An Indigenous Quality Control System for Small and Medium Paper Industries

P. Sudhakara Rao, G. Prasad and Kalahasti Ravi*

CEERI, CSIR Complex, Taramani, Chennai-600 113,
*Marvan Industries, Chennai,

INTRODUCTION

Paper is one of the indispensable commodities in the modern world. With opening up of Indian economy, the value of imported paper is continuously on rise. At the same time, in recent times some of the most instrumented mills are exporting certain varieties of paper to other countries. However, the least or no instrumented mills are facing closure due to fierce competition from quality and cost of imported paper at low cost. To meet this growing demand, the existing mills are required to be modernized to increase production and minimize rejects by enhancing the quality of paper produced. In this respect, modern computer control systems play a vital role. Computer based DDC (Direct Digital Control) systems would not only enable manufacturing quality paper but also help the management to economize all operations including production, reduced wastage of raw materials, energy savings, etc. Some of the possible benefits of such systems are shown in Fig. 1.

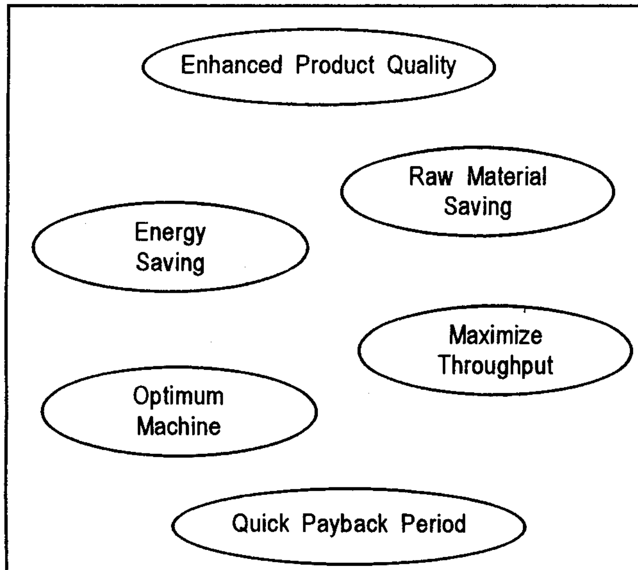

Fig. 1 QCS System

Important quality parameters

Basisweight, Moisture, Caliper and Ash content of the paper are considered as the most important quality parameters of the paper. The minimum instrumentation and automation required for maintaining reasonably good quality, in most cases of papers, includes the control of Basisweight and Moisture in machine direction. Further, in order to effectively implement the above controls, it is desirable to monitor and control the consistency of pulp in the chest.

CEERI Centre, realizing the above importance, had developed totally indigenous technology including the sensors, scanning mechanism, software to monitor, maintain and control the quality parameters. the technology developed is field tested and retrofitted in two paper mills. Though, several approaches are available in the literature, the most proven principle and technique adopted by the leading manufacturers of such instrumentation has been the considered approach. All the merits and availability of different materials in the country have been considered in the design. In the following sections, the principle of measurement of the three parameters and the functioning of the 'O" frame that facilitates scanning are explained in brief.

Basisweight measurement

Basisweight is measured using the principle of absorption of Beta particles by the process (paper). This sensor, also called Beta gauge, employs nucleonic source that releases electrons called β (Beta) rays or β particles, which pass through the paper and bombard the detector unit. The number and energy of β rays transmitted through the paper vary inversely with Basisweight of the sheet. The attenuation can then be expressed by the following Beer's law.

$$N_1 = N_0 e^{-\mu\rho t}$$

where,

N_0 is the number of particles incident on the sheet.

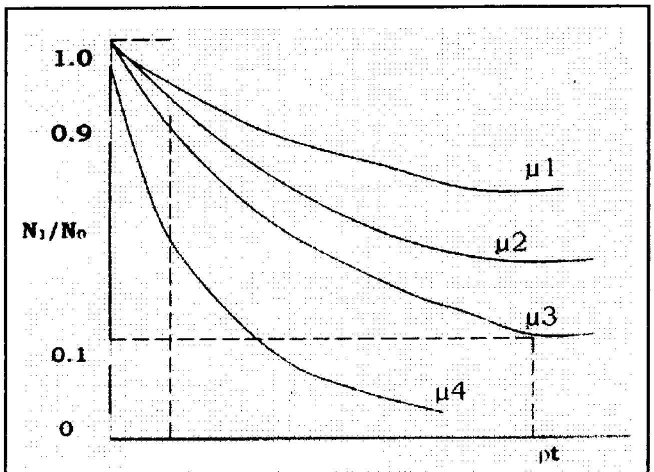

Fig. 2 Process Resolution

N_1 is the number of particles emerged from the sheet

μ is the mass attenuation coefficient

ρ is the density of the paper and

t is the sheet thickness

The mass attenuation coefficient 'μ' is a function of the type of radiation used, the radiation energy spectrum, and the composition of paper as shown in Fig. 2.

However, the Basisweight sensor enables seeing the total weight per unit area of paper i.e., ρt and it has been found that the highest measurement of accuracy is possible with β particles. Various sources for Basisweight measurement are shown in Fig. 3. The basic technique is illustrated in Fig. 4 wherein β particles are attenuated by paper and the transmitted radiation is detected by a radiation detector.

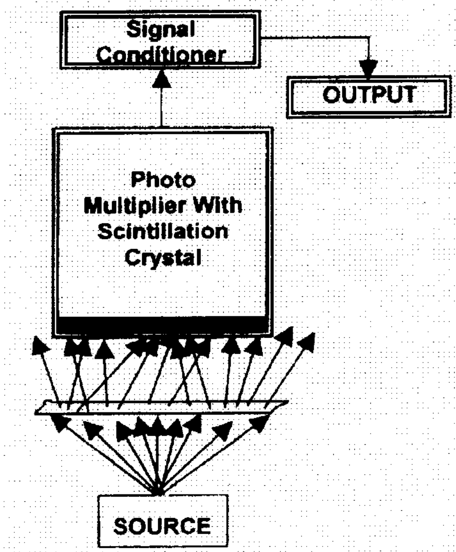

Fig. 4

Since no single Beta source will cover the entire range of measurement and each one has its own sensitivity, a specific source may be recommended for use depending on the application. It is found that Kr-85 finds maximum applications as it covers wider range of Basisweight with reasonable accuracy and has long half-life. However, this source is not available in the country and also expensive. Though the Beta absorption curve is theoretically exponential, in practice the curve deviates for the rule, due to various factors like energy conversion from one state to other, each of the constituent of

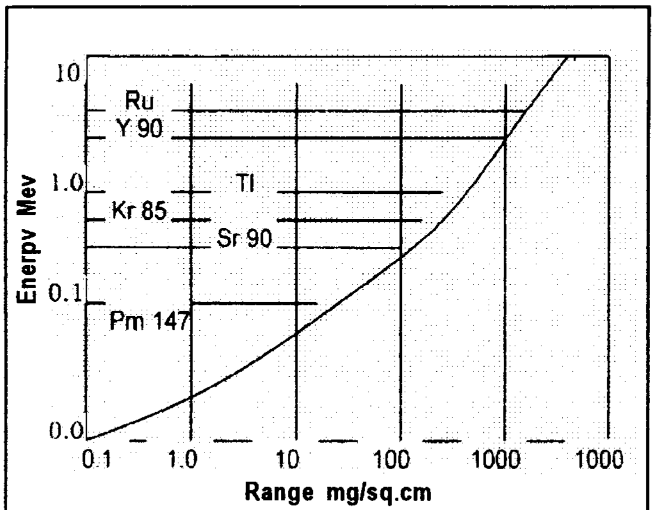

Fig. 3 Beta Particle Range

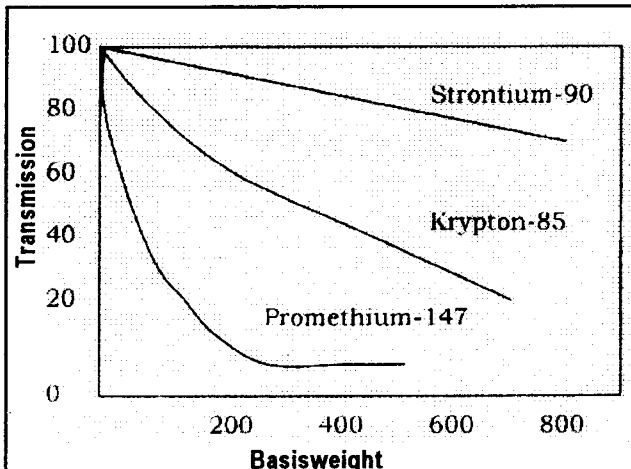

Fig. 5 Comparison of Source Sensitivities.

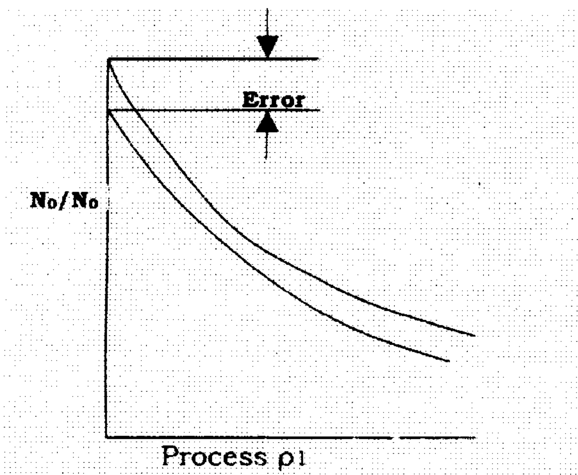

Fig. 6 Deviation from Std. Absorption

Source	Half-Life (Y)	Energy (Mev.)
Pm147	2.52	0.233
Kr 85	10.6	0.670
Tl 04	4.1	0.765
Sr 90	28.0	0.543
Y 90	28.0	2.280

Fig. 7 Show various beta sources useful for basisweight measurement of paper and their half-life.

the process exhibits different absorption constant, etc., and hence requires more complex linearisation process. Fig. 6 shows the deviation from standard absorption curve.

Source decay

The nucleonic source decay is governed by the equation

$N_1 = N_{Oe}^{(-t/\lambda)}$

N_0 is number of Beta particles leaving source

N_1 is number of Beta particles reaching detector after time 't' but collected for the same duration λ is half-life.

Air column temperature compensation

It is known that the air column height 'h' obeys gas laws between the source and detector modules

$N = N_{Oe}^{(-t/\lambda)} e^{(-\mu\sigma h)}$

where σ is the air column density 't' is the time duration

Misalignment

This is one of the major sources of error for measuring paper Basisweight cross profile, using the scanner. (Fig. 8). Since N_0 (Beta counts in the absence of paper) cannot be obtained during the scanning, any of the axis misalignment of the source and detector will create measurement error. When the source and detector are perfectly aligned, all the beta particles released from source, after suffering absorption will reach the detector. However, in case of any lateral shift, some portion of them will not reach detector and this will show up as increased Basisweight. In case of vertical shift, due to the fact that the air column will increase or decrease from the reference, the air column Basisweight will either increase or decrease respectively, which results in the variation (error) in the Basisweight measurement. This problem is solved by obtaining the signature of frame misalignment in all the axis and apply appropriate correction to the measured data.

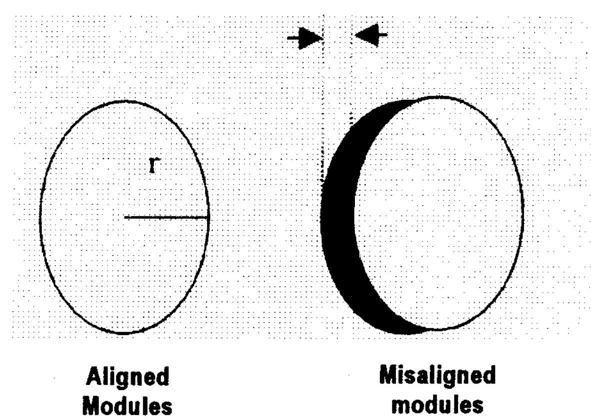

Fig. 8 Misalignment of source and detector

Dirt buildup

Another serious measurement error is due to dirt that gets buildup on the source surface over the time, as the source shutter is open all through the measuring time. This will appear as Basisweight and gets added to the actual Basisweight of the process. This is solved by collecting the reference Beta particles count for fixed interval of time and then apply suitable compensation.

Moisture measurement

The operating principle of IR moisture measurement system employs the selective IR absorption by water molecules. The bonds that attach the two Hydrogen atoms to the oxygen atom stretch, contract and flex and for this action it takes specific amounts of energy to produce a given vibration, only specific wavelengths can provide the right amount of energy and in doing so only these wavelengths are absorbed. For these vibrations water molecule absorbs near IR energy at 1.93μ and 1.4μ wavelengths among others. There are various IR absorption bands due to single or combined resonance in the IR region (1.19μ, 1.42μ, 1.93μ, 2.95μ, 3.10μ, 3.65μ, & 6.0μ). The absorption band at 1.93μ is stable over wide temperature ranges and is not absorbed by other components of paper. The essence of the measurement is to choose two wavelengths, which exhibit differential absorption for the moisture to be measured, but roughly the same absorption for other substances in the paper. Thus, for the measurement of moisture in paper, a wavelength close to 1.94μ is to be normally chosen in conjunction with a reference wavelength of about 1.8μ. Fig. 9 shows the transmission spectra of two films of water, 1μ and 10μ thick. Note that typical paper moisture integrated through the sheet will be fairly comparable with the thickness of these. The absorption by moisture is exponentially related to the path length as described by Beer's law.

$I = I_0 e^{-\alpha\rho t}$ where I_0 is the incident intensity, α is the absorption coefficient, ρ is the path length through the sheet and t is the sheet thickness.

Absorbance $A = \log (I_0/I)$

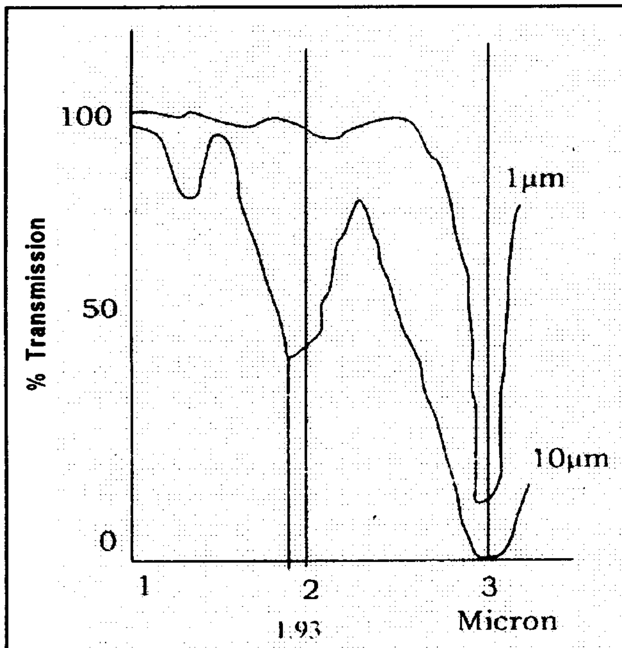

Fig. 9 IR Spectrum of Water

Caliper measurement

The paper web is sandwiched between a coil carrying current and a base plate, which closes the electromagnetic path. The method is based on the change in reluctance in a magnetic circuit, when the path length is altered. If the permeability of the medium is high enough, then even a small change in path length effects a large change in reluctance. The magnetic field is created by exciting a coil with altering current and the paper thickness provides the varying path length. Ensuring that the magnetic path due to other elements in the circuit are constant and accurate positioning of the dial is essential as we have to minimize the errors due to vibration. Also converting the dial output to electrical signal is a difficult process and so this method is not preferred. Fig. 10 shows this technique.

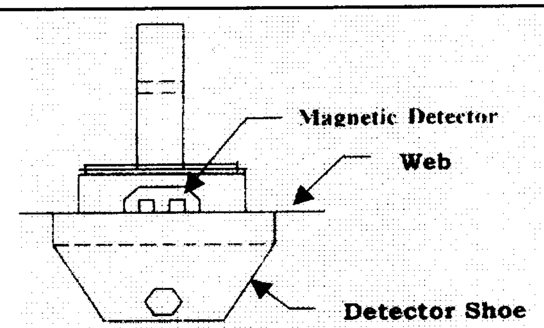

Fig. 10

Computer system

The block diagram of the computer system implementation and scan direction is shown in Fig. 11 and Fig. 12 respectively.

The computer system has 2 parts, viz;

1. Process computer and
2. I/O computer

The complete system is designed based on PC/AT hardware. The process computer system has the analogue data acquisition hardware and optically isolated digital data acquisition hardware. The analogue data acquisition card is located on the process computer PC bus. It measures the analogue data with 12-bit resolution. A digital I/O card is also plugged on to process computer's PC bus to interface all the field digital input as well as output channels. The I/O computer system is basically a diskless system connected to an industrial monitor and a specially designed operator's keyboard. The process computer and I/O computer are connected

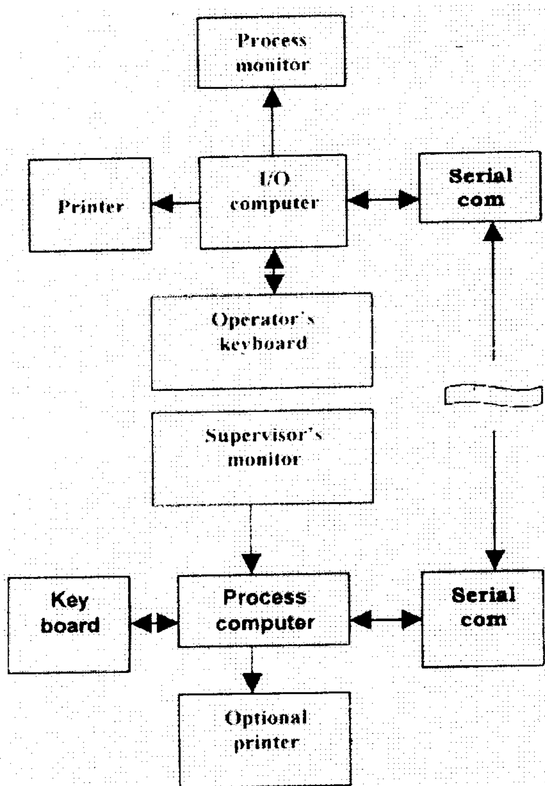

Fig. 11

through the serial communication link. They continuously exchange the information through this link. The salient features of the system are listed below.

- On-line tonnage measurement
- Basis weight and moisture control in the machine direction
- Automatic roll change detection
- On-machine paper cut detection
- Compensation for frame misalignment
- Temperature compensation
- Modular software to suit the individual mill
- Off-sheet calibration facility and sensor verification
- Single point monitoring facility
- Safety shutter for the nucleonic source
- Remote digital display of the parameters
- Graphic display of the cross, trend and composite profiles
- Complete menu driven operation
- Data storage is only limited by the hard disk capacity
- Custom key board for the operator
- Programmable display and print page layouts

Some of the display pages are shown in the following figures.

Basis weight and moisture control implementation

Most of the paper mills would like to control the basisweight and moisture parameters of the paper at least in the machine direction (MD) of the paper. Machine direction control involves the stock flow control while cross direction control (CD) involves control of individual jets at the head box. Machine direction control of both the basisweight and moisture of the paper had been successfully implemented in two mills. This section describes briefly the implementation of these control loops.

Paper Machine Dynamics

The paper machine as a whole can be considered as a two input and two output system as shown

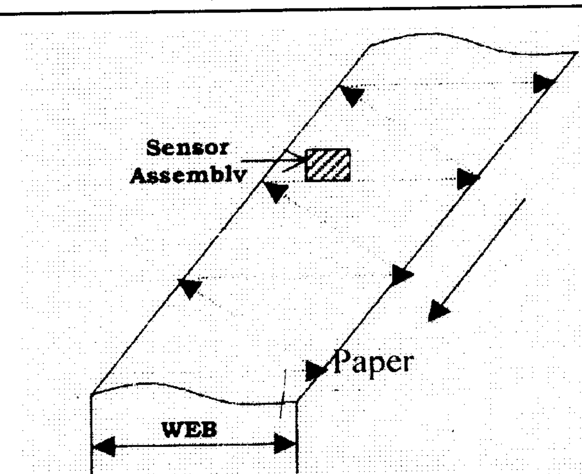

Fig. 12

in Fig. 13. Stock flow to the headbox is controlled to control the basisweight while steam pressure to the dryers is controlled to control the paper moisture and therefore it becomes multi input and multi output (MIMO) system.

For a better control of these two parameters, it is required to model the paper machine. Mathematical model of a paper machine through a set of thermal and mass balance equations is rather difficult to achieve and therefore usually a step change is given at the input and the output response curve is observed. The system can be modeled and approximated from this curve. This

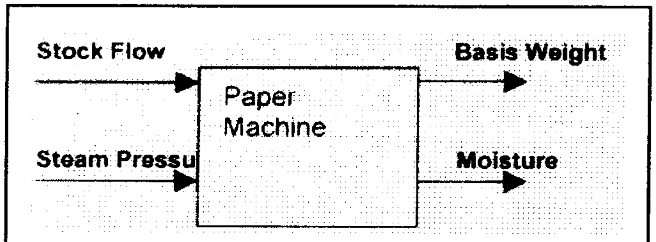

Fig. 13 Paper Machine as a MIMIO system

method has been used to derive the model for basisweight and moisture control loop.

Mathematical models for baissweight and moisture loops

Machine speed and stock flow are assumed to be constants to get the mathematical models for these two parameters. The model for basisweight is obtained from the open loop response curve after applying a step change to the stock flow control when the system was in steady state. A typical response curve is shown in Fig. 14. From this curve, the model parameters like 'Dead Time', 'Time Constant' and process gain were calculated. The basisweight loop transfer function has been approximated to first order system as shown below.

A typical transfer function of the basisweight loop is given below.

BW loop Transfer Function =

K exp (- Td s) / 1 + Tc s)

where

K is process gain

Td is process dead time

Tc is system time constant.

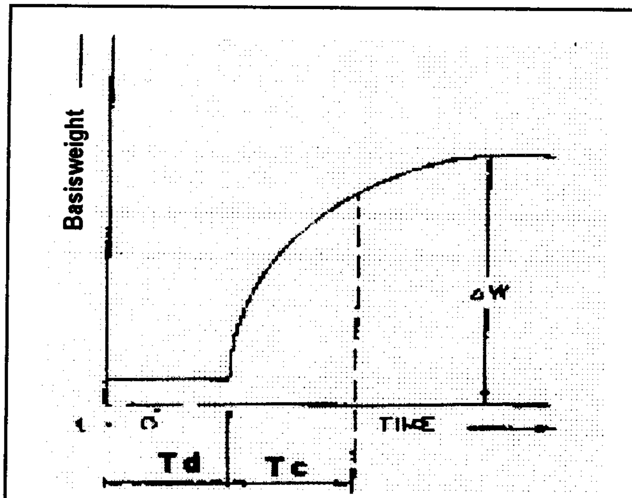

Fig. 14 Open loop response curve for step input at stock flow valve

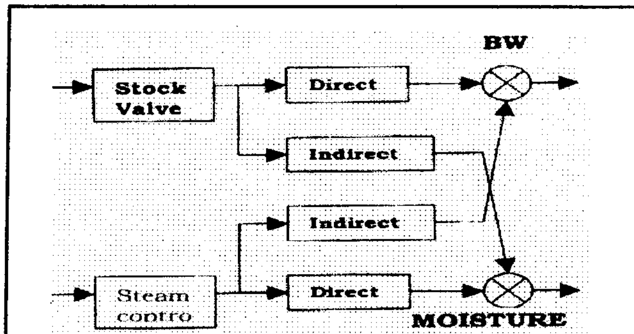

Fig. 15

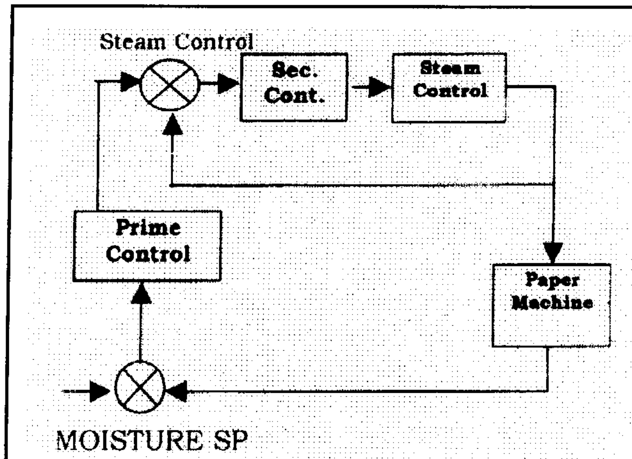

Fig. 16

Similarly, applying a step response to the steam pressure valve and observing the output response of the moisture we obtain the mathematical model for the moisture loop and the transfer function for this loop also is approximated as a first order system with dead time indentical to the equation shown above. Even though the transfer functions are identical the valves of process gain (K), dead time (Td) and time constant (Tc) for this loop will be different as the process dynamics of the moisture loop are different. As in the case of any MIMO system, the basisweight and moisture paramters are highly interactive. This means any change in one of the inputs will have an impact on both the output parameters and therefore basisweight and moisture loops cannot be considered as two independent loops for control until both loops are decoupled or made noninteractive.

Decoupling of loops

Basisweight and moisture interaction is illustrated in Fig. 15. The decoupling of these two loops is done using the standard control techniques, which

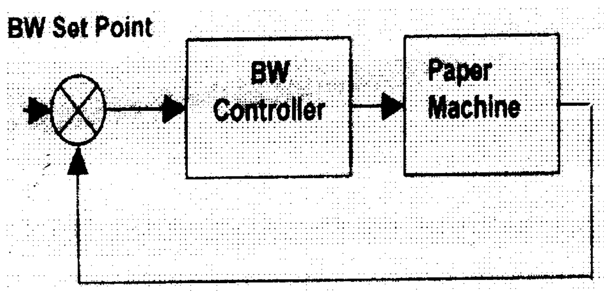

Fig. 17 Basis weight control is rather straightforward. The control loop is illustrated.

would enable to decouple the loops into two independent loops so that the normal control algorithmas can be implemented.

In the case of moisture, a cascade control loop has been implemented in one of the mills. The outer loop will provide a set point to the inner loop, which controls the steam control valve to get the desired moisture. The cascade control of the moisture control is shown in Fig. 16.

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