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# MODELLING A PAPER MAKING MACHINE FOR BASIS WEIGHT AND MOISTURE CONTROL

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## Abstract

All paper makers are expected to produce quality paper with good machine efficiency. To achieve the above goal, the quality parameters that are to be normally controlled during the production of paper are basis weight, moisture, calipre and ash content. Although it would be enough to keep these quality parameters under control in the machine direction, but in this case, there is no guarantee of these parameters remaining fairly constant in the cross direction. Hence, it would be advantageous to provide control on the above mentioned quality parameters both in the machine as well as in the cross direction in real time during production. To achieve this performance it is necessary to have appropriate model of the paper making machine and this model could then be used to provide support for the control action deisred. In this paper, only two quality parameters viz, basis weight and moisture are taken to describe the model based control action. It has been shown that a simple first order model taking into account the transport delay would be adequate for machine direction control. Equations which enable writing control algorithm for achieving computer control in the machine direction have been derived. A method to separate out the interaction between basis weight and moisture values has been indicated. The importance of slice lip control for achieving cross direction profile control is stressed. A computer based startegy that depends heavily on a dynamic predictive model for cross profile optimisation is also explained.

## 1. Introduction:

All paper makers are expected to produce quality paper with good machine efficiency. To achieve the above goal, the quality parameters that are to be normally controlled during the production of paper are basis weight, moisture, calipre and ash content. These parameters are not only to be sensed and monitored in real time, but also used against their target values specified during production of each type of paper for control purpose. To start with, it would be enough to keep these quality parameters under control in the machine direction. In this case, there is no guarantee of these parameters remaining fairly constant in the cross direction. Hence, it would be advantageous to provide control on the above mentioned quality parameters both in the machine as well as in the cross direction in real time during production. To achieve this performance, it is necessary to have a model of the paper making machine and some of its inpute elements. This model is then used to provide support for the control action needed. In this paper, only two quality parameters viz, basis weight and moisture are taken to describe the model based control action.

## 2. Process Dynamics:

To start with, let us consider control of the two parameters in the machine direction only. A non-systematic method for achieving control over the parameters is to employ an analogue controller and get it tuned by trial and error technique to arrive at the result. A more systematic approach is through modelling the process. It is possible to describe the process by a set of energy and material balance equations and arrive at the mathematical model of the process (1,2). Normally it would be difficult to put down these equations in practice from machine to machine. In these cases, it would be advantageous to get the output time response of the machine for a given manipulated inpute variable. In general one of the most common models that characterise the paper making machine, is a first order time constant with dead (delay) time as far as machine direction control is considered. Let us now consider an example of a paper making machine where the response of basis weight to the Headbox stock consistency is as shown in Fib. 1. It is assumed that the pulp flow from the Headbox is constant and the wire speed and all such parameters are maintained constant. The terms mentioned in Fig. 1, viz, gain, first order time constant and dead time are the three parameters that describe the dynamics of the process i.e., the paper making machine. These parameters are defined as under.

### K (Process Gain):

Change measured in the output variable divided by the change in the input variable.

i.e, $K = \Delta$ Basic Weight/ $\Delta$ Headbox Consistency.

**$\tau$ (Dead Time):**
This transport delay is defined as the time taken for a change in input to start changing the output. This delay is primarily due to transportation of fibres along the paper machine.

**Tc (Time Constant):**
It is the time taken for the output variable to reach 63.2% of its final value as a result of a step change in the input variable. 63.2% is obtained by setting t to Tc in the equation that describes the first order process as:

$$\text{Output} = (1 - \epsilon^{-t/Tc}) \text{ input}$$

Where $\epsilon$ = exponential constant 2.718.

**Tr (Response Time):**
It is the total process delay and is defined as the time taken for the output variable to reach 95% of its final value as a result of a step change in the input variable. It is very often expressed[3] as:

$$Tr = \tau + 4\ Tc$$

Thus for a paper machine having a dead time of 80 seconds and time constant of 70 seconds would have a response time of 80 + 4 * 70 = 360 seconds or 6 minutes.

## 3. Digital Control in The Machine Direction:

Earlier analogue controllers were used for controlling the two parameters in the machine direction. With the advent of microprocessor based computer control, it would be advantageous to employ digital control technique. The well known two mode analogue PI is replaced in this case by a software based control algorithm which now resides in the computer. The merit of a controller is not only in its efficiency to control but the simplicity with which it can be tuned i.e., adjust it for obtaining the best result. Here an adaptive or a self tuning controller serves the purpose. But designing such a controller is rather difficult. Let us now consider a digital controller[3] as shown in Fig. 2. The control algorithm could now be developed as follows. Since, only sampled data are involved in using the digital computer, the dead time t will be NT where T is the sampling time and N is the number of sampling period. Now the process can be represented by the following Z-transform equation.

$$G(z) = \frac{KEz^{-(N+1)}}{1-(1-E)z^{-1}}$$

where $E = (1-\epsilon^{-T/Tc})$

$z^{-1} =$ delay due to one sampling period

and $z^{-(N+1)} =$ delay due to (N+1) sampling periods

Now if the required response R (z) is exponential having a closed loop time constant To, then.

$$R(z) = \frac{Qz^{-(N+1)}}{1-(1-Q)z^{-1}}$$

where $Q = (1-\epsilon^{-T/To})$

From Fig. 2, the following hold good.

$$e = I - O$$

and. $$O = R(z) * G(z) * e$$

The desired closed loop response is given by:

$$R(z) = O/I$$

where I = target or the set point

O = output variable

and e = error

Combining the above equations,

$$H(z) = \frac{R(z)}{1-R(z)} * \frac{1}{G(z)}$$

Substituting for R(z) and G(z)

$$H(z) = \frac{\text{Controller output}}{\text{Controller input}}$$

$$= \frac{Q\left[1-(1-E)z^{-1}\right]}{KE\left[1-(1-Q)z^{-1}-Qz^{-(N+1)}\right]}$$

converting the above positional equation into an incremental one,

$$\Delta H(z) = \frac{\text{Change in controller output}}{\text{Controller input}}$$

$$= \frac{Q\left[1-(1-E)z^{-1}\right](1-z^{-1})}{KE\left[1-(1-Q)z^{-1}-Qz^{-(N+z)}\right]}$$

The above equation enables writing an appropriate algorithm for providing digital control.

The basis weight and moisture parameters are interactive in nature by their very definition. This is explained in Fig. 3. A decoupling/non-interactive control technique has to be used to enable using the well known single loop control techniques for independently controlling these two parameters. A scheme that is generally used to control the basis weight and moisture parameters in the machine direction is shown in Figs. 4 to 6. The "O" frame/scanner instrumentation provides data samples at regular intervals (Table-I & II) and their average for every web scan, is used to control the two parameters. The stock and the steam valves are controlled respectively to provide basis weight and moisture control. Although there may be variations in the sample values of these parameters in the cross direction, the average of these for every scan in the cross direction, the average of these for every scan in the cross direction will be well within the tolerance value, due to computer control. This is explained in Fig. 7, where it can be seen that the machine direction values remain controlled.

## 4. **Cross Direction Control:**

The ultimate goal in manufacturing paper is to produce good quality paper by not only controlling basis weight and moisture in the machine direction but also in the cross direction. History tells us that from 1900 onwards slice screw jacks were attached to Headboxes to provide open loop control in the cross direction. With the advent of "O" frame/scanner instrumentation to provide both machine and cross direction monitoring of the parameters at the calender end, automatic control techniques to provide cross direction control (4,5) have come into vogue. The technique for basis weight control, however, depends heavily on a dynamic model and ability to measure accurately the slice lip opening. It may also be mentioned that for good cross direction control, adequate number of sample profile data is essential. The cross direction control for arriving at the optimum slice profile depends on various factors as shown in Fig. 8. Moreover movement of one slice screw causes changes in the flow distribution out of the Headbox. Similarly, speed changes also have an effect on the respends heavily on the availability of a dynamic and predictive model which could be established based on a large collection of cross direction dry weight data and the response to slice opening/closing.

If it is desired that cross direction control of basis weight could be achieved through manual open loop control, then the slice control strategy could be indicated on the CRT screen which information could then be used by the operator for slice lip opening/closing. In the close loop control, shown in Fig. 9, every few minutes the new optimum slice lip set points are computed. Sensors situated on the slice lip enable measuring the current lip opening. The slice lip opening error is now computed from the above two data and used to control the lip opening/closing through appropriate actuators. Similar technique is possible for moisture control also in the cross direction. However, in this case instead of controlling the slice lip opening/closing, water jet/infra red source is used to increase or decrease the moisture content. All these control strategies should take into account various distrurbances entering into machine operation. Self tuning regulators are being tried in various mills abroad to achieve this end.

## 5. **Conclusions:**

In this paper the importance of model based control technique used to keep under control the two parameters viz, basis weight and moisture in the machine and the cross direction is stressed. It has been shown that a simple first order model taking into account the transport delay would be adequate for machine direction control. Equations which enable writing control algorithm for achieving computer control in the machine direction have been derived. A method to separate out the interaction between basis weight and moisture values has been indicated. The importance of slice lip control for achieving cross direction profile control is stressed. A computer based startegy that depends heavily on a dynamic predictive model for profile optimisation is also explained.

## 6. **References:**

1. Beecher A.E., Dynamic Modelling techniques in the paper industry, TAPPI 46 (1963), p 117-120.
2. Sankaranarayanan P.E. and Prasad G., Mathematical model of a paper making machine for machine direction profile control (under publication).
3. Al Al-Shaikh, Fundamentals of control, Measurex Technical Note.
4. Karlsson. H. Lundquist. I and Ostman. T., Principles and potentials of CD-basis weight control, Proc. EUCEPA Symosium on control systems in the pulp and paper industry, Stockholm, May 11-14, P. 238-243.
5. 5. Karlsson. H and Haglund. I, Optimal cross direction basis weight and moisture profile control on paper machines, Proc. ISC-CP international pulp and paper process control symposium, Vancouver, B.C., 1983, p. 139-145.

## TABLE - I

PRODUCT NO : 9 SHIFT: FIRST ROLL NO : 9
DATE: 12-9-88 TIME: 15.29.24
Target Grammage : 49.0 GSM Target Moisture : 6.0%

| Lane | Grammage | Moisture |
|---|---|---|
| 1 | 49.1 | 5.7 |
| 2 | 47.8 | 6.0 |
| 3 | 49.3 | 6.2 |
| 4 | 48.6 | 6.5 |
| 5 | 48.2 | 6.4 |
| 6 | 47.6 | 6.4 |
| 7 | 49.3 | 6.6 |
| 8 | 49.9 | 6.5 |
| 9 | 49.4 | 6.6 |
| 10 | 49.2 | 6.5 |
| 11 | 49.3 | 6.3 |
| 12 | 49.7 | 6.5 |
| 13 | 48.3 | 6.5 |
| 14 | 48.4 | 6.8 |
| 15 | 47.4 | 6.5 |

## TABLE - II

PRODUCT NO: 5 SHIFT: FIRST ROLL NO: 1

DATE: 12-10-88 TIME: 13-01-33

Target Grammage: 44.0 GSM Target Moisture :7.0%

| Lane | Grammage | Moisture |
|---|---|---|
| 1 | 47.7 | 7.0 |
| 2 | 46.9 | 7.0 |
| 3 | 46.8 | 6.8 |
| 4 | 46.4 | 6.8 |
| 5 | 47.2 | 7.1 |
| 6 | 47.1 | 7.0 |
| 7 | 47.9 | 7.1 |
| 8 | 48.9 | 7.1 |
| 9 | 48.9 | 6.9 |
| 10 | 48.0 | 7.1 |
| 11 | 46.9 | 7.0 |
| 12 | 47.1 | 6.9 |
| 13 | 46.7 | 6.9 |
| 14 | 46.9 | 6.7 |
| 15 | 46.6 | 6.9 |

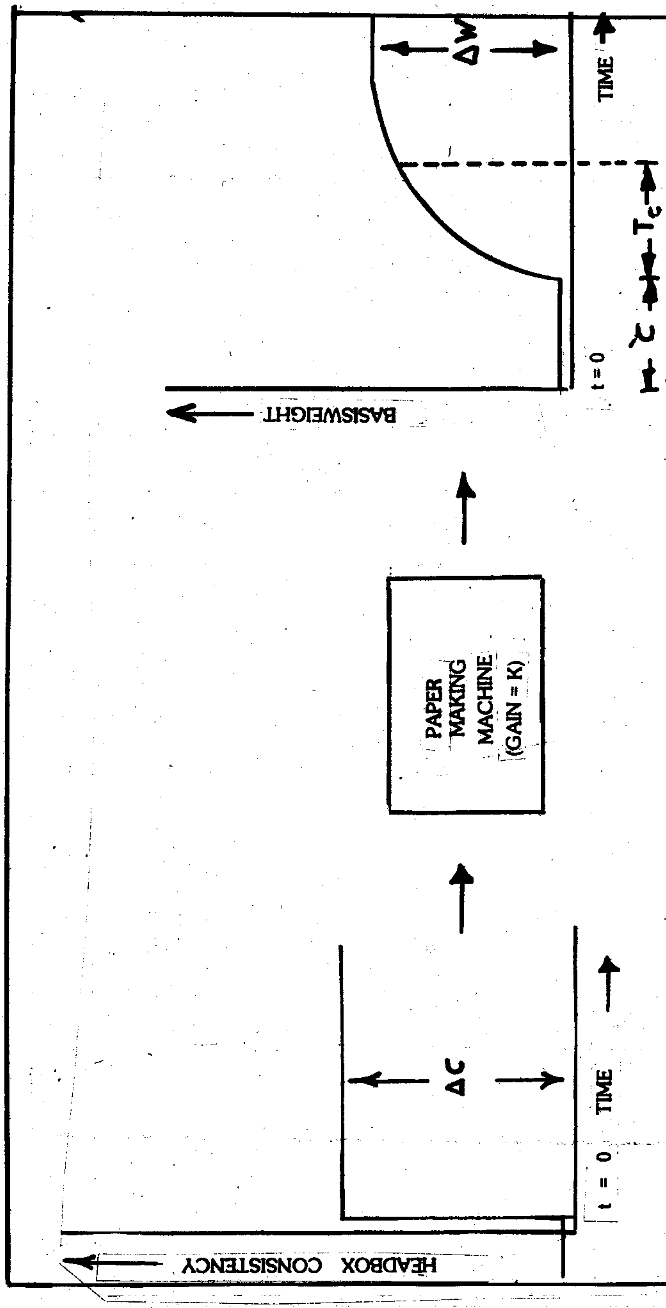


FIG. 1 OUTPUT RESPONSE TO A STEP INPUT

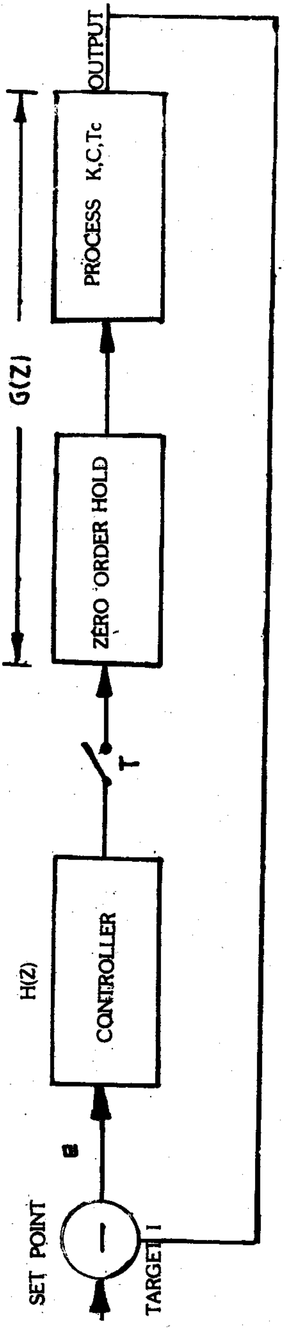


FIG. 2 SCHEMATIC OF A DIGITAL CONTROLLER

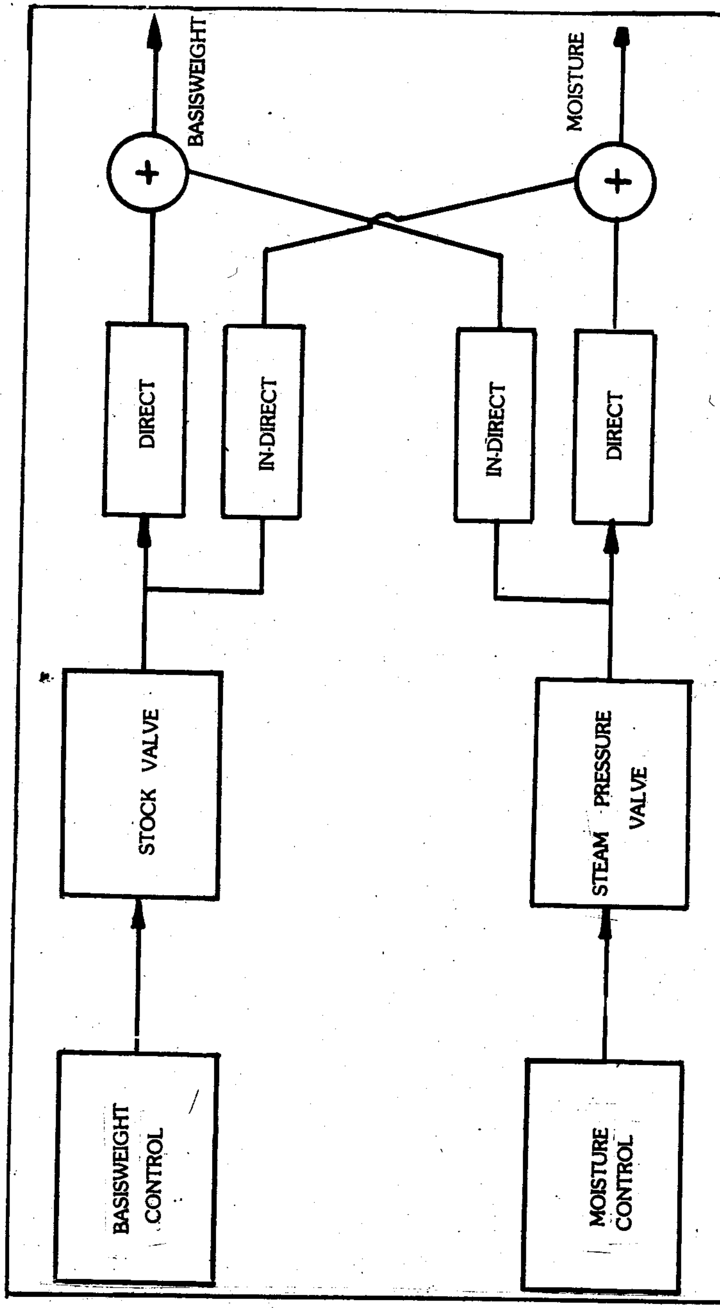


FIG. 3 BASIS WEIGHT AND MOISTURE INTERACTION

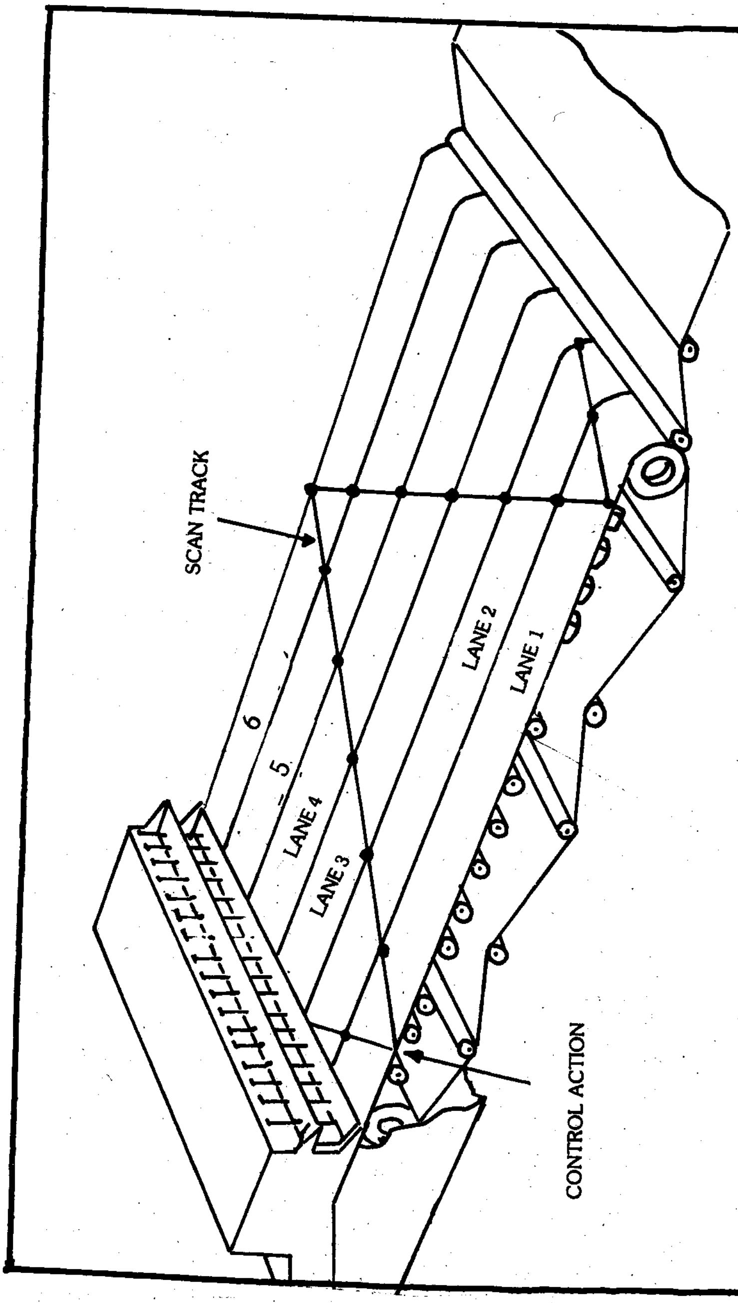


FIG. 4 SCHEMATIC OF LANE SCAN

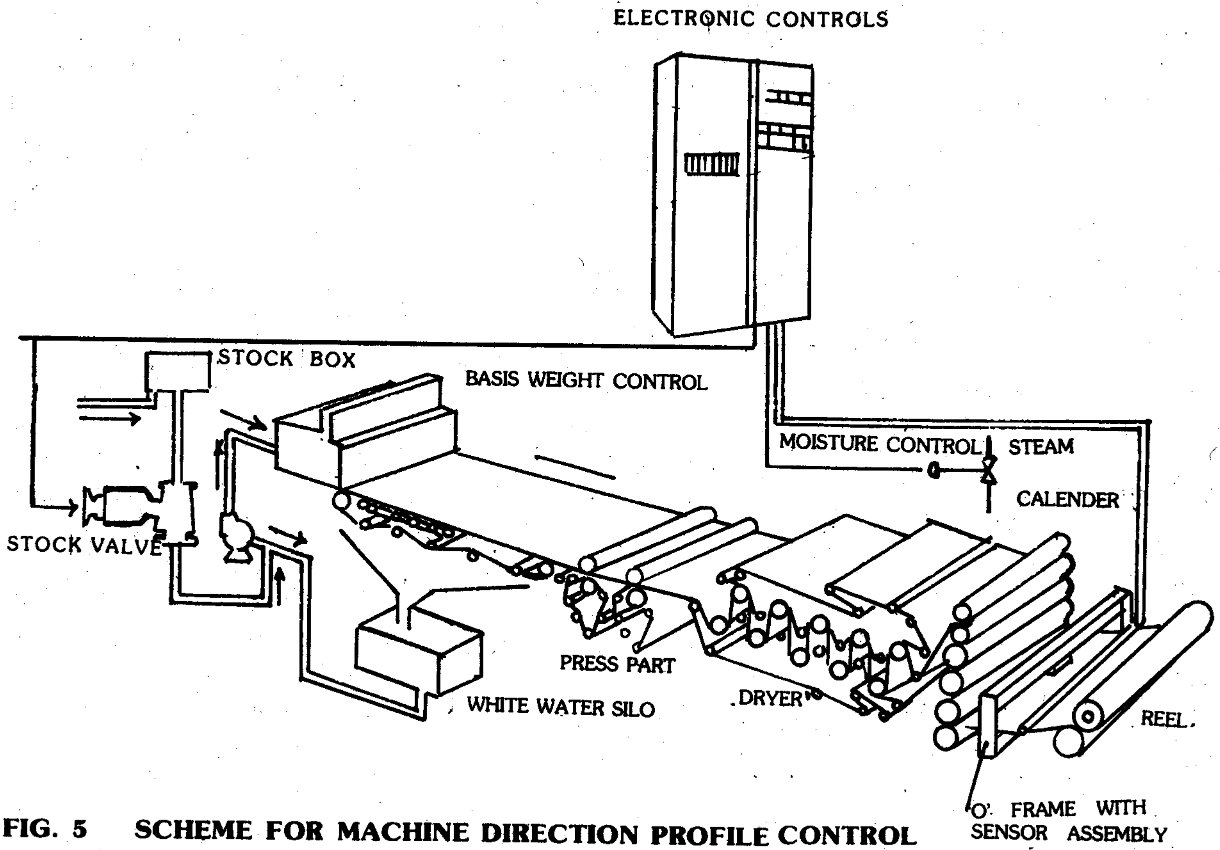


**FIG. 5** SCHEME FOR MACHINE DIRECTION PROFILE CONTROL

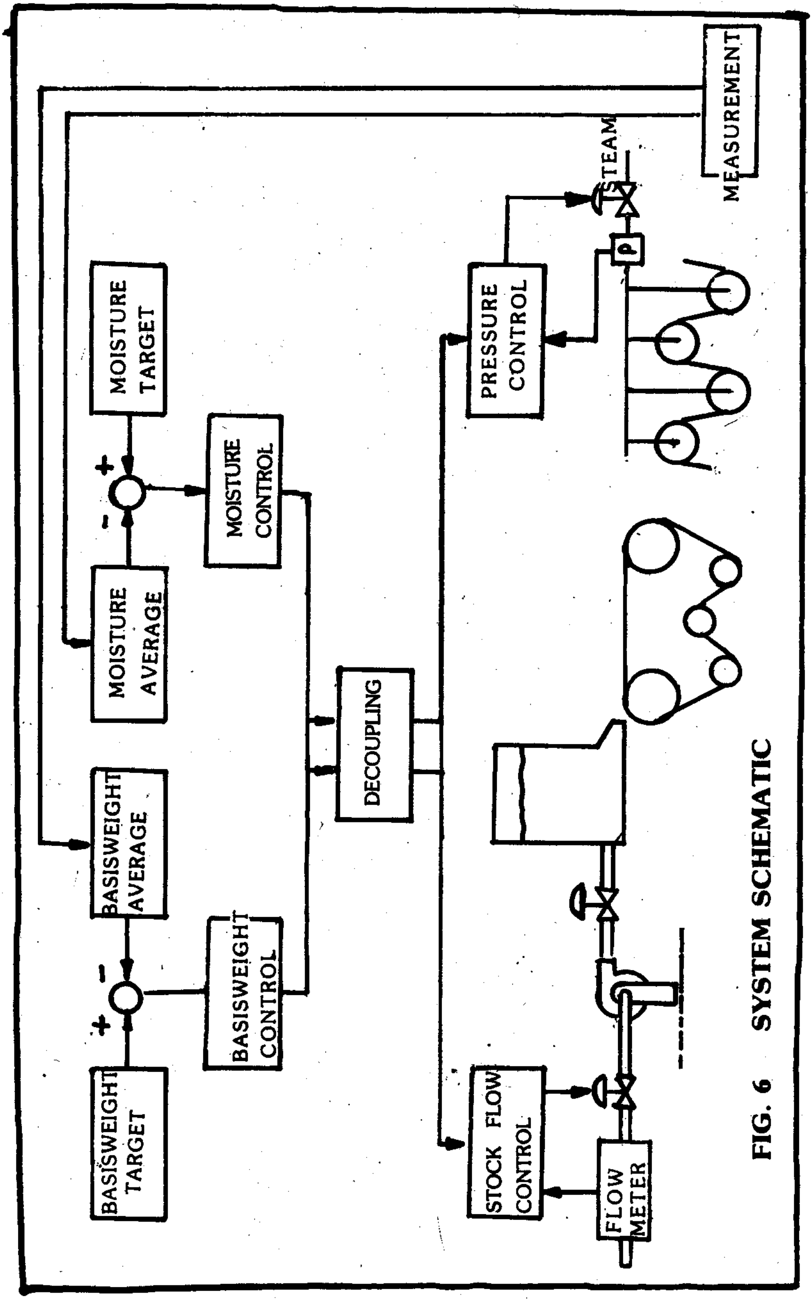
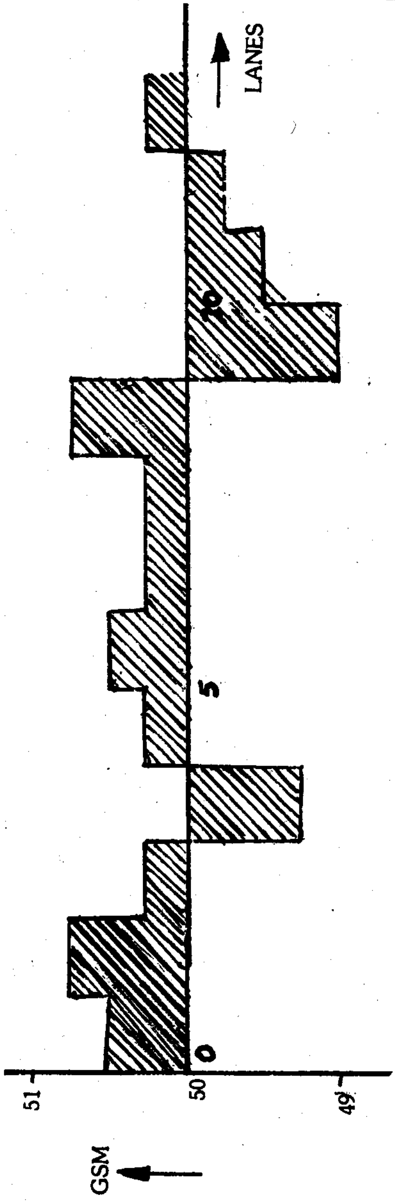


FIG. 6 SYSTEM SCHEMATIC



(GSM VALUES IN THE CROSS DIRECTION EVERY SCAN)

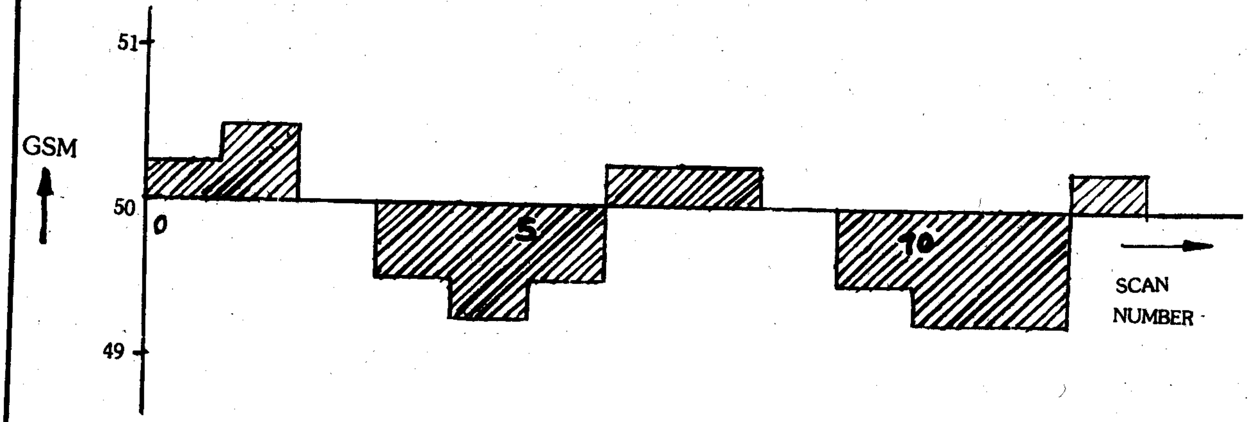


FIG. 7 CD AND MD PROFILES

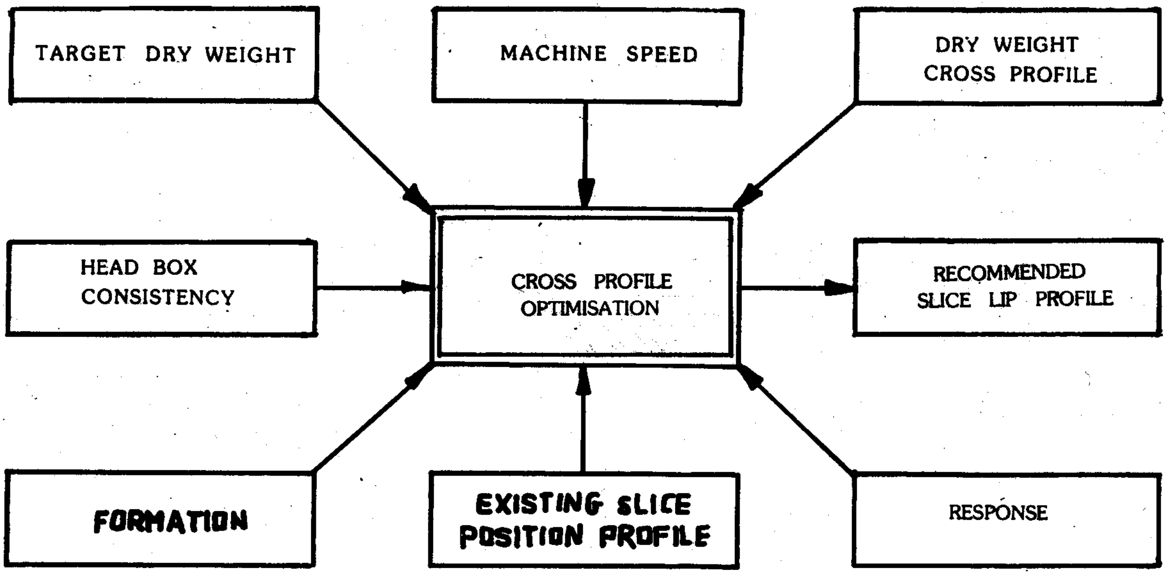


FIG. 8 FACTORS INVOLVED IN SLICE PROFILE CONTROL

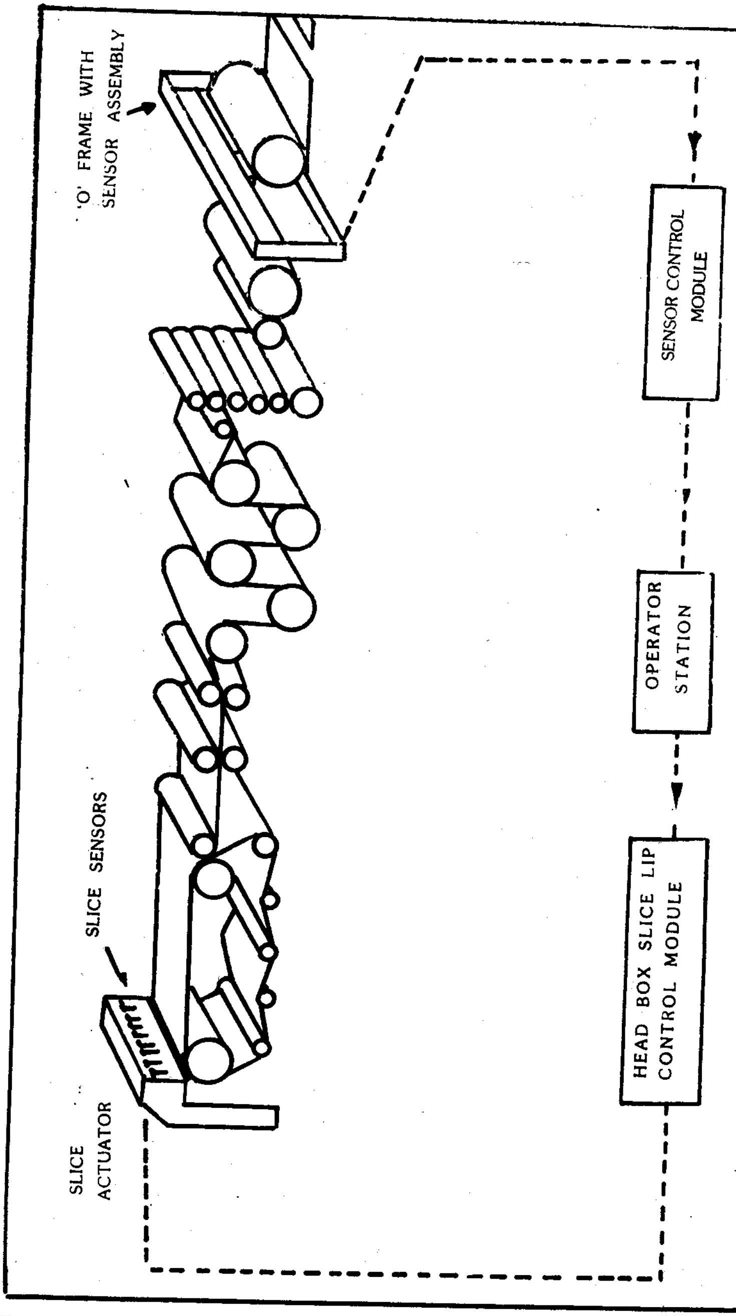


FIG. 9 SCHEME FOR CROSS DIRECTION PROFILE CONTROL