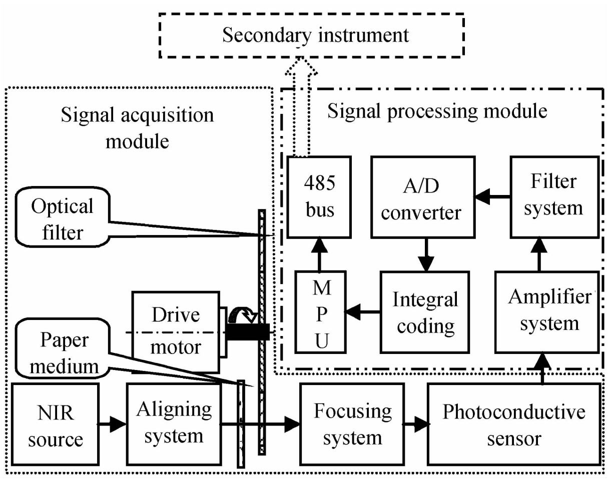

Fig. 2 Paper moisture rate measure based on NIR spectrum technology

The entire system consists of two parts, namely the signal sensing part and the signal processing part. The former generates and picks up light signal that act on specific paper at selected wavelength. The latter produce standard electrical signal after amplification, filtering, AD conversion, digital integration, encoding with the weak signal from sensor, it will send to secondary instrument via the 485 interface bus for the subsequent processing.

2.1 Signal pick block of the moisture rate measurement

Signal collection module includes near-infrared light source, optical system, optical signal sampler, sensor and drive motor, etc.

The specified spectral range of optical signal generation and optical signal sensing are achieved in this module. A near-infrared light passing through the lens will be paralleled, the optical energy is partially absorbed when passing through the analyte (paper), absorbed energy is a function of wavelength, this function represents absorption of water and other components in paper at different wavelength (Fig. 1).

The optical signal sampler is a mechanical device consisting of two optical filters (sensitive to λ_1 and λ_2 respectively), which under the action of the drive motor, alternating filters through the media (paper) near-infrared optical signal dynamic sampling, two sensitive wavelength optical signal, light sensors to pick up and converted to electrical signals sent to the signal processing module. Two sensitive NIR wavelength optical signals are dynamic sampled alternately and collected by the photosensitive sensor, it will be converted to electrical signals and sent to the signal conditioning module.

2.2 Signal processing block of the moisture rate measurement

Signal conditioning module includes signal amplification, filtering, A/D converter, digital integration, etc. the main function is converting the light intensity signal to the electrical signal and sending it to the signal processing module for further processing, finally the signal is quantified, and the moisture ratio can be obtained after processing according to Eq. (6).

The key part of the module is the digital integrated circuit; the integral values can be calculated corresponding to λ_1 and λ_2, the two integral values represent the measuring signal and the reference signal respectively in moisture ratio measurement. This original data is send to the secondary instrument by the 485 bus; finally, the paper moisture ratio can be measured.

2.3 Implementation of moisture measurement based on the spectral analysis

According to optical transmission characteristic of analyte (paper), λ_1 and λ_2 is selected at 1.94 μm and 1.81 μm in the experimental study respectively; the response curve linearity of lead sulfide photosensitive sensor is very well from 0.4 μm to 2 μm. We chose lead sulfide photosensitive sensor as our measuring sensor to ensure effective measurement at two wavelengths.

In order to pickup the monochromatic light signals, mechanical device is designed as shown in Fig. 3(a). A mechanical disc with two symmetrical holes installed optical filter sensitive to λ_1 and λ_2 (the distance between hole center and the disc rotation axis distance is r) rotates at uniform rates derived by motor. The distance between the optical axis and the disc rotation axis distance is r, light intensity signals will be alternately transmitted to the photosensitive detectors (P_bS photo-resistor) shown in Fig. 3(b) at a circle rotation. Thus, signals picked up are respectively the measuring signal (M) and the reference signal (R). The rest of the infrared light is filtered.

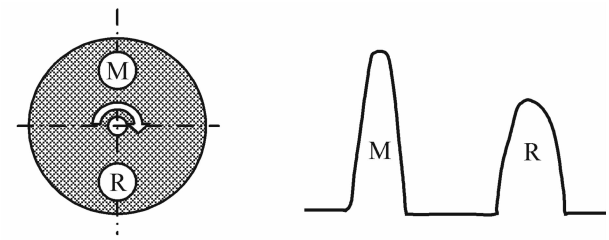

Fig. 3 Sample mechanics and light intensity signal

After digital integral and quantification processing, when the analyte (paper) type is confirmed (paper's thickness, paper's absorption coefficient at different wavelength), the detected signal is sent to the second instrument via the 485 bus for further processing. The paper moisture ratio will be calculated, and the result will be displayed on a liquid crystal screen. At the same time, the result will be transmitted to IPC in real-time, and the paper production will be controlled by the PC.

According to the experimental system, the following experiment is planned. A group of samples that are 6 pieces of paper with same specifications are selected. The samples are respectively putted in vessels in which moisture is different. Take out the samples after 24 hours. Respectively measure the samples' the moisture rate with dry method and near infrared method, measurement data as shown in Table 1.

From Table 1 it can be indicated that the measurement error of the moisture rate is less than ±0.5% with dry method and near infrared method measurement. It can completely meet the requirements of the on-line detection of paper production line.

Table 1 Measurement data by different method

Sample No.	Dry method/(%)	Near infrared method/(%)	Measurement error/(Abs)
1	3.5	3.4	−0.1
2	4.3	4.1	−0.2
3	4.7	4.9	0.2
4	4.9	5.0	0.1
5	5.2	5.2	0
6	7.1	7.2	0.1

3 Conclusions

In this paper, the near infrared spectrum analysis method is applied to paper moisture ratio on-line testing. Based on detailed analysis the application principle, a specific research method is presented. The study result has shown that this method is feasible and can meet paper moisture ratio online testing in industrial sites. Its popularity and applications will promote the development of paper detection technology and improve the quality of paper.

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