Development of a NIR device for measuring varnish thickness on-line

Francisco Manero[a], Javier Anduaga[a], Kepa Mayora[a], Izaskun Garmendia[b], Pentti Niemelä[c], Eero Hietala[c] & Jouni Tornberg[c]

[a]*Ikerlan Technological Research Centre. Pº J.M. Arizmendiarrieta 2, 20500 Mondragon. Spain*

[b]*Cidemco Technological Research Centre. Bº Lasao 5, 20730 Azpeitia. Spain*

[c]*VTT Electronics. Kaitoväylä 1, P.O. Box 1100, 90571, Oulu, Finland*

Introduction

The current manual methods used to control thickness, based on weighting of pieces, must be overcome allowing the direct manipulation of the equipment to adjust the coating quantity to be applied. An optimisation in this step involves consequently the saving in time and money (weight of coating applied).

The key step in the achievement of these objectives is the measurement of wet thickness. Techniques based on optical absorption can measure coating thickness on-line, providing high measurement accuracy. Non-contact nature of these measurements is a major advantage of optic techniques.

Initial trials

The NIR absorption method is based on a selective absorption band of the varnish material. As the NIR beam is directed towards the coated board, it reflects from the board surface and meets absorption in both passages through the varnish layer. A two-channel method is normally used in NIR absorption measurements: the filter band of the measurement channel is chosen within the varnish absorption region and that of the reference channel just outside it. The reference channel compensates for instabilities of the instrument and for optical properties of the sample, which are independent of the wavelength (grey factors).

Spectral properties of different kinds of varnishes and fiberboards were first measured in order to define the proper absorption bands for the measurement.

All the varnishes have absorption bands centred at 1.7 µm (6000–5700cm^{-1}) and at 2.3 µm (4500–4000cm^{-1}), which represent harmonic and combination bands of CH stretching vibrations, respectively (see Figure 1). Some changes in the band features could be seen during the drying process, as the solvent is lost by evaporation and/or by chemical reaction with the resin.

The spectra of fiberboards with different wood veneers, for example, are quite similar in NIR spectral region, although their colours (and reflectance in the visible region) vary from dark (bubinga) to light (pine). Reflectance of the tested boards at the CH absorption bands 1.7 and 2.3 µm are mainly between 30–50% and 20–30%, respectively.

Filter bands

A pair of filters was chosen both for the 1.7 and 2.3 µm absorption bands (see Figure 1). Magnitude of the 2.3 µm band makes it an obvious choice for the thickness range of a roller coater,

Near Infrared Spectroscopy: Proceedings of the 11th International Conference.

but the weaker 1.7 µm band can be used when the 2.3 µm band starts to saturate, for example, with thicker layers applied by a curtain coater. The filters in Table 1 were chosen from the standard stock types of filter supplier Spectrogon.

Table 1. Narrowband NIR filters chosen for the thickness measurement.

Centre wavelength (nm)	Bandwidth (nm)	Channel
1600	33	Reference
1700	37	Measurement
2200	48	Reference
2300	65	Measurement

The same filters can be used with all three types of varnishes: polyurethane, nitro-cellulose and polyester, which have quite similar CH absorption bands (Figure 1). The band intensities can vary, however, and a separate calibration for each varnish has to be used. In addition, the filter bands are selected so that interference from the strong absorption bands of water vapour is kept as small as possible.

Sensor design

Its main components are an illumination source, a fiber-optic probe and a four-channel detector, which is equipped with the narrow-band channel filters. The illumination beam is chopped and a synchronous detection is used for the reflected signals in order to eliminate the effects of ambient light sources.

Physically, the measurement device can be divided into two main components, the sensor head (probe) and the main unit. The optical probe, which consists only of optics, works as an interface between the process (varnishing line) and the main unit. The probe and the main unit are connected to each other optically via fibre bundles. The schematic figure of measurement system is shown as Figure 2(a) and a picture of the NIR sensor with the coater is in Figure 2(b).

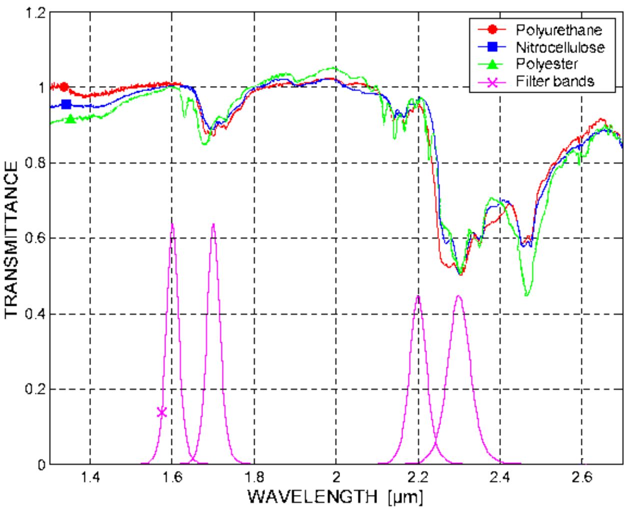

Figure 1. Variations in absorption bands of different varnish types and the spectra of the filters selected.

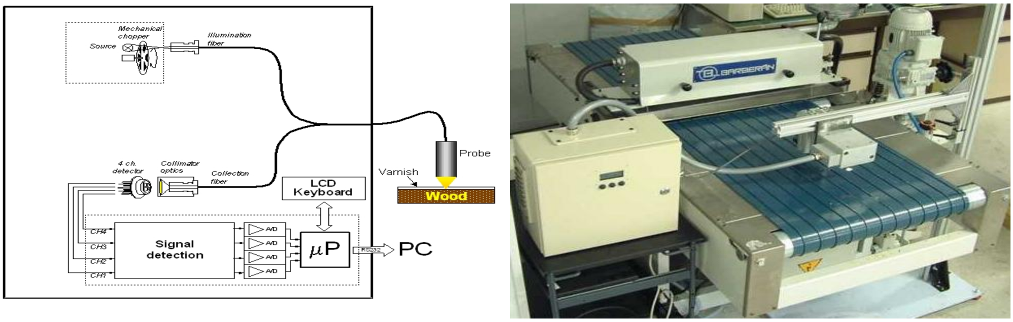

Figure 2. a) The structure of NIR sensor. b) NIR sensor (main unit and the probe head) mounted in a curtain coater.

Optics

Multi-channel detector technique offers many benefits in NIR spectrometers.[1,2] It is possible to design and manufacture a rugged process apparatus without complex mechanical structures with the 2–4 channel detector technique. All channels are detected simultaneously, which is important for fast moving samples. Furthermore, several individual detectors and focusing optics are not needed at every wavelength. One detector includes all needed optical channels in the same package.

The illumination light is coupled to process line by a focusing mirror and a collecting mirror focuses the reflected light to the collecting fibre bundle. Both mirrors and mounting points for fibres are manufactured[3] from one piece of aircraft aluminium to ensure firm and easy alignment. The illumination mirror illuminates a 12 × 15 mm^2 elliptical area on the sample and the collecting mirror is designed to achieve maximum optical signal from a Ø8 mm spot at 68 ± 2mm distance from sample surface.

The illumination onto the sample is tilted 20º to avoid direct reflection from sample surface. Direct reflection that comes from the varnish surface does not contain information on layer thickness.

Additionally, the illumination beam direction, in respect to board, is rotated optically 45° in order to minimise the effect of board grain direction effect (machine or cross direction).

Electronics unit

All important features (lamp power, chopper speed and detector temperature) are controlled to maintain good measurement accuracy, stability and repeatability. There are nine basic functional modules in NIR sensor front end electronics: Peltier controller, detector temperature controller, preamplifier, phase sensitive detection (PSD), chopper pulse transfer, output stage, DC/DC-converters, lamp controller and chopper speed controller.

Signal detection is done simultaneously for each wavelength channel. Detected signal is first amplified in the preamplifier unit. Then the signal is led to the PSD unit, where it is amplified, filtered with wide band filter and recovered with PSD (low-pass filter 1.6 Hz). Then the signal is led to the output stage.

The system is controlled by a microprocessor, which sets a programmable gain to fit the signal levels to the 12-bit A/D conversion range. The system also has an integrated user interface with a LCD and three buttons and a RS232 communication. There are also two capacitive presence sensors indicating the presence or absence of parts.

Experiment and results

The initial approach (one sensor head and control electronics) was able to measure boards covered with a single layer of varnish. The tests performed showed the correct functioning of the measuring system, but also the great effect of the board surface. Because of the effect of the board surface and the fact that almost all companies within the sector work with several layers of varnish, it was decided to use two measuring prototypes. One is put in position before the application and the second afterwards. In this way, the system calculates the difference between the two measurements, corrects the background and thus knows exactly what amount of varnish has been applied. The calculations are carried out in the PC.

As now the measure takes place in a computer, the calibration is always carried out offline. To determine the calibration procedure, several tests were made in order to fix the measurement algorithm and validate the sensors.

On Figure 3 are the calibration lines of the sensor for nitro-cellulose-melamine process. These results correspond to the channel 1, set at 2300 nm. It is the most sensitive and is the standard measuring channel. Due to the absorption in this band being heavier, thickest layers will absorb almost all the light and saturate the signal.

The tests were carried out with a curtain coater. The different thicknesses were achieved changing the speed of the conveyor belt. The samples had an area of 0.1 m^2 and were weighted before and after coating with a precision scale.

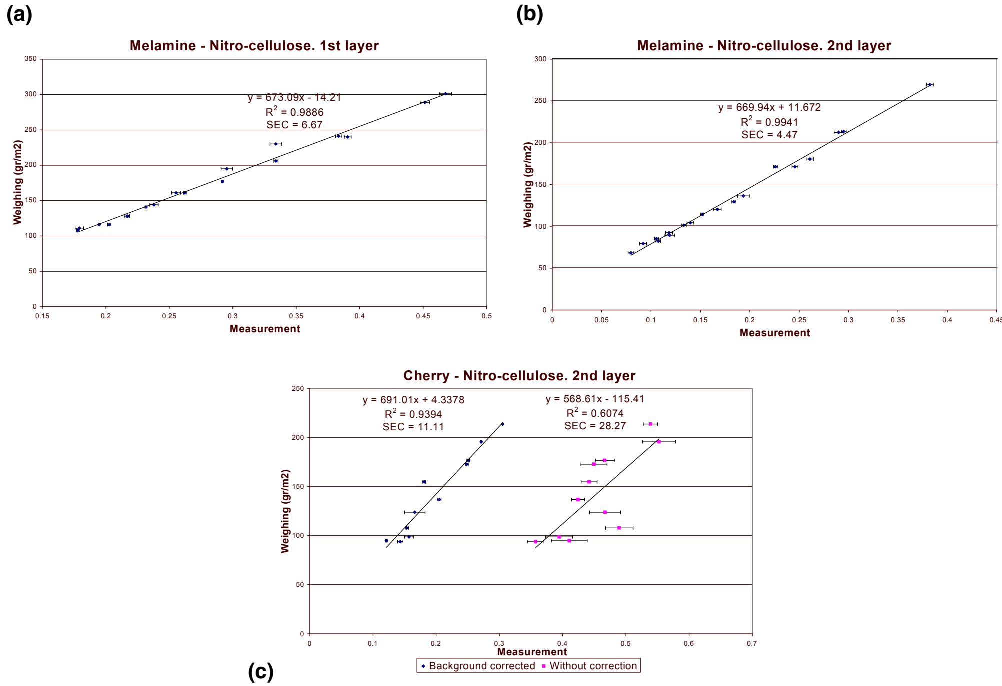

Figure 3. Some calibration lines: (a) Nitro-cellulose on melamine (corrected). (b) Nitro-cellulose on precoated melamine (corrected). (c) Nitro-cellulose on precoated cherry. Uncorrected measuring (one sensor) and corrected (two sensors).

On smooth melamine surface 1st layer measurement gives rather good results, *SEC* = 6.67 µm (*SEC* = standard error of calibration). When applying 2nd layer of varnish on these precoated samples, the results get even better (*SEC* = 4.47 µm).

Rough surface makes the measurement more demanding. By using the background correction method it is still possible to get good results, for example, pre-coated cherry fibreboard (*SEC* = 11.11 µm).

Conclusions

An on-line measurement system was developed. It measures each varnish layer before and after the deposition, deriving the real thickness by subtracting the reading of the first sensor from the second one. Good calibration parameters for all the support-varnish pairs were achieved using this approach.

Setting the precision of the system is difficult because the methods for verify the real thickness of one point are inexact and weighing is an average measure of the thickness of the whole layer. Nevertheless, the repeatability between two sensor's measurements in the same point is around 1 µm.

The estimated error in measuring layer thickness over similar boards is around 5–10 µm, comparing the sensor measurement (one-point measure) with weighing (average measure), in measurement ranges of 50–500 µm.

References

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