Integrated multichannel detector analysers at process control

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Introduction

Several optical configurations are in use or being developed to achieve the wavelength selectivity needed in spectroscopic measurement methods (Table 1). A large number of possible configurations make it rather difficult to determine the best instrument for each application. This is difficult enough with laboratory applications and even more difficult with on-line applications. The selection procedure involves specifying such factors as wavelength range, wavelength resolution, dynamic range and measurement time. In addition to these, on-line applications have some special requirements, e.g. ruggedness, stray light rejection and sample presentation. Most existing near infrared (NIR) analysers employ either a rotating filter wheel or mechanically scanned diffraction grating. These types of analysers are not very well suited for measuring fast moving process streams. Many of these instruments have been developed to be versatile and can thus be regarded as mainly research grade instruments. Due to the versatility demand and the use of moving parts these devices are likely to be rather expensive and their construction large and fairly complicated. The approach for process applications has often involved mounting the laboratory instrument in a special housing, which will further increase the cost.

Table 1. Techniques for wavelength separation in spectroscopic instruments

	Fixed Wavelengths	Full spectrum measurement
Scanning:	Filter wheel	Tilting filter
	LEDs and lasers (also parallel)	Variable wavelength filter
	Acousto-optical filter	Oscillating grating
		Acousto-optical tuneable filter
		LED array and monochromator
		Tuneable lasers
		Fabry-Pérot interferometer
Scanning parallel:		Moving mirror interferometer
		Hadamard transform spectrometer
Parallel:	Multichannel detector	Spectrograph and detector array
		Spatial interferometer

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

The rapidly extending recognition and acceptance of NIR (and other spectroscopic methods) as a real problem solver and the increasing number of proven applications are creating a new kind of market: a market for specific spectroscopic analysers and sensors featuring fixed operational parameters (wavelength or wavelength range, resolution and sample presentation) for each specific application. The solutions offered by research grade instruments are too cumbersome and expensive for on-line purposes.

The Optoelectronics Research Area of VTT Electronics is using optoelectronic hybrid integration to develop compact and low cost, while still high-performance techniques that can be used as OEM modules for spectroscopic analysers and sensors. This paper describes two analyser applications based on integrated multichannel detector, which provides exactly parallel measurement at each wavelength. This kind of construction inherently offers high performance even with measurement of non-homogeneous rapidly moving processes. This multichannel detector technology has been applied in various industrial applications since 1980's at VTT.[1]

Integrated multichannel detector technology

In applications requiring only few measuring channels, the integrated detector technique developed by VTT Electronics can be used instead of the traditional filter-wheel construction. The integrated detector has 2 to 4 parallel channels, each of them comprising a specific interference filter. The channel components are mounted on a metal frame, each channel in a chamber of its own for preventing optical crosstalk. The metal frame is mounted on a Peltier cooler for stabilising the temperature below the ambient; a bead thermistor is used for temperature measurements. All these components are mounted in a hermetically sealed window package (Figures 1 and 2).

The technique developed at VTT Electronics offers obvious advantages for process applications. It provides a small and rugged instrument construction. The interference filters, which are often made of soft and even hygroscopic materials, are well protected against ambient stresses in the hermetic package. The parallel channels provide an exactly simultaneous measurement at each wavelength, thus minimising the noise caused by rapid variations in fast moving process streams.

Our multichannel detector construction can be used over a wide spectral range from UV to IR by selecting the detector type and the window material according to the specific need. Up to now we have used mainly PbS and PbSe detectors in the 1-5 μm spectral region. The temperature of these photoconductive detectors has to be stabilised carefully, because of their high temperature coefficient 2-5 %/°C. In our construction, the change of the ratio of the channel signals caused by variations of the ambient temperature is typically ca. 100 ppm/°C.

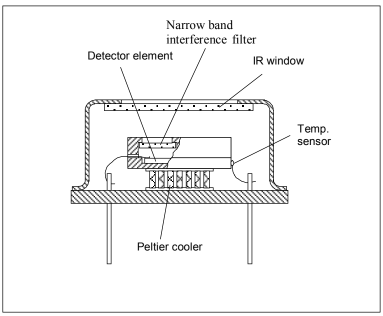

Figure 1. Schematic of an integrated two-channel detector.

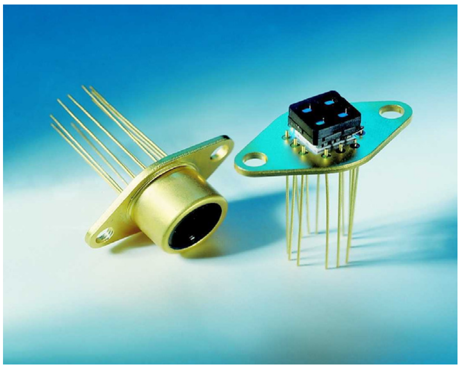

Figure 2. Image of encapsulated four-channel detector and detector without windowed cap.

Multichannel in-line NIR moisture measurement in fluidised bed granulator

Demand for automated unit operations in pharmaceutical manufacturing has increased during recent years. Monitoring of critical process steps secures a high degree of assurance for the final product. Together with novel process analytical applications (e.g. NIR techniques), a new tool for in-process control of pharmaceutics production has been achieved. The use of fiber-optic probes enables non-invasive measuring in the reflectance mode directly from the process stream.

Principally, the developed multichannel NIR sensor can be separated into two main units, the NIR probe and the main unit. The optical probe works as an interface between the process (fluidised bed granulator) and the main unit. The probe and the main unit have been connected to each other optically via fiber bundles. The schematic figure of the NIR sensor is shown as Figure 3.

A chopper will modulate light from a source, namely a halogen lamp. Modulated light will be coupled to the illumination fiber bundle by focusing optics (mirrors), in order to get good coupling efficiency. The illumination light is coupled to a process and a collecting fiber bundle collects reflected optical signal from the sample. The illumination and collecting fibers are adjusted to optimised angle in order to achieve maximum optical signal from a process. Light from collection fibers is coupled to a detection unit, where the optics collimates it to a detector. The multichannel detector detects optical signals from four different wavelengths (moisture, baseline, and sample reference) simultaneously. These signals are then amplified by preamplifier electronics. The electrical signals from a preamplifier unit are coupled to a detection circuit (PSD unit), where the signals will be filtered, sampled and detected. Output signals (differential or single-ended) will be coupled to a Siemens analogue input (SM331) module via electrical cables. The moisture content of the granules will be then calculated by the SCADA system.[2]

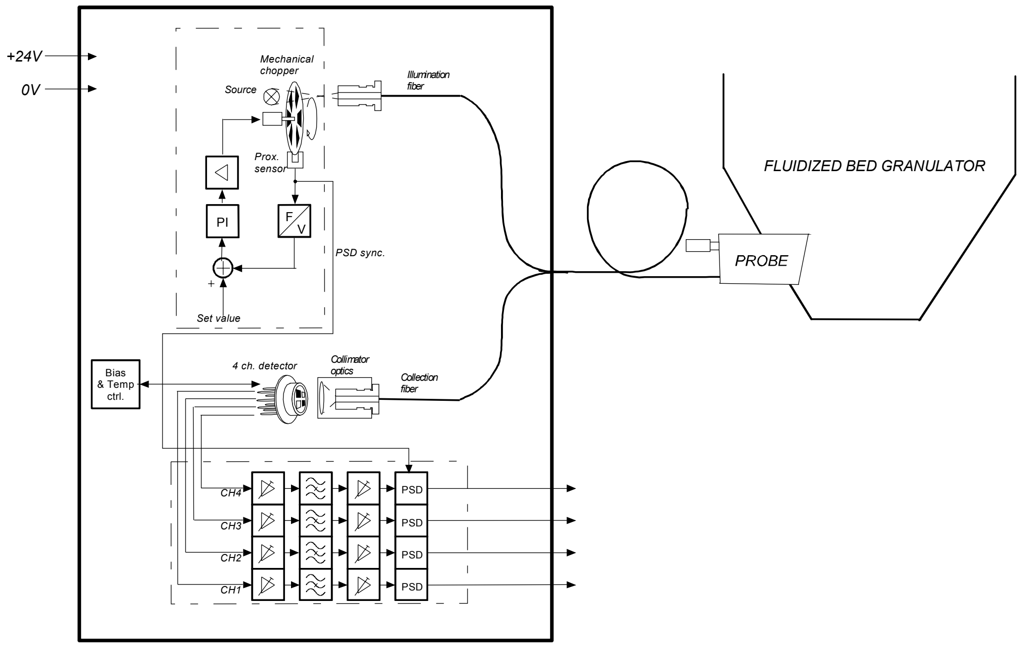

Figure 3. The main components of NIR moisture gauge for fluidised bed granulator.

All important components (lamp, chopper frequency and detector temperature) are controlled and stabilised to maintain good measurement accuracy, stability and repeatability. Phase sensitive detection (PSD) has several advantages, explaining why it has been selected as the signal recovery method in this application. It greatly reduces offset, drift, 1/f noise, mains noise (50Hz) and narrows the noise bandwidth. Also, the implementation of PSD is rather simple. PSD can also recover a signal that is totally submerged in noise at the detector input.

The four-wavelength detection proved accurate, reliable and rapid moisture measurement during granulation (Figure 4). Any future work should concentrate on the development of fast and simultaneous detection of several measuring wavelengths. More on-line information could be achieved through the use of a detector array spectrograph.

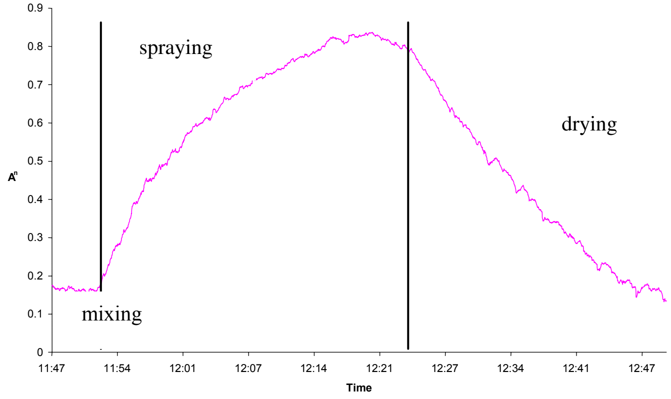

Figure 4. An example of normalised moisture absorbance behaviour during granulation process.

Paper machine wet end moisture and moisture profile measurement

A key prerequisite for improving paper machine runnability (=increased production) or enhancing paper quality is to know the moisture profile at the wet end. The sooner you can identify problems in the process, the easier it is to find a solution. Unfortunately the environment at the paper machine press section is really harsh and requirements for instruments are demanding. Integrated four-wavelength sensor was used in a moisture analyser developed for traversing measurements in the press section of a paper mill. The use of rugged, hermetically sealed sensor technique enabled successful operation in demanding environmental conditions, with humidity more than 90% (condensing) and temperatures exceeding 60°C.

On-line moisture gauge

A chopper will chop light from a source, elliptical reflector halogen lamp. Chopped light will be coupled to paper web via illumination optics, which is so called Köhler optics and gives even illumination across the measurement spot. Light path is 90º folded to minimise the device dimensions perpendicular to the web. Scattered and reflected light is collected with folding mirror and concave mirror, which focuses the light to mixing diffuse reflector. The collected light is then coupled to detection unit, where the optics collimates it to four-channel detector. Four-channel detector detects optical signals from four different wavelengths (moisture, baseline, cellulose absorbance and scattering reference). Optics is illustrated in the Figure 5 below.

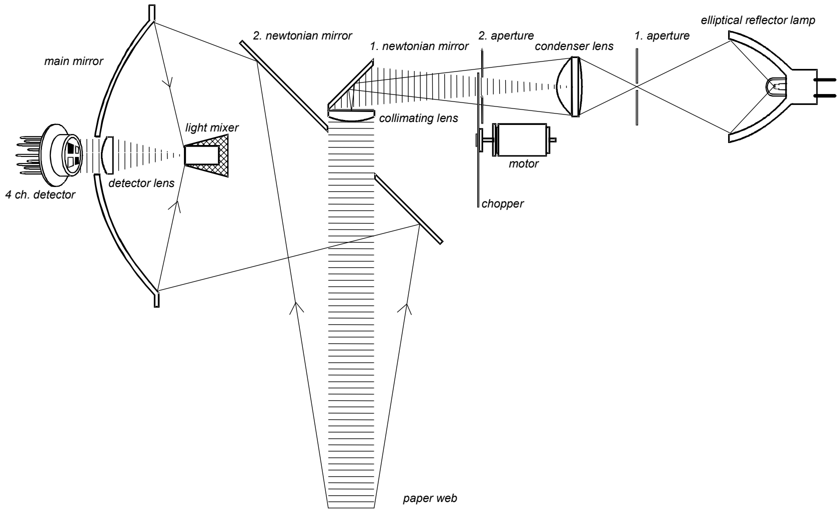

Figure 5. Optical configuration of moisture gauge.

These signals are then amplified by preamplifier electronics. Detector has been soldered directly to the preamplifier circuit, in order to avoid electrical interference between different channels and to reduce capacitive noise caused by coaxial cables. The electrical signals from preamplifier unit are coupled to detection circuit (phase sensitive detection unit, PSD), where the signals will be filtered for all four channels. Output signals (4-20 mA) are coupled to external analogue-to-digital (AD) unit via electrical cables. Moisture gauge is installed to traversing scanner, which allows the measurement of moisture profile across paper web. User interface (Figure 6) allows users to control the scanning of instrument and averaging of measurement results.

Figure 6. Plot of user interface and dry matter profile across 9 m wide paper web

Discussion

Integrated multichannel detector module is a miniature, TO-8 sized sensor, which can monitor up to four measuring wavelengths in a truly parallel operation. The wavelengths can be chosen to application specifications, either visible, near infrared or mid infrared operation is possible. The integrated multichannel detector technique offers obvious advantages for spectroscopic analysers in process applications and portable instruments alike. In the traditional NIR region and also in MIR, the multichannel detector technique makes the rotating filter wheel redundant. This technique has been successfully used in developing high-performance hand-held instruments, and process analysers requiring truly simultaneous measurement at each wavelength.

References

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2. J. Rantanen, M. Känsäkoski, J. Suhonen, J. Tenhunen, S. Lehtonen, T. Rajalahti, J.-P. Mannermaa and J. Yliruusi, AAPS PharmSciTech, **1(2)**, 9, (http://www.aapspharmscitech.org/), (2000).