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COMPUTERISED PAPER WEB PROFILE CONTROL

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Synopsis This paper presents the Warkaus Mill computer system and is focused particularly on the paper web moisture profile control developed in our company. The aim is to make use of the possibilities given by the second and the third presses with controlled crown rolls. Special attention is directed to profile measurement data analysis techniques and an on-line continuous statistical variation partitioning method is developed. The information is then used for operator guidance control, based on a derived control law. The profile control is not yet integrated in the system, but the control parameters are being established.

General

THE basic structure of the Warkaus Mill process computer system is represented in Fig. 1.

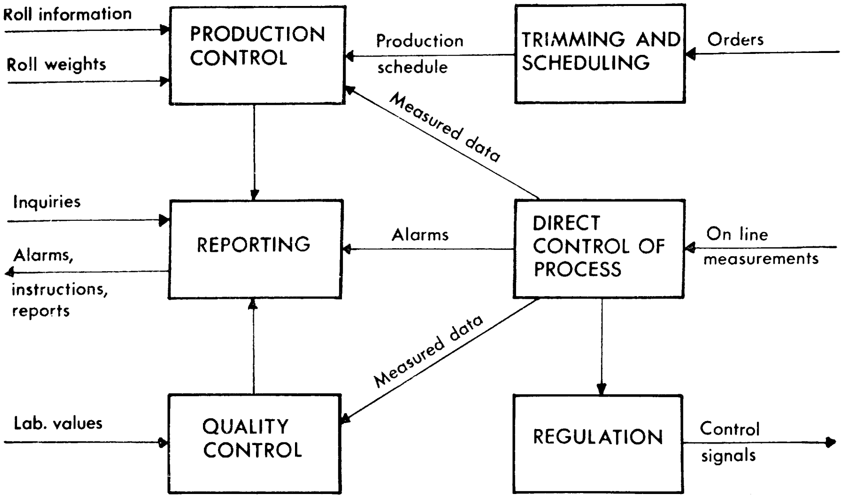


Fig. 1—General system's layout

Under the chairmanship of P. E. Wrist

The orders are allocated manually to three papermachines, then fed to the computer where the trimming and sequencing is done automatically. The possibility of criticising and making changes manually in the production schedule thus produced is an integral part of the production planning.

The automatically read scale readings are the main input to the production follow-up system, which has to work according to the approved production schedule. In this system, single-reel quality ratings are also accumulated from on-line and laboratory measurements and compared with specifications. The good reels are accepted and the rejected reels separated into two classes, those that are unconditionally broke and those that are subject to quality inspection. The broke is then directed to the best suitable use.

The on-line measurements are processed in the process control system. The basic functions of the system are filtering, limit checking conversion, averaging, control action calculations, logging and the control of scanning instruments. One part of the process control system is paper web profile control discussed below.

The quality control system is a data processing and cumulating system. Its basic functions are filtering, limit checking, averaging, statistical analysis, prediction and cumulation per order, per grade and per time period. The inputs are both manual and automatic.

All the written reports are designed to form the basis of an effective information system serving the managerial, superintendent and machine personnel level. The reporting can be made periodically, at request or automatically as alarms.

As a typical example of our process computer system, we will discuss the paper web profile control, which affects the greater part of the whole system. For example, the profiles are important factors when judging reel quality, thus important information inputs to production control and quality control.

Paper web profiles

THE paper web cross-direction profiles of main interest are basis weight, moisture content and caliper. The first two can be reduced to the independent oven-dry basis weight and moisture content profiles. The main variables affecting the oven-dry basis weight profile are thin stock consistency distribution over the slice, thin stock flow on to the wire, hydrodynamic conditions on the wire and retention on the wire. After the Fourdrinier section, the oven-dry basis weight profile is not noticeably altered.

All these factors affect the moisture content profile. In addition, the moisture content profile is modified in the press section and the dryers. The caliper depends on the basis weight and moisture and is mainly formed in the press section, breaker stack and calender.

Before we take control of the profiles into consideration, any major deficiencies in the normal working conditions should have been taken care of, say, for moisture, the consistency distribution over the slice, bad ventilation conditions, plugged press felts, etc.

The control policies for these profiles are the following. The oven-dry basis weight profile gross level is determined by the thin stock flow and average consistency by dry stock flow at the thick stock valve, head box pressures, temperatures and gross slice opening. The variations in gross level—that is, the machine-direction basis weight variations—are controlled by the computer through feedback from the dry end basis weight measurement to the thick stock valve. The other adjustments mentioned are determined and made by the machine personnel. The control of the oven-dry basis weight profile is made through slice screw settings suggested by an analysis of the dry end profile measurements. These setting deviations from the gross level are restricted by certain limits with which we may control, for example, the maximum deviation on the moisture profile caused by the slice screw settings.

The Fourdrinier section will cause deviations from the ideal moisture profile. To correct this and to compensate for uneven drying in the dryer section, we intend to manipulate the pressure settings on the press section, thus to control the moisture profile.

There are three presses in the press section of our No. 1 papermachine under consideration. Press No. 1 is a rubber-covered couch roll pressing against a stone roll. Press No. 2 is a controlled crown roll with a grooved stainless steel cover pressing the paper and the press felt against a stone roll from above. Press No. 3 is similar to press No. 2, but the paper is pressed against the stone roll from below. The average line pressures in the presses are determined and set by the machine personnel. As there are two similar presses in the grouping mentioned above, the personnel can control such quality variables as two-sidedness and oil absorption. The moisture profile is controlled by the ilne pressure profiles at the nips of the second and third presses. This can be done by changing the balance of the back and front loads of the press rolls and by changing the crown pressures.

Then changes to be made in the pressure settings are suggested by the computer after analysing the dry end profile measurements. The control policy of making changes that correct the dry end profile without caring about the profile anywhere else (such as before the dryer section) gives us the chance to work only with dry end measurements. A wet end scanning moisture gauge is, however, foreseen.

The restrictions imposed on the pressure sections by other quality factors—such as caliper, smoothness and running conditions, fluttering edges in the dryer section or similar conditions—are inserted in the control by limits on the pressure setting deviations from the normal level. The caliper is controlled in the calender, where there is also a controlled crown roll. When judging the evenness of the paper web, we have given the profiles mentioned different priorities. This has been done more from the customers' viewpoint. The classification in decreasing importance is thus caliper, moisture content and basis weight.

The control problem can be divided in three parts—

1. Defining the process.
2. Measurements.
3. Design of the control law.

Case study: moisture profile

Definition of the process

Considering only the third press, we want the dry end moisture profile expressed as a function of the pressure and load settings. These settings are—

F_A = front load,
F_B = back load,
K_{pc} = relative excess crown line pressure ratio.

We have the following equalities—

$$q_o = \frac{F_A+F_B}{l}$$
$$q_c = D.P_c$$
$$q_{co} = q_o$$
$$K_{pc} = \frac{q_c-q_{co}}{q_{co}}$$

where P_c = crown pressure,
q_o = average line pressure,
q_c = crown line pressure,
q_{co} = crown equilibrium pressure,
l = length of press roll,
D = diameter of press roll.

The dry end moisture k_d may be represented as a rough approximation by the expression—

$$k_d = L(x)M(k_o,q_o,v,w,c_f(t))G(t).y(x,F_A,F_B,K_{pc})$$

The first term $L(x)$ takes into account non-linear drying characteristics in the dryer section, which are reflected in the profile variation sensitivity at the dry end. The second term $M(k_o, q_o, v, w, c_f(t))$ takes into account the press section working level characteristics and is primarily a function of ingoing moisture ratio k_o, nip line pressure q_o, machine speed v, basis weight w (mainly through rewetting) and felt quality factors $c_f(t)$, which vary slowly with time.

The dynamics of the press section drying process is mostly determined by the moisture equilibrium between the paper web and the press felt. Any small change will thus be followed by a certain settling time. The press dynamics are taken into account in the third term $G(t)$.

The last term $y(x, F_A, F_B, K_{pc})$, where x denotes the cross-direction, takes into account profile variations around the working level. This term depends on the settings.

If we assume that to water removal depends linearly on the paper web and press felt compression, we may calculate the compression profile and thus the water removal profile as follows.

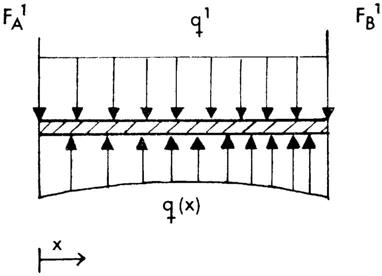


Fig. 2—Force diagram for the press roll crown considered as a bar on an elastic mat

We equalise the swimming roll shell with a long bar that lies on an elastic mat (Fig. 2). The pressure inside the shell is even so that the force per length unit is a constant q_1. In addition, to this force is added on the front end a force through the bearing F'_A that equals $F'_A = F_A - \frac{1}{2}q_1 l$ and, analogously, we have a force $F'_B = F_B - \frac{1}{2}q_1 . l$ on the rear end. The reaction is a force per length unit $q(x) = cy$. This leads to a fourth degree differential equation—

$$EI\frac{d^4y}{dx^4} = q_1 - cy$$

which has the following solution—

$$y = \frac{q_1}{EI} \cdot \frac{1}{4\beta^4} + e^{\beta x}(A \cos \beta x + B \sin \beta x) + e^{\beta x}(C \cos \beta x + D \sin \beta x)$$

where $\beta = \sqrt[4]{\frac{C}{4EI}}$

E = elasticity constant,
I = stiffness.

The parameters A, B, C, and D in the equation are evaluated by applying the boundary condition—

$$\frac{d^2y(o)}{dx^2}=0 \qquad \frac{d^2y(l)}{dx^2}=0$$

$$\frac{d^3y(o)}{dx^3}=-\frac{F'_A}{EI} \qquad \frac{d^3y(l)}{dx^3}=-\frac{F'_B}{EI}$$

The parameters listed above are all functions of F_A, F_B and q_1—that is, the load and pressure settings. Because of the complexity of the equation and the approximations made in deriving it, we have decided to take another approach to the problem.

Measurements

The moisture is measured with an on-line moisture gauge traversing in one direction. The gauge is read periodically and the start of the traverse is in phase with the gauge reading. Thus, we in effect take readings at N equispaced (Δx) machine-direction strings on the paper web. The readings of one scan lie on a diagonal over the paper. The data are exponentially filtered in the machine-direction along the mentioned sample strings. The filtering formula is—

$$X_F = X_F(t-\Gamma)+K[x(t)-X_F(t-\Gamma)]$$

where X_F = the filtered value,
Γ = sample interval,
K = filtering constant.

This filtering method is mainly used because of its compatibility with the computer. It requires little computer calculating time and little computer storage, because we only have to store the last filtered value.

Effect of sampling—The process of converting continuous data through sampling and quantification to discrete numbers we call digitising.

If the sampling frequency is f_s the cut-off frequency of the attainable information is $f_c = \frac{1}{2}f_s$. For any frequency of f in the range $0 \leqq f \leqq f_c$, the higher frequencies that are aliased with f are defined by—

$$(2f_c \pm f),\ (4f_c \pm f), \ldots,\ (2nf_c \pm f), \ldots$$

To avoid this aliasing problem, we could either choose f_s sufficiently high so that it is physically unreasonable for data to exist above f_c or filter the data before sampling so the information above a preselected maximum cut-off frequency is no longer included in the filtered data.

With a scanning measuring unit, the aliasing will be substantial. The practical scanning velocity is limited by the gauge response time and mechanical rigidity, etc., which will make the sampling time between adjacent samples on the same string relatively large. Prefiltering of the data before sampling is not permitted, because this will bring unwanted information from nearby sampling points.

We have run several autocorrelation studies and have found that, owing to the long sampling time and the aliasing effect, the aliased power spectrum on the frequency area $(0-f_c)$ is essentially constant (white). The band width of the band width limited Gaussian white noise is thus $B_s = f_c$.

We consider the case where $x(t)$ has a mean value. We assume that the power spectral density function is—

$$\begin{aligned} G_x(f) &= \frac{1}{B} + \mu_x{}^2\delta(f) && 0 \leqq f \leqq B \\ &= 0 && f > B \end{aligned}$$

where $\delta(f)$ is the Dirac delta function. The associated autocovariance function is—

$$C_x(\Gamma) = \frac{\sin 2\pi B\tau}{2\pi B\tau}$$

The variance of the mean value estimate is then—

$$\text{Var}\ [\mu_x] \approx \frac{1}{2B\Gamma}$$

If $C_x(0) \neq 1$, we get—

$$\text{Var}\ [\hat{\mu}_x] \approx \frac{1}{2B\Gamma}\,\delta x^2$$

From this, we get the mean value estimate variance for an N-sample moving average—

$$\text{Var}\ [\hat{\mu}_x] \approx \frac{\delta x^2}{N},$$

which is familiar from statistical analysis.

We are interested in how good a mean square value estimate we get with the data filtered using the above approximate exponential formula.

$$\text{Var}\ [\hat{\mu}(t)] = E\{(x_F(t) - \mu(t))^2\}$$

where

$$x_F = \sum_{m=o}^{\infty} K(1-k)^m x(t - m\Gamma)$$

The autocorrelation function values $R_x(mT)$ are zero for the band width limited Gaussian white noise and we thus get—

$$\begin{aligned}\text{Var}\,[\hat{\mu}(t)] &= E\{(X_F(t)-\mu(t)-\mu(t))^2\}\\ &= R_x(o)\sum_{m=o}^{\infty} K(1-K)^{2m}-\mu(t)^2\\ &= \sigma x^2\,\frac{K}{1-K}\end{aligned}$$

If we set this equal to the moving average estimate variance, we get an expression relating N and K for equally good estimates—

$$N=\frac{2-K}{K};\ K=\frac{2}{N+1}$$

These conditions apply when the sample number is very large. If the sample number M is finite, we get—

$$\text{Var}\,[\hat{\mu}(t)] = \sigma x^2\left[\frac{K}{2-K}+(1-K)^{2(M-1)}\left(1-\frac{K}{2-K}\right)\right]$$

Problems of a diagonal scan—The aim is to get a true picture of the cross-direction stable profile with a continuously scanning measuring unit. The measuring path will be a diagonal across the paper web. The measuring data will thus be contaminated with machine-direction variations. It is of interest to know how well a single scan represents the true momentary cross-direction profile. The error introduced into the measured data for two adjacent measuring points by the machine-direction variations may be estimated with the one-step Markov process prediction method. If the measured point represents the wanted momentary profile, the mean square error of the next point on the diagonal is—

$$\sigma^2 = R_x(o)-R_x(h) = C_k(o)-C_x(h)$$

The R values are the autocorrelation functions and the C values the autocovariance functions of the machine-direction data. In our measurements, the time interval h was 2 s and this gives a mean square error approximately to 10 per cent of the machine-direction mean square error.

Partitioning of the data—During one scan, we calculate the following values—

One-scan measurement average.
The stable profile by filtering.
One-scan mean square error (see below).
Total variance estimate by filtering.

In connection with special profile inquiries, the total average estimate and the stable profile fixed effects variance are also evaluated.

Thus, we have always available in the computer the profile measurement data approximately partitioned into—

Machine-direction variation.
Cross-direction profile variation.
Stable profile evennness figure.

We define the following values—

1. The cross-direction profile fixed effects variance estimate—

$$\hat{s}^2_{CD} = \frac{1}{M-1}\sum_{j=1}^{M}(x_{Fj}-\bar{x}_F)^2$$

2. The total random variation variance—

$$\sigma^2_T = E\left\{\frac{1}{M}\sum_{1}^{M}(x_j(t)-\bar{x}_j(t))^2\right\}$$

3. The machine-direction variation variance—

$$\sigma^2_{MD} = E\{\bar{x}((t)-\hat{\mu}x)^2\}$$

4. The cross-direction profile random effects variance—

$$\sigma^2_{XD} = E\left\{\frac{1}{M}\sum_{1}^{M}(x_j(t)-\bar{x}_j(t)+\bar{x}(t)-\mu_x)^2\right\}$$
$$= \sigma^2_T - \sigma^2_{MD}$$

If we introduce the above filtering formula and assume that all the samples are statistically independent (this is not true, but will give a rough picture), we may calculate the variances—

$$\sigma^2_{FT}(t) = E\left\{\frac{1}{M}\sum_{1}^{M}(x_j(t)-x_{Fj}(t))^2\right\} = \frac{(1-K)^2}{1-K/2}\sigma^2_T(t)$$

$$\sigma^2_{FMD}(t) = E\{(\bar{x}(t)-\bar{x}_F(t))^2\{ = \frac{(1-K)^2}{1-K/2}\sigma^2_{MD}(t)$$

$$\sigma^2_{FMD}(t) = \sigma^2_{FT}(t)-\sigma^2_{FMD} = \frac{(1-K)^2}{1-K/2}\sigma^2_{XD}(t)$$

In the above expressions, $x(t)$ is the measured datum and μ_x the entire average. The subscripts j denote the different cross-direction measuring points and a bar above a symbol denotes an average.

$\hat{\sigma}^2(t)$ is the time-varying estimate of the expected values σ^2. If we approximate these estimates with the same filtering formula, we get—

$$\hat{\sigma}_F{}^2(t) = \sum_{i=o}^{\infty} L(1-L)^i\hat{\sigma}^2(t-i\Gamma)$$

The expected value is—

$$E\{\hat{\sigma}_F{}^2\} = E\{\hat{\sigma}^2\}$$

and the variance is—

$$E\{(\hat{\sigma}^2{}_F-\hat{\sigma}^2)^2\} = \sigma^2{}_\sigma\frac{L}{2-L}$$

where σ^2 denotes the estimate of the variance and $\sigma^2{}_\sigma$ as its expected value. The filtered variance estimation is thus consistent. For convenience, we may choose $L = K$. We thus have continuously available in the computer the following standard deviations—

$S_{CD} = \sqrt{S^2{}_{CD}}$ which is a measure of profile evenness

$\sigma_{MD} = \sqrt{\sigma^2{}_{MD}} = \sqrt{a\sigma^2{}_{F(FMD)}}$ which is a measure of machine-direction stability

${}_\sigma XD = \sqrt{\sigma^2{}_{XD}} = \sqrt{a\sigma^2{}_{F(FXD)}}$ which is a measure of profile stability

where $a = \dfrac{1-K/2}{(1-K)^2}$

and $\sigma^2{}_{F(F..)}(t) = L\sigma^2{}_{F..}+(1-L)\sigma^2{}_{F(F..)}(t-\Gamma)$

We have thus an effective tool for judging papermachine operations.

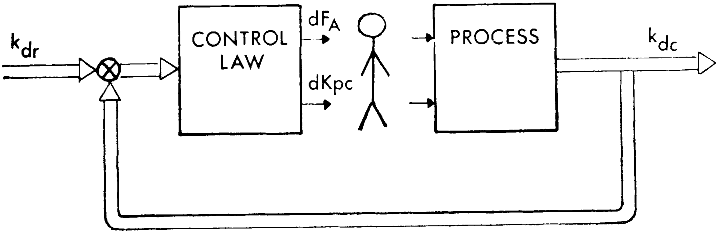


Fig. 3—The control flow diagram

Design of the control law

The control loop under consideration is illustrated in Fig. 3. The target moisture profile is denoted k_{d_r} and the actual profile k_{d_c}. The input to the control system consists of the measured and filtered dry end moisture profile. The profile k_{d_o} is subtracted from the measured data, then the term $L(x)$ is removed from the process model by multiplying the profile with a first order polynomial in k_d—

$$dk'_w(x) = (k_d'(x)-k_{do})(E+Fk_d(x))$$

In effect, we are reflecting the dry end profile to the wet end. We then fit the data to a second-order profile model—

$$dk'_w(x) = \simeq A'x^2+B'x+c'$$

The wet end moisture after the presses is written—

$$k_w(x) = MGy$$

where the term y is the profile model—

$$y = Ax^2+Bx+C$$

If we differentiate the wet end moisture model thus defined, we get—

$$dk_w(x) = M.G.Z.y(x)$$

where Z denotes the differential operator.

$$Z = dF_A\frac{\partial}{\partial F_A}+dF_B\frac{\partial}{\partial F_B}+dK_{pc}\frac{\partial}{\partial K_{pc}}$$

We may write the wet end profile—

$$dk_w(x) = M.G.x'DU$$

$$\text{where } x = \begin{bmatrix} x^2 \\ x \\ 1 \end{bmatrix}$$

$$D = \begin{bmatrix} \frac{\partial A}{\partial F_A} & \frac{\partial A}{\partial F_B} & \frac{\partial A}{\partial K_{pc}} \\ \frac{\partial B}{\partial F_A} & \frac{\partial B}{\partial F_B} & \frac{\partial B}{\partial K_{pc}} \\ \frac{\partial C}{\partial F_A} & \frac{\partial C}{\partial F_B} & \frac{\partial C}{\partial K_{pc}} \end{bmatrix}$$

$$U = \begin{bmatrix} F_A-\frac{1}{2}q_ol \\ F_B-\frac{1}{2}q_ol \\ k_{pc} \end{bmatrix}$$

In the matrix U, we have linearised the process around the normal operating conditions. If we require that—

$$q_o = \frac{F_A+F_B}{l}$$

and disregard the constant term in the profile model, we may rewrite the above expression for changes in the profile arising from changes in the setting values in the form $dk_{we}(x)$,

$$\text{where } x = \begin{bmatrix} x^2 \\ x \end{bmatrix}$$

$$D = \begin{bmatrix} \dfrac{\partial A}{\partial F_A} - \dfrac{\partial A}{\partial F_B} & \dfrac{\partial A}{\partial K_{pc}} \\ \dfrac{\partial B}{\partial F_A} - \dfrac{\partial B}{\partial F_B} & \dfrac{\partial B}{\partial K_{pc}} \end{bmatrix}$$

$$U = \begin{bmatrix} dF_A \\ dK_{pc} \end{bmatrix}$$

If

$$G(s) = \frac{1}{s+a}$$

we may write the proportional control law—

$$dU(t) = \frac{1}{M} D^{-1}[-A_1(t) - aA_1(t) - aA_1(t-\Gamma)]$$

where

$$A_1(t) = \begin{bmatrix} A'(t) \\ B'(t) \end{bmatrix}$$

The terms $A'(t)$ and $B'(t)$ are actually the differences between the second-order and first-order terms in the target profile and the actual profile.

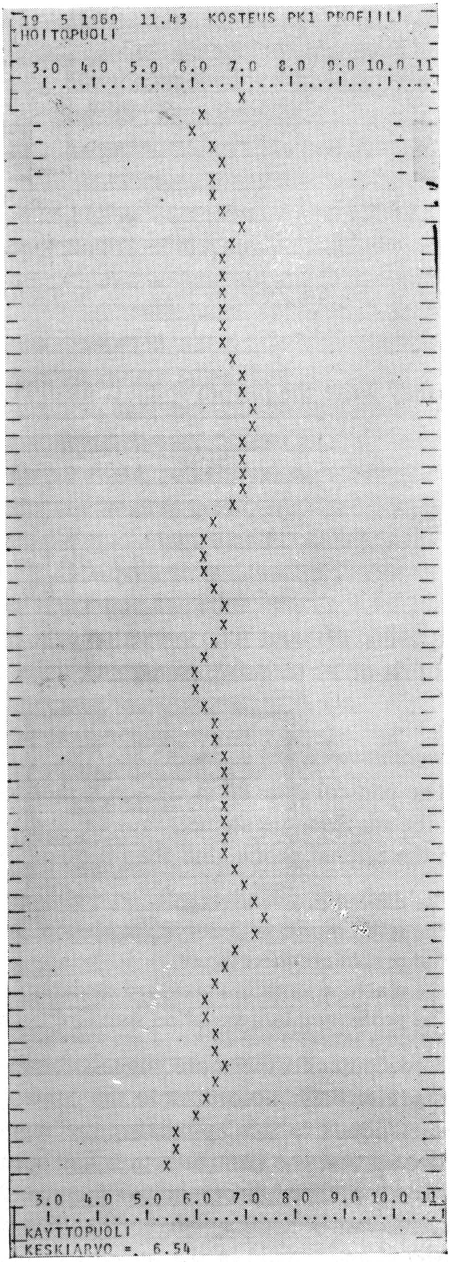
Implementation of the control

The control interval is chosen rather long, say, 30 min, to be convenient for the machine personnel, thus to be accepted. The control program prints out the filtered profile and the following values defined above—

The filtered profile average.
The given moisture upper limit.
The profile evenness figure.
The machine variation standard deviation.
The profile random variation standard deviation.

The computer furthermore suggests changes in the third press loading and pressure settings, according to the control law derived above. The operator then responds to this by making the suggested adjustments and notifies the computer that the control action has been performed. If he does not notify the computer, the program will not consider the suggested adjustment an effected control action.

Any change made in the settings without notifying the computer will be



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19 5 1969  11.43  KOSTEUS PK1 PROFIILI
HOITOPUOLI
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KAYTTOPUOLI
KESKIARVO =  6.54
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Fig. 4—The complete output of a filtered moisture profile

The text reads—
19/5/69 11.43 h Moisture content profile
No. 1 machine
Control side
Drive side
Mean value = 6.54 per cent

considered as process noise. A feature of the program is that it can continuously change the set point of the automatic machine-direction moisture control so that it is 2 σ below the moisture upper limit. The term σ is the total moisture variation standard deviation. The profile fixed effects must be taken into account when this deviation is calculated.

State of the study: future objectives

THIS preliminary study forms the basis of the research work on profile management that is being done at our mill today. The control is not yet wholly integrated in the system. Work is being done to establish the values of the parameters in the derived control law. In Fig. 4, we have a typical output of the profile control program as it is today. The filtered profile was printed on an IBM 1053 printer. The part of the profile exceeding the prescribed upper limit is printed in red.

The press felt factors vary slowly with time, and thus also the gain of the control law. In order to avoid this, the total gain should be made adaptive. Another possibility is to make the parameters in the matrix D adaptive. This would make it possible to follow the evolution of the cross-direction felt characteristics, thus to detect faults in the felts automatically.

One major object of this study has been to develop a method by which the evenness of the paper web can be judged by quality control. This may be accomplished by presenting at request, the paper web profiles and standard deviations in a clear common summary report.

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Discussion

Mr B. Radvan May I be the first to congratulate the author that he has tackled something that we have not heard enough about up to now—the control of cross-direction profile. With all the instrumentation and its ability to take profiles continuously and to analyse them so fast, would it be not worthwhile to derive the autocorrelogram, as well as the standard deviations? It is surely almost as informative as some of the deviations, particularly the standard deviation of the permanent profile. Would it be very difficult to alter the programs to produce the autocorrelograms as well as standard deviations?

The Chairman Unless I am confused, you can only do an autocorrelation within a series, which in this case would be a single cross-direction profile.

Mr Radvan I stand to be corrected, but I understand that a set of graphs such as were shown would yield an autocorrelogram.

Mr D. L. Cooper There is no reason for one not to carry out autocorrelation for cross-direction variation, but one problem is the degree of accuracy of the result. One assumes that one is not going to have very many values from a single cross-directional scan. I imagine you could do something by averaging the coefficients as different lags, using the results from each scan. If you are taking a very short sample, you might find yourself in some difficulty.

Mr U. J. G. Ström Just a small comment—these were in a way average profiles. We have made autocorrelation studies on the machine-direction and found that the correlation between two samples at 1·5 min interval is very small in our machine.

Dr I. B. Sanborn A recent paper* recommended that the first derivative of the profile be taken, then plotted and the number of oscillations that show a greater rate of change than some specified value be determined. Most of those

* Wingrove, H. G., Madeley, G. D. and Shabi, F. A., *Paper Tech.*, 1969, **10** (1), T1–T7

who have worked with profiles, whether they be basis weight, caliper or whatever, have found that the total change in profile is not as important as the rate at which it changes.

Mr M. M. Kaila If I understood correctly, Mr Ström did not actually try to find out whether this is a statistical set of values, then define a standard deviation of these set of values, but instead he tried apparently just to characterise how much these values vary so as to give the amplitude of the variations by condensing all this information into one number, exactly in the same way as one does when giving a standard deviation.

Mr Cooper We have done many such analyses on behalf of our members. On very rare occasions, do we find the autocorrelation function tends to zero in such a short time. I did in fact show a slide in my talk earlier this week—taken from actual results—where we saw variations occurring with wavelengths in the 10–15 min range. I would not like it to be thought natural for all machines to show zero relationship between consecutive points when those points reach as little as a few minutes separation.

Mr H. B. Carter Our experience might be helpful. We installed a moisture profiler on the same traversing gear as the basis weight unit. The average of each profile (about every 4 min) was recorded. For four months, we were recording only these averages until we put basis weight on stuff valve control, then we noticed an immediate improvement in basis weight variation.We therefore did a distribution of basis weight averages before and after control: a 50 per cent reduction in the standard deviation was found. We then repeated this with moisture content and found that it had practically an identical improvement. From this, I infer that, if basis weight is perfectly controlled, absolutely no trouble with moisture content will be experienced. The control method may be of interest. We computed the average of the profile and compared it with the standard: 70 per cent of this error is fed as a timed pulse to reposition the stuff valve. This is the elementary system that gave us this kind of improvement and seems to be better than the very complicated one referred to a few minutes ago.

The Chairman As we are leading into the topic of our last paper, namely, the interaction between moisture content and basis weight in the dry section, perhaps we could leave that comment until after the session's last paper.

Mr G. Gavelin It might be relevant to point out that the standard deviation obtained with moisture and basis weight gauges depends entirely on the time constants of the instruments. One cannot therefore compare one installation with another for improvements achieved.

Dr Sanborn Might I ask Mr Ström to repeat his figures with respect to the correction that he was able to achieve with his crown roll and whether the standard deviation was the term used to measure the variation of moisture across the profile.

Mr Ström With good basis weight profile management, we could reach about 65 per cent reduction in the sample standard deviation. With normal basis weight profile management, this reduction still reached 40 per cent. A typical value of the sample standard deviation, considered normal before control at an average moisture content of 7 per cent, is 0·30 per cent moisture (peak-to-peak value 1·50 per cent).

Mr L. D. Edenborough Although not pretending to understand all Mr Ström's mathematics, his techniques have obviously led to some useful results. I would raise some queries on the basic measurements and consider the factors that affect the profile obtained from a traversing instrument. If the instrument has a finite head width, a finite time constant and it traverses the sheet at a finite speed, the read-out is not the same as the actual variability of the paper over which the head has travelled. How does one establish the criteria by which these three variables are chosen, also has any work been done to correlate the profile results to gravimetric determinations on the paper scanned?

Mr Ström The time constant of the instrument was 1s, the distance in time between two measuring points was 2 s, so the shift to nearby points is not very large. The measuring window diameter is 60 mm. What we actually want is not a diagonal profile, but a measure of the stable cross-machine variation with one single profile.

The Chairman We are moving into an area thoroughly debated in the literature over the past 12 years. Whereas we must readily admit that scanning gauges with their finite time constants and scanning areas introduce complexities into the measurements, they are the only means on the machines for our purpose and they have a value that overrides their limitations.

Dr M. Judt Allow me to revert to Mr Hoath's question—have papermaking systems been changed under the impact of computer process control?

At Feldmuehle AG., a process control group was founded eight years ago and, together with the central engineering department and some mill managers, a number of rules were laid down that were adhered to when rebuilding and modernising existing papermachines, especially when designing completely new systems.

Some of the rules were—

1. Never return whitewater from the papermill to the groundwood mill.
2. When using sedimentation savealls, return the reclaimed stock continuously to pulpers for broke and pulp.
3. Create independent broke systems—
   (*a*) Treat coated and uncoated broke separately.
   (*b*) Thicken broke before returning to storage chest.
   (*c*) Never put broke into, say, groundwood or pulp chests.
4. Eliminate machine chests by installing continuous stock metering systems, paddle or magnetic flow meters and feed the furnish straight into the inlet of the fan pumps.
5. Build small wire pits and de-aerate the stock.
6. Try continuous mixing of coating colours when using all synthetic binder combinations.

Such rules helped tremendously to reduce dead times and interdependencies between, say, papermill and groundwood mill or broke department. I want to stress that you have to start rather early modifying your machines in order to make them easier to be put on computer control.

Feldmuehle's approach to computer control of a papermachine was quite different from what we have heard so far. I want to give Mr Mardon the assurance that he is not alone in his thinking. For three years, we have a 'hot' process control computer system working at our Reisholz mill. There, we try to achieve perfect production, low waste, excellent quality, which now and then occurs for a few days. We want to have this state of the machine for the total month, giving operators and foreman the information back from the ideal state all the time. I think you call this supervisory control. This approach was very successful. The operators and production management fixed their own targets and the variance per target. Deviations are printed out in red and action is demanded. There were no psychological problems in this mill; on the contrary, there is a waiting list now of Feldmuehle mills that would like to go into computer process control with their machines on similar lines.