

The Stationary Bone-Dry Weight Sensor

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ABSTRACT

InstaScan, developed by Francis Systems, is a non-scanning bone dry weight sensor capable of accurate measurement of both machine direction and cross direction profiles at a frequency of one megahertz. This sensor measures the entire sheet and replaces the paper machine scanner as the primary source of measurement information for both cross machine and machine direction control of the paper fiber. This technology represents the first opportunity to identify, measure and control short term cross machine variations and provides accurate separation of short term cross direction and machine direction variations. Among the advantages of this non-scanning sensor are: better accuracy, better reliability, control of cross direction variations at frequencies of one half minute, and control of machine direction variations at optimum intervals without the limitations of fast scanning.

KEYWORDS

Composite Profile, Machine Direction, Stock Valve, Cross Machine Direction, Bone Dry Weight, Scanner, Process Control, Slice Screw, Stationary Sensor, Transport Delay

SOME HISTORY

The History of Paper Measurement

If we go back about thirty five years to the beginning of on line measurement of the paper web, some of the first efforts involved placing a single spot beta gauge on the sheet to measure the machine direction basis weight (figure 1). It didn't take long to determine that this measurement would not provide a representative measurement and would not correlate with the back tender's samples, which were typically taken as a series of samples 30.5 cm x 30.5 cm (twelve by twelve inches) all the way across the web. As a result, the scanner was born (figure 2).

Initially, the primary measurement of interest was machine direction basis weight and the scanner worked, within limits. However, paper makers and suppliers of scanning sensors soon realized that some

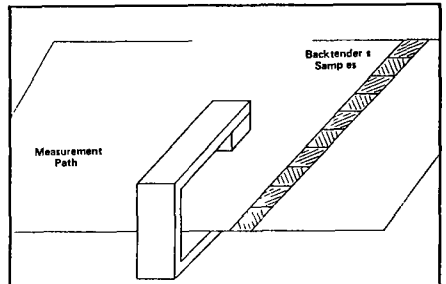


Fig. 1. C frame and non-scanning sensor

cross direction benefits could be gained from the scanning measurement. In fact, on paper machines where the cross direction variations were significantly greater than machine direction variations, fairly good cross direction information was obtained and used by the operators to improve the profile.

When digital computers became available, even better cross direction information was obtained by applying exponential filtering to a series of scans, effectively separating cross direction and machine direction variations.

The History of Control

Control on the paper machine has followed a parallel course of improvement. As measurement has improved, control has improved. In the 60's, we achieved the capability to do effective machine direction control on the paper machine. During the 70's, machine direction controls became far more capable and automatic grade change and production maximizing controls were ac-

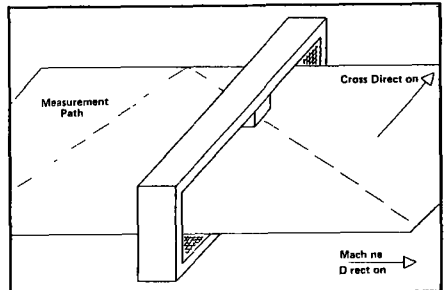


Fig. 2. C frame and scanning sensor

cepted. During the 80's, the new thrust has been to achieve effective cross direction control. The 90's will see further improvement in machine direction control and major advances in cross direction control.

LIMITATIONS OF SCANNING

Scanners, for the measurement of machine direction and cross direction weight and moisture on paper machines, have served us well for the past thirty five years. Major quality improvements and economic benefits have been achieved.

Mechanical Limitations

However, we must recognize that scanners do have some serious limitations. The mechanical complexity of a device designed to continuously scan back and forth across the sheet 2880 times a day or over one million times a year means high initial cost, high maintenance cost, and less than ideal reliability.

Control Limitations

If you take a critical look at the information provided by scanning the sheet, it becomes obvious that we have reached the point in our quest for perfect control where the scanner has become one of the limiting factors.

In any evaluation of process control objectives, it is necessary to define the practical limitations of control. For example, how fast can paper machine stock flow valves and headbox slice screws respond to correct the measured errors? This becomes the real practical limit of control of the paper making process even though the ideal desired control for most papers would be defined at the formation level. Let's make the assumption that the typical paper machine's stock valve and slice screws can respond fast enough to provide a one percent bone dry weight change per second. In this case, to correct an error of one percent, the ideal sensor would have to provide an accurate and representative bone dry weight measurement at a frequency of no less than once per second.

Machine Direction Control Limitations

The response of the typical beta gauge and moisture sensor combination is adequate to meet the one second frequency required for optimum practical control. However, for control of the stock valve, we need to use scan averages instead of instantaneous readings. The typical scanner falls short of meeting this requirement by about thirty seconds (the time it takes to scan the width of the sheet and collect a scan average measurement). In other words, the scanner has become a limiting factor in the

drive for further improvement in machine direction control.

Cross Direction Control Limitations

For optimum control of the slice we ideally need data, again, once every second. However, the composite profile information from the scanner is available, typically, only after 180 to 300 seconds (six to ten scans). Another limitation here is that a mathematically accurate composite profile can only be achieved if the profile remains constant during the composite building interval. Common sense, along with recent evidence derived from a stationary fast response profile sensor, indicates that cross direction profiles on paper machines do have significant short term variations. Modulation of the slice screws for cross direction control also contributes to the generation of errors in the building of a composite profile from a scanner.

STATIONARY SENSOR

The obvious solution to the limitations of scanners would be to use a full cross machine stationary sensor with a measurement resolution providing, at a minimum, an accurate measurement for each slice region.

Using Beta Weight and IR Moisture Sensors

In the past, the only sensors that could be used in such a cross sheet configuration were beta weight and infrared moisture sensors. In fact, in a few applications (e.g. left side/right side coater applications where fast control response is necessary) a limited number of such stationary sensors (two to four) have been used. However, this is not satisfactory on paper machines because it is not possible to reconstruct the cross direction profile from a limited number of measurements across the sheet.

Using multiple beta weight and infrared

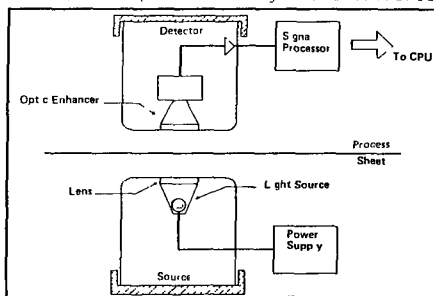


Fig. 3 The optical sensor

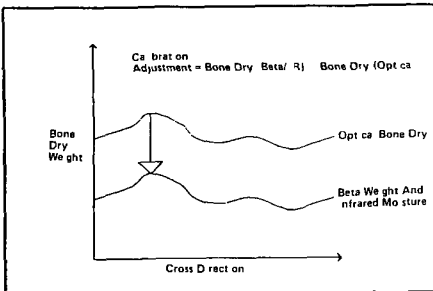


Fig. 4. Calibration of the optical sensor

moisture sensors (with discrete sensors used for each slice and typically twenty to seventy slices on the machine) is not practical. The cost would be prohibitive (return on investment would be negative), hazardous radiation levels would result from the multiple radioactive sources, the sensors are not suited to environments where measurement would be optimum, and the maintenance effort to maintain the sensors would be enormous. In addition, although these sensors are accurate long term, they still require a routine off sheet standardization process to maintain accuracy by compensating for dirt on the windows and electronic drift. A mechanism to pull all of the sensors off sheet every thirty minutes for standardization would be necessary.

Using Optical Sensors

An alternative to using beta weight and infrared moisture sensors is, however, now available. Today, the stationary sensor design can make use of optical sensor technology providing a low cost low maintenance,

non hazardous measurement of bone dry weight with a much higher frequency response and usable area of measurement than is possible with the beta weight sensor (figure 3).

An optical sensor uses the absorption and transmittance of photon energy by paper fiber as a short term measure of bone dry weight. The measurement is actually a measurement of opacity, but, in the short term, measuring opacity can be equated to measuring fiber weight.

By the very nature of the measurement, the optical sensor is affected by changes in opacity. These changes are especially significant when they result from the use of additives, such as titanium dioxide, which affect opacity without having an equivalent effect on weight. Such changes affect the mean measurement of the optical sensor even while actual bone dry weight remains constant. The result is that a calibrated mean measurement under these conditions is only accurate in the short-term.

Maintaining Optical Sensor Calibration

Since paper making materials are well mixed, it usually takes several minutes or longer before changes in the mix become a significant factor in producing errors in the optical bone dry measurement. It is possible, therefore, to use the long term accuracy of the beta weight and infrared moisture sensors to correct the calibration of the optical sensor so that it continues to accurately measure the mean bone dry weight of the sheet. This method corrects for the long term limitations of the optical measurement and allows the process control computer access to an accurate, high frequency response, low noise measurement of the weight of the sheet.

Correction of the optical sensor calibration generally involves adjusting the off

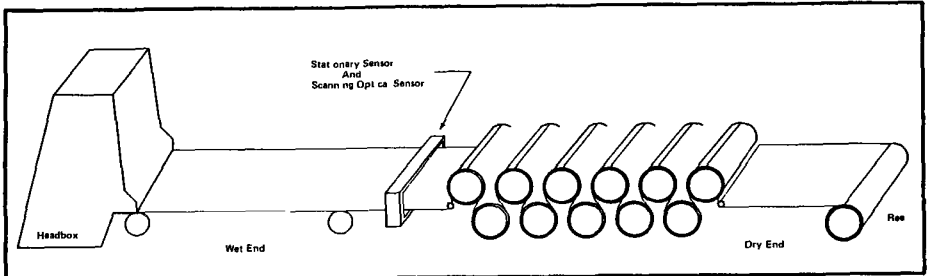


Fig 5 Configuration one Stationary sensor with scanning optical sensor

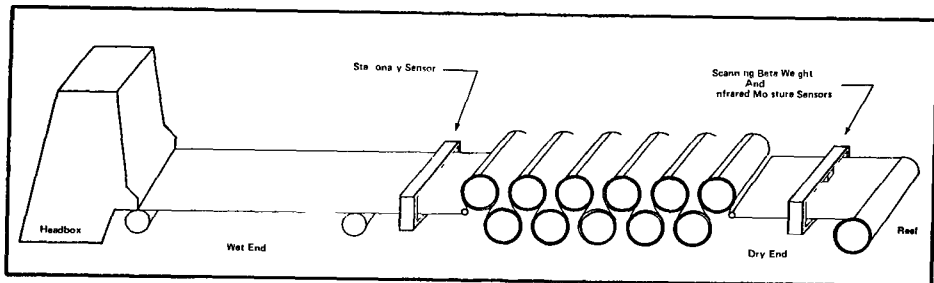


Fig. 6 Configuration two Stationary sensor with scanning weight and moisture

set used in converting the sensor voltage to bone dry weight, this forces the average from the optical sensor to agree with the average bone dry weight from the beta weight and infrared moisture sensors. The slope in the conversion algorithm can also be adjusted, but generally does not require adjustment the variation displayed in the bone dry weight profile from the optical sensor normally maintains its accuracy even as the measured mean begins to deviate from the actual mean (figure 4)

The Optical Stationary Sensor

The discrete optical sensors in a stationary sensor can cover any area of measurement, typically 0.025 cm to 15 cm (0.01 inch to 6.0 inches). This allows the stationary sensor to be precisely engineered to the application, with discrete sensors measuring selected areas of the sheet. One useful configuration, for example, uses each sensor across the sheet to measure the area controlled by a single slice screw on the headbox.

A stationary sensor based on optical sensor technology, like InstaScan, provides a nearly instantaneous bone dry weight measurement across the entire width of the sheet. It provides a short term measure of the cross direction profile of the sheet, a measurement that simply has not been possible with the scanning systems of the past. With a frequency response of one megahertz, the stationary optical sensor can provide a measure of the cross direction variation every microsecond. The optical sensor's measurement is, however, accurate only in the short term and periodic recalibration with scanning sensors is necessary typically every ten to one hundred minutes.

Stationary and Scanning Optical Sensors

This low cost stationary sensor configuration (figure 5) is most useful when beta

and moisture sensors are unavailable or when the desire is for cross direction control only. If uses a scanning optical sensor to maintain the accuracy of the stationary sensor. This configuration provides nearly instantaneous measurement of the profile of the sheet a measurement most useful for cross direction profile control on the paper machine. As with any strictly optical sensor configuration, this system provides an accurate measure of the deviation of the bone dry weight about the mean, but does not provide an accurate value for the mean itself. This configuration cannot be used for machine direction control on the paper machine.

The scanning optical sensor must be used to maintain calibration of the relative mean of the stationary sensor across the sheet. The stationary sensor cannot be retracted from the sheet to standardize and compensate for dirt build up. Also, since the stationary sensor consists of discrete sensors across the sheet, variations due to differential dirt build up and other sources of drift between the individual sensors must be calibrated out of the measurements with the scanning reference sensor.

Stationary and Scanning Weight and Moisture

This configuration (figure 6) uses the long term accuracy of the scanning beta weight and infrared moisture sensors to maintain the long term accuracy of the stationary sensor. The resulting measurement from the stationary sensor provides the nearly instantaneous cross direction profile and, simultaneously, the machine direction mean bone dry weight. There is complete and instantaneous separation of the cross direction variation from the machine direction variation from the slice screw and stock flow control algorithms.

The accuracy of the mean bone dry weight

from the stationary sensor is equal to that achieved by scanning sensors, however, useful information is available from the stationary sensor every microsecond (versus thirty second availability from scanning sensors).

The accuracy of the cross direction weight profile from the stationary sensor is far superior to that achieved from the exponentially filtered composite profiles built by scanning sensors. Useful cross direction information is available every microsecond from the stationary sensor (versus a maximum rate of every three to five minutes for scanning sensors).

STATIONARY SENSOR ADVANTAGES

Measurement Resolution

The stationary bone dry weight sensor can produce both cross direction and machine direction information at a frequency of one megahertz. One megahertz translates into a cross direction snapshot of the entire sheet in 0.0025 cm (0.001 inch) at a machine speed of 1525 meters per minute (5000 fpm). The real limitation to resolution, therefore, turns out to be the sensor's minimum measurement size which is 0.025 cm (0.01 inch). This means that for any paper machine, regardless of speed, the stationary sensor can provide highly accurate bone dry measurement of both cross direction and machine direction at a machine direction resolution of 0.025 cm (0.01 inch) of paper through the paper machine.

A typical scanner generated bone dry measurement, by contrast, will provide machine direction information on a 1525 meters per minute (5000 fpm) machine in about 762.5 meters (2500 feet) of paper and 152.5 meters (500 feet) of paper on a 305 meters per minute (1000 fpm) machine (given a scan rate of one scan every thirty seconds).

The stationary sensor can produce cross direction information with the same high speed and accuracy as it measures machine direction. Cross direction measurement comparisons between the stationary sensor and the scanner are, however, more difficult. Both the time required to obtain the measurement and the accuracy achieved with a scanner are a function of the magnitude of machine direction versus cross direction variation along with the short term stability of the cross direction profile as generated by the paper machine. As we gain more information with the stationary sensor on the short term cross direction variations on paper machines we will gain a better perspective on just how accurately the scanner produces cross direction data.

A common practice is to assume that scanners provide usable cross direction infor-

mation on composites of six to ten scans. If we use six scans at thirty seconds per scan on a 305 meters per minute (1000 fpm) machine, then the scanner would require 915 meters (3000 feet) of paper through the machine to obtain useful profile information.

Advantages for Machine Direction Control

The stationary sensor will produce significantly better machine direction control on fast paper machines because accurate machine direction data can be generated at an optimum frequency for control. Tissue machines are an excellent example with, typically, a ten second transport delay between the stock valve and the reel. Existing control algorithms provide best control with a minimum of four (4) accurate machine direction determinations within a transport delay. This would require a machine direction update every 2.5 seconds for optimum control far beyond the capability of a scanner but well within the capability of the stationary sensor.

For machine direction control on heavy weight paper machines, the primary advantage of a stationary sensor over scanning sensors is the ability to directly measure bone dry weight at the wet end of the paper machine. The ideal measurement location is between the wet presses and the dryers. By measuring closer to the stock valve, the transport delay will be reduced, allowing improved machine direction control.

Advantages for Cross Direction Control

Although the improvement in machine direction control is significant, the major advantages of the stationary sensor are for cross direction control. When the sensor is located at the wet end of the machine, the slice to sensor transport delay is typically around ten seconds. This compares to several minutes to get representative profile data from a scanner.

Using a stationary sensor means much of the effort currently required to model and predict the probable results of turning a slice screw can be eliminated, since ten seconds after an adjustment the sensor will provide accurate results for the full width of the sheet. The stationary sensor will provide both better data with which to define the model for control and a reduced feed forward requirement in the control.

BENEFITS GAINED ON THE PAPER MACHINE

We know that the scanner has contributed to significant improvements in our ability to control the paper making process. However, the scanner has now become the limiting factor in the technological advance toward producing the perfect sheet of paper. The advance can continue, though, with the use

of the stationary sensor. We have discussed some of the benefits to be gained in the area of process control; but, it would be useful to examine the theoretical advantages on the machine if we could produce a sheet without variations from the desired weight. The sheet would be expected to form better on the wire. Suction rolls, suction boxes, table rolls and foils would perform more efficiently with a perfect sheet. Press loading could be increased to obtain optimum mechanical water removal and felts would wear evenly, reducing the tendency for selective filling and crushing. Dryer efficiency could be optimized with a sheet that produced a constant cross direction temperature through the dryers.

Additionally, a perfect sheet would allow optimum savings of raw materials and, for most paper machines, result in increased production. Quality would be as near perfect as possible and rejects would be largely eliminated.

We can expect it will be a while before we can make perfect paper; but, we continue to work toward that goal. With each step we encounter the next technological challenge to be solved.

TABLE 1. A Comparison of Optical Bone Dry and Beta Weight Sensors

AREA OF MEASUREMENT RESOLUTION		Beta Weight
Optical Weight		5 cm (2.0")
0.025 cm to 15 cm (0.01 to 6.0), depending on the application		
FREQUENCY RESPONSE		Beta Weight
Optical Weight		0.5 hertz (the ion chamber introduces an inherent time constant into the measurement)
1.0 megahertz		
NOISE LEVELS		Beta Weight
Optical Weight		
Signal to noise ratio at 1.0 megahertz 0.01% for 0 to 400 GSM. Eliminates the need for smoothing and filtering for noise reduction		
AIR GAP TEMPERATURE SENSITIVITY		Beta Weight
Optical Weight		Air temperature compensation necessary (beta particles are absorbed by air)
None (light is not absorbed by air)		
ACCURACY AND REPEATABILITY		Beta Weight
Optical Weight		Static sample accuracy 0.1% for 10 to 150 GSM, dynamic sample accuracy 0.05% 0.15%. Short term repeatability 0.25% at 50 millisecond T.C. and long term repeatability 0.05% at 10 minute T.C.
Static sample accuracy 0.01%, dynamic sample accuracy 0.05% Repeatability 0.01%		

TABLE 2 A comparison of Optical Bone Dry, Beta Weight, and Infrared Moisture Sensors

SOURCE		
<u>Optical Weight</u>	<u>Beta Weight</u>	<u>Moisture</u>
<u>Light energy</u>	<u>Radioactive energy</u>	<u>Infrared energy</u>
DETECTOR		
<u>Optical Weight</u>	<u>Beta Weight</u>	<u>Moisture</u>
Uses extremely reliable light and signal processing electronics	Far less reliable ion chamber and signal processing electronics in the detector	Requires complex mechanics and signal processing electronics in the detector
SOURCE/DETECTOR GEOMETRY		
<u>Optical Weight</u>	<u>Beta Weight</u>	<u>Moisture</u>
Simple detector and source geometry requirements	Demanding X, Y, and Z axis requirements for source/detector geometry. Radiation must be focused on the detector	Relatively simple geometry
SENSITIVITY TO ENVIRONMENT		
<u>Optical Weight</u>	<u>Beta Weight</u>	<u>Moisture</u>
Relatively non-sensitive, can be used accurately measure bone dry weight at the wet end of paper machines	Relatively sensitive to sheet flutter, sensor head and air gap temperature variations, and X/Y/Z axis misalignment	Very sensitive to environmental water and air temperature, not accurate enough at the wet end of paper machines due to the poor resolution of IR reflected energy
LONG TERM/SHORT TERM MEASUREMENT		
<u>Optical Weight</u>	<u>Beta Weight</u>	<u>Moisture</u>
Relatively sensitive to variations in opacity the bone-dry measurement is only accurate short term	Through compensation for environmental effects, provides extremely stable long term measurement of total mass	Through compensation for opacity, flutter, brightness, and basis weight, provides a stable, long term measurement of moisture



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