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CONTROLLABILITY OF PAPER MAKING

H. Karlsson and L. Eriksson
Swedish Pulp and Paper Research Institute, STFI,
P.O. Box 5604, S-114 86 Stockholm, Sweden

ABSTRACT

This paper discusses the controllability of paper making. We have chosen to take a broad view on the subject. With such an approach, there are four major factors that can contribute to the over-all controllability, viz.: the process with its actuators, the measurement possibilities (sensors), the information technology and, not the least, the humans involved in the paper making operation.

In the introduction to this paper, we try to put controllability in perspective. In order to make our following discussion less abstract, we then describe three cases related to controllability in which STFI has been involved. The first deals with CD-control; the second with closed-loop quality control; the third with wet-end/retention control. Following these cases, we then discuss the four above-mentioned components that contribute to controllability and we conclude by indicating where we believe the major development needs and opportunities lie, viz.:

- we still lack essential controllability due to inadequate process design.

- new measurement possibilities are essential in order to improve the observability and thereby controllability.

- the human organization has a key role in controllability. Full automation is utopia. The operators have an increasingly difficult task. Their motivation is important.

- knowledge-based systems is an interesting area. Such systems can be of great value, but much development work is still needed.

- it is important to increase the fundamental knowledge of paper making and to establish the knowledge in such a way that it can be used for better control.

Keywords: control, paper making, paper properties, processes, sensors, information systems, human factors.

"How could such richness, such unpredictability - such chaos - arise from a simple deterministic system"
James Gleick in a review book on the science of chaotic systems.

Paper making - both controllable and chaotic?

Paper production obeys physical and chemical laws and therefore represents a deterministic system. Clearly, paper production is also controllable - for most of the time a paper machine produces useful products. But not all the time. So, the issue is the degree of controllability and this is what we want to discuss in this review of the topic.

In recent years "chaos" has become a popular topic. The "Butterfly-effect" is by now famous. It says that a butterfly stirring the air today in Beijing can transform storm systems next month in New York. The idea is that certain systems are so sensitive to minute variations in initial conditions, that - although in principle predictable - they are in reality unpredictable. In other words, they are not controllable. Does paper making represent a chaotic system? The answer is clearly not yes; paper making is to a significant degree controllable. Still, there are elements of what can be experienced as chaotic behaviour. For example, it can not be ruled out that subtle, undetectable changes in wood chip quality, can give rise to unexplainable effects on paper quality (a butterfly effect). On the micro scale, we certainly deal with true chaotic systems in paper making - turbulence being a good example. There are also other types of seemingly unpredictable behaviour in paper making (for example web breaks). So, the operators may often feel they don't have complete control over the system due to insufficient knowledge, lack of information etc. Thus, they may sometimes feel they deal with a chaotic system.

With this prelude, we want to reiterate the obvious point that the paper making is by no means simple - practically or theoretically. The paper making system actually contains elements which make it both deterministic and chaotic.

Why control and thus controllability?

The major part of this symposium deals with the fundamental physical and chemical behaviour of the various unit processes. With this paper we wish to emphasize that paper making is the integrated behaviour of not only these unit processes, but also of human beings and computer support. It is this whole system that must be under control.

It is selfevident that paper of good quality cannot be produced without measurement and control. The purpose of control is primarily to control quality (level and variability) and to control production efficiency (use of raw materials, up-time etc). Optimum for the total system very seldom means maximizing the different subtargets. For example, several different "quality" parameters must be maintained within relatively narrow ranges for each specific type of paper. Still, all these quality parameters cannot be maximized - compromises must be made.

What is meant by controllability?

In the literature on control, the term controllability is defined in mathematical terms and this was done relatively recently in 1960. In a more general sense, controllability can be viewed as 1) the ability of a system (process, actuators etc) and its support systems (operators, control systems etc) to stay within given quality and cost specifications when time variations in the system occur, e.g. due to variations in raw materials or to wear or 2) as the ability of a system to shift from one equilibrium to another (quality change). Another important aspect of controllability is how quickly control actions can be excecuted.

An interesting question is of course how we rate our present paper making systems in this context. In this paper we will argue that controllability can be much improved. At the same time it should be said that great progress has been made in recent years.

A general trend in recent years has been the increased market demands on product quality. At the same time, process systems have been pushed to their limits (e.g. speed) and they are built with tighter specifications to reduce investment costs. This lowers the ability of the process to tolerate deviations and demands very close control even if the controllability actually becomes lower. Do we presently have the necessary tools to cope with this? We will try to answer this important question.

Views on quality control

The quality control target can be seen as a box in a multi-dimensional space, where each axis represents one important quality parameter. Inside this box the quality is accepted and one specific point represents the optimum. When the system drifts away from this optimum, and especially when there are risks to end up outside the box, corrective control actions are taken. This can lead to decreased production efficiency. As examples, more energy is used for refining, more reinforcement pulp is added, more pigments are added, more retention aids are added, the machine speed is lowered etc.

For the individual paper machine, where the level of quality (market niche) has been chosen, the prime object of quality control is less variations. At this point we want to place the concepts of "quality" and of "even quality" in a control perspective. In Table 1 we have listed some quality properties and dimensional scales of importance to the converter or to the end user. We can conclude that many of the properties that affect print quality (e.g. pin holes, mottling) or web break tendency lie in the range less (or much less) than 1 x 1 cm^2. Almost no end products represent surface areas larger than 0.1 - 1 m^2 (a sheet of copy paper, a tissue napkin, a newspaper, a food package). So if we want to talk of true quality control, important quality targets lie at these dimensions.

QUALITY PARAMETER	SIZE SCALE
Pin-holes	0.1 x 0.1 mm^2
Contour sharpness	
Wire marks	
Specks	
Fish-eyes	
Napping/Picking	
Creaseability	
Mottling	
Gloss variations	
Ply bond/Blistering	1 x 1 cm^2
Bending stiffness	10 x 10 cm^2
Curl	
Dimensional stability	1 x 1 m^2
Roll quality[1)]	10 x 10 000 m^2

1) (tension, sheet length, wrinkles etc)

Table 1. Examples of paper quality from the user's point-of-view and the typical paper size determining this quality (cf Fig 1).

Ideally, if the process is not inherently able to produce even quality on these dimensions, we would wish to assert controllability. What is the present situation? Fig. 1 tries to illustrate this. We can conclude that there is a wide range of variations that can presently neither be observed, nor reached by corrective control actions. The advantage in measuring things like gloss, formation and strength on machine as compared to in the lab is obvious.

If loss of quality is not to occur too frequently, the machine design must be such that certain definciencies (pin-holes, specks, wire marks) are minimized. Major sources for variations in paper quality at dimensions that cannot yet be reached by control are:

- non-perfect consistency control of approach systems to the paper machine,

- non-ideal retention and formation

- machine clothing (which cannot be manufactured with a perfectly smooth surface since it must also allow dewatering)

It might be remarked, that surface treatment (e.g. calendering and coating) is a way to improve quality despite certain deficiencies in the base paper.

Control situations

Four major control situations can be defined:

1. The system is in reasonable equilibrium and the control purpose is to keep it there in an optimal way. Besides this, the support systems should occupy themselves with preactive control, i.e. to watch for long term drifts etc. It is important to keep the operators alert under these rather passive conditions.

2. The system is brought from one equilibrium to another (e.g. a grade change or a start-up). The purpose of the control is to execute this change as efficiently and safely as possible. This active control usually requires full attention from the operators. Generally, control algorithms for these step-wise changes are not so well developed as for the equilibirum situation.

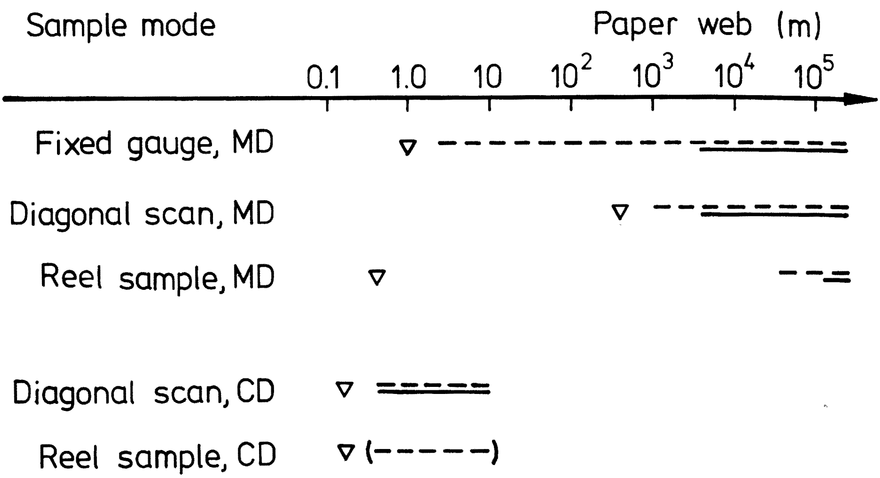

Fig. 1 Schematic picture of present observability and controllability in paper making. ∇ depicts typical sample size, ---- depicts areas for observable variations, —— depicts areas which can be controlled based on the sampling.

Comments:

- A fixed position MD sensor is seldom used. Down to 1 meter can be sampled. The dead-time of the process limits the controllability.

- with diagonal scan, the MD-range below 300 m is never analysed.

- An MD-reel sample can only control disturbancies on the level of several hours. A single sample can be very misleading and lead to erroneous control actions (due to so called aliasing). An MD reel sample can of course have smaller size than indicated.

- The CD reel sample has been set equal to the distance between slice-screws. A reel sample is seldom used for CD-measurement, but can for example give information about CD-mechanical properties. Presently, control based on CD reel sampling is essentially lacking.

3. The system is off equilibrium due to some kind of disturbance. The control purpose is then to bring the system back to equilibrium as quickly as possible. This situation requires high attention from the operators. The disturbance may very well be so significant that one is outside the range of the regular control algorithms. If the situation is not handled well, a stop is likely.

4. The system is exposed to a new situation. This can mean to produce a new paper quality or the introduction of some new technology (i.e. process equipment or chemical addition).

In general we can say that the majority of computer control so far has dealt with situation 1. One simple reason is probably that situations 2 and 3 are much more difficult to deal with. However, since the greatest profits are made on "the marginal tons", situations 2 and 3 are important. Introduction of new paper qualities and of equipment that upgrades capacity make situation 4 extremely important.

Factors influencing controllability

The object of this paper is to discuss the degree of controllability of paper making. Although one approach could be to analyse how well we are currently able to control each individual unit process or subsystem in the paper making process, we have chosen to take a broader approach. In the more general meaning of the word that we wish to adopt here, the following factors (cf. Fig. 2) can contribute to the controllability of the paper making system:

- the process system as it is designed and maintained. We consider the various types of actuators installed to execute control actions as part of the process system.

- the measurement facilities providing data from the process system, the material flows and the product. This includes on-line as well as off-line (lab testing) measurements. Important here is the treatment given to measurement signals before they are used for control (filtering, averaging etc).

- the computer based systems that directly or indirectly control the process and other types of systems based on information technology that assist the human resources in controlling the process.

- the human resources (especially the operators)

We may also remark, that the variability of the properties of the material flows (particularly the pulp) entering the paper making process is of importance. Large variations call for high degree of controllability. For this reason, all measures to decrease such variations (e.g. in the pulp mill) are essential.

A further comment is, that much of what we do today is based on empirical knowledge. Improved fundamental knowledge of the paper making process is important if we are to advance in the area of controllability. This is important for process design, for the understanding of the process by the operators, for the development of mathematical models used for simulation and control etc.

Before discussing the aspects mentioned above in more detail, we will describe three actual cases in which STFI has been involved. They illustrate the various aspects of controllability identified above.

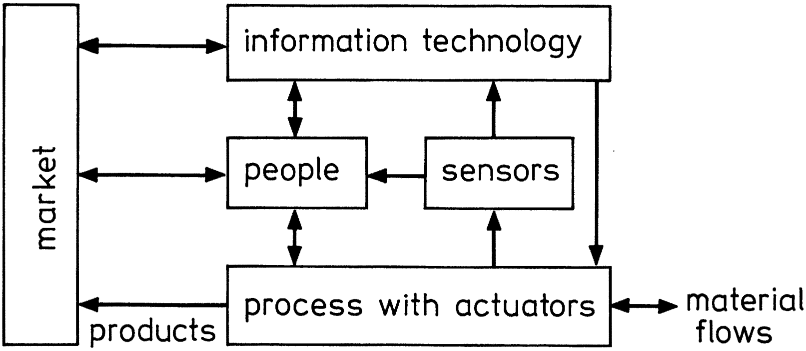

Fig. 2 Schematics of the interrelating factors of importance for controllability (in the over-all sense).

Case 1: CD-control of dry weight

STFI has long been heavily involved in CD-control. We have developed an algorithm for CD-control of dry weight and implemented CD-control systems in mills. When the work started during the 1970's, it was concentrated on fourdrinier machines having low headbox consistencies. Through discussions with the operators, we learned how difficult it was to predict the effect on dry-weight profile from slice-screw adjustments. Adjustments in one position often resulted in changes in another. There were many times where the profile actually deteriorated after making adjustments. The system behaviour appeared chaotic because the effect of a slice-screw adjustment was not precisely known (the limits of controllability were not known). However, closer scrutiny showed that it was possible to understand in quantitative terms the phenomena involved. We established the detailed response of dry-weight distribution on the wire when one slice-screw was adjusted. Process models suitable for control were developed and in 1979, control trials utilizing such models were made on a commercial paper machine with good results.

It is interesting to note that as recently as the mid 1970's, paper makers had not established detailed knowledge of what really happens to the dry weight profile when one slice screw is adjusted. Only when data were needed that could be used for control, was such quantitative knowledge established by the control engineers.

Investments in CD-control through slice adjustments have increased dramatically during the eighties. Why did it not happen earlier? At an early stage in MD-control, it was already evident that approximately 50% of the dry-weight variations were CD-variations. It was also clear that the existing traversing gauges could be used as part of computer based CD-control. Maybe the market did not really ask for more even profiles? Maybe good profiles became a competitive factor only when one producer had found that dramatically better CD-control could be achieved? Evidently, once the barrier was broken and it became a new product for the control systems suppliers, the change came very quickly. Today, virtually every paper machine has automtic CD-control.

In this context it is interesting to note that the slow response of the paper machine manufacturers in recognizing the market potential for automatic CD-control allowed a new segment of suppliers to gain a foothold.

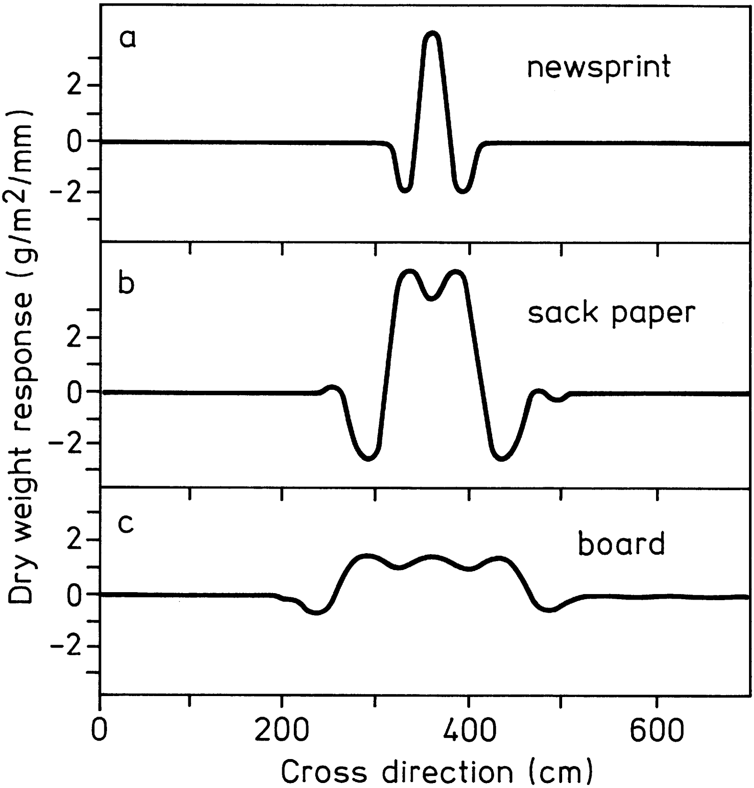

Fig. 3 Examples of responses in dry-weight profile, following a unit change upwards of the slice lip in one slice-screw position. All examples refer to fourdrinier machines. It should be observed that in case c, the response extends over half the total width of the machine.

The result which can be obtained from a slice-lip control system for dry weight obviously depends on the controllability of the process, i.e. how the process reacts to changes in the control variables. We view the CD-profile as composed of a spectrum of disturbances - from over-all scewness to streaks. The response in dry weight which results when a unit change is made in a single slice-screw is usually termed the dry-weight response. The extension and amplitude of this response determines the controllability. If the response is narrow (cf Fig. 3a), as for a fast, twin-wire machine, then the controllability is usually good. If the response is broad (cf Fig. 3c), the controllability becomes worse from the process point of view and it is very difficult to control relatively narrow CD-variations. For a slow fourdrinier board machine with low head-box consistency, the controllability can be quite limited. This situation places high demands on the control system if it is to contribute anything.

Another limitation in controllability that we have observed arises when the width of the response (measured at half height) is smaller than the distance between two slice-screws. This becomes a problem for the machine manufacturer to solve. The current trend is to decrease the slice-screw spacing and today, spacings down to 75 mm are delivered compared to the 150 mm spacing common only a few years ago.

So depending on the situation, the controllability of the dry-weight profile varies significantly. We must remark, however, that for most paper grades, dramatic improvements in CD-profiles have been obtained. Certain profile errors will, however, remain even after CD-control is applied. It is important to identify and correct the causes for such residual variations.

Fig. 4a shows a CD-profile in dry weight from a machine with a well-functioning slice control system. All variations that can be controlled through slice adjustments have been removed, but some still remain. These residual variations were very stable over months. Most of the variations in the middle part of the profile were found to originate from the fixed lower lip and were eventually eliminated. The over-all variations could also be minimized by adjusting the jet geometry. The final result is shown in Fig. 4b.

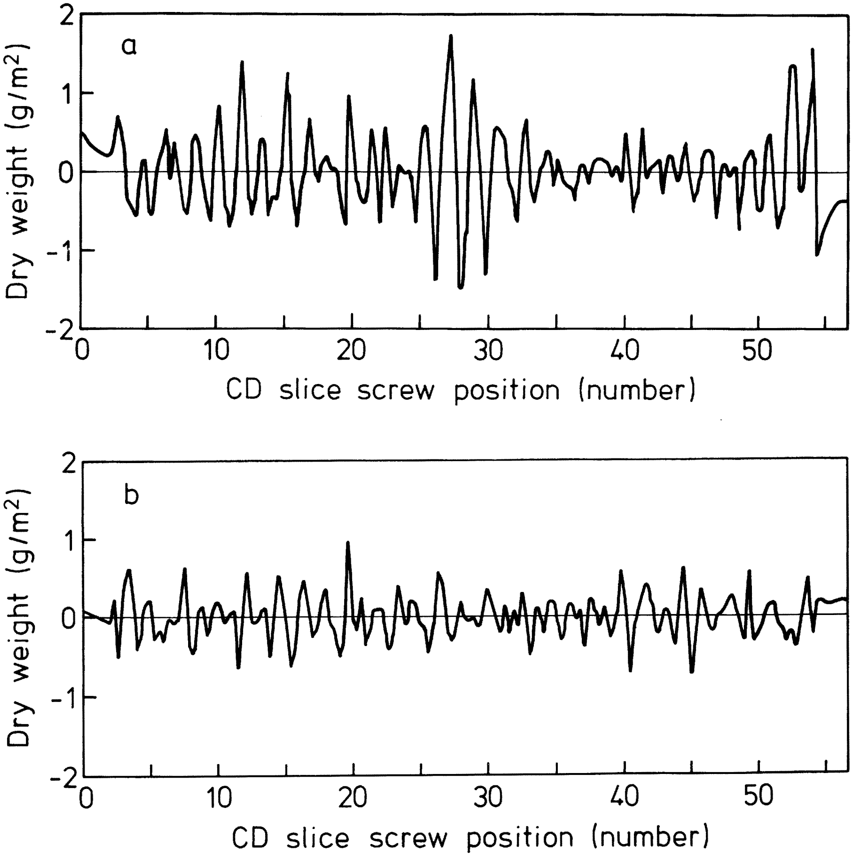

Fig. 4 Curve a. gives an example of residual cross-machine variations in dry-weight, after that a well-functioning CD-control system has minimized the variations. Curve b. shows the final variations after that some process adjustments were made (lower lip, jet geometry).

A prerequisite for good CD-control is of course that the profile can be measured with high accuracy and cross-machine resolution. A complicating factor here is that we do not have a true CD-measurement with today's traversing gauges. Instead, the composite signal is broken into its MD and CD components using statistical computations.

The effect of measurement resolution is illustrated in Fig. 5. The difficulty in controlling narrow streaks is clearly demonstrated. It can be remarked that if a resolution according to curve (a) was applied to the data of Fig. 4a, then the variations shown would be completely obscured, i.e. the existance of these variations would never be detected. If the operator is to know the true CD-variations, it is important not to filter the data in such a way that the variations disappear. At the very least, it is important to use high resolution measurements when control actions are calculated. It is important here to obey the sampling-theorem, which means that a signal must be sampled at least at twice the frequency one wants to control.

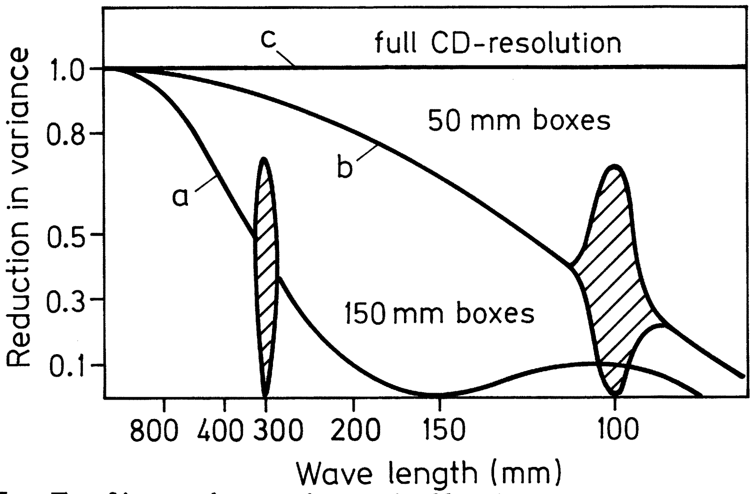

Fig. 5 The figure shows, theoretically, how the variance in the CD direction signal can be reduced as a function of wave-length of the disturbance and of applied filtering, in this case referred to as the width over which the measurement signal is averaged (databox). The appearance of two curves at wave lengths 300 and 100 mm is a result of a phase phenomenon. As an example, for 150 mm resolution, a 50 % reduction would be obtained for wave lengths of 350 mm.

Fig. 6 shows control results that have been achieved when CD-weight control was introduced in stages on a 60 g/m^2 fine-paper machine. In this case, an extensive effort was made to characterize the typical (average) variations in dry-weight profile under the different conditions. The different curves depict:

(a) manual adjustments of the slice screws (before model-based control)

(b) after installation of a CD-control system with manual adjustments of the slice screws based on computer recommendations (i.e. computer-assisted manual control)

(c) after rebuild of the machine, when the number of slice-screws was increased from 46 to 56

(d) after installation of step motors to execute automatic control.

It can be noted that the greatest improvement was obtained when going from (a) to (b). We interpret this to mean that it was more important to execute the correct actions than to do them often. This is because CD-control is mainly a control of variations in space, which variations are usually rather stable with time. Going from (b) to (c) also represents a significant improvement in the wave-length region around 300 mm.

From a controllability point of view, this case demonstrates the following:

- initially neither the paper machine nor the measurement system were adequate enough for good CD-control of dry-weight. As a result of the CD-control efforts, large improvements have now been made.

- the operators alone are not able to perform a sufficiently good CD-control. Support from a computer-based control system is needed. The major reason for this is the complicated behaviour of the furnish on the wire and the complicated response to slice adjustments.

- the control requirements demanded more precise "knowledge" of the flow conditions on the wire.

- there will always be CD-variations that cannot (and should not) be adjusted by a CD-control system but should be corrected by other means.

- the response in basis weight to slice-screw adjustments varies a lot from case to case (and even on the same machine).

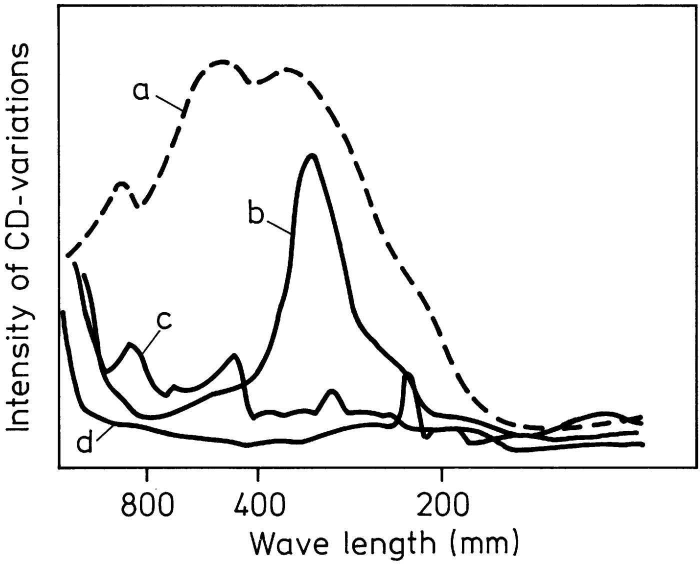

Fig. 6 Results from the gradual implementation of CD dry-weight control on a large fine-paper machine (dry weight 60 g/m^2). Shown are mean autospectra, where the intensity in CD-variations is plotted against wave length.

a. Before, i.e under manual control, 46 slice screws

b. With a control system recommending slice adjustments to the operator, 46 slice screws

c. Same as b. with number of screws increased to 56

d. Same as c. but with automatic slice-screw adjustments.

Case 2: Integrated quality control

When paper properties vary in an unexpected and unexplainable way, the blame is often conveniently placed on the pulp mill. At STFI we have during many years worked with techniques (primarily optical) to make on-line measurements of important pulp properties such as fiber length, fiber diameter, kappa-number, crill content and more. Two important applications were foreseen. One was to first establish how pulp properties vary and then use such information for feed-back control of the pulp manufacture. The other application foreseen was to investigate the possibility of predicting final paper properties from measurements of the pulp furnish. If so, a new dimension in the controllability of paper making would be opened.

As part of this effort, we carried out a project in a sack-paper operation, where an on-line measurement system for pulp quality was installed with the aim to establish pulp quality variations and to investigate the possibilities for integrated quality control. An important aspect of this research effort was to determine if better control of the refining process (HC- and LC-refiners were employed) could be used to compensate for pulp quality variations (strength potential). We also wanted to investigate the possibility for energy saving in refining. With integrated quality control we meant the use of pulp quality measurements and paper quality measurements on-line and in the laboratory to control paper quality using the refiners as actuators.

We found that the pulp had great variability (cf Fig 7), mainly originating from the continuous digester. We have found that the continuous digester is a good example of a process with poor controllability. Additionally, the measurement of pulp fiber dimensions revealed significant variations. These variations originated from the method of mixing in the saw-mill chips at the woodyard. A complex pattern in pulp quality variations was discovered which precluded a simple feed-forward control of the specific energy in the refiners based on kappa number variations.

It was eventually possible to establish diagrams (cf Fig. 8) showing, for a given incoming pulp-quality level, the relations between tensile energy absorption index, air resistance and specific energy in the HC- and LC-refiners respectively. If, in such a diagram quality limits on tensile energy absorption index and air resistance are introduced (Fig. 8c), an area of accepted quality can be defined.

As can be seen, control of the specific energy in the LC-refiners affects air resistance significantly (Fig. 8a) as well as tensile energy absorption index (Fig. 8b). HC-refining gives an extra control function, by mainly affecting the tensile energy absorption index (Fig. 8a).

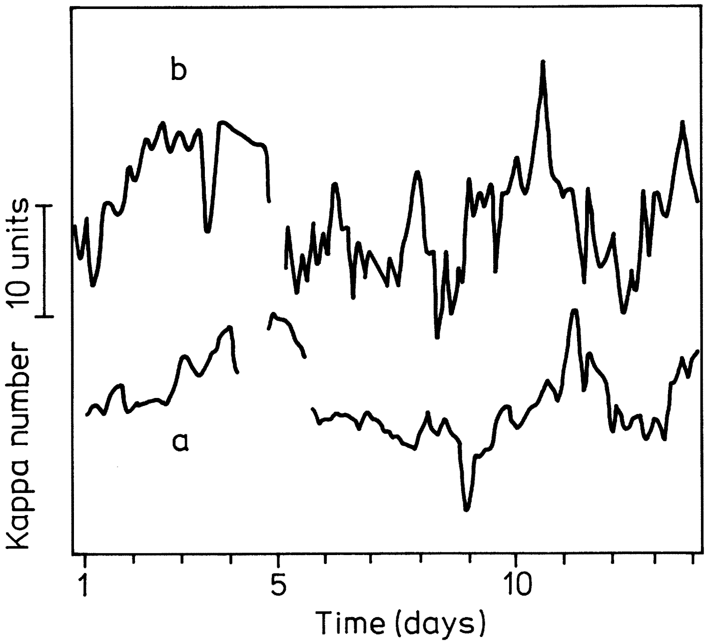

Fig. 7 On-line measurements of kappa number in an integrated sack-paper mill. Curve b. shows variations measured in the pulp mill. Curve a. shows measurements immediately before refining. The curves have not been shifted to take care of the time delay. Note that in curve a. the variations are somewhat dampened due to mixing.

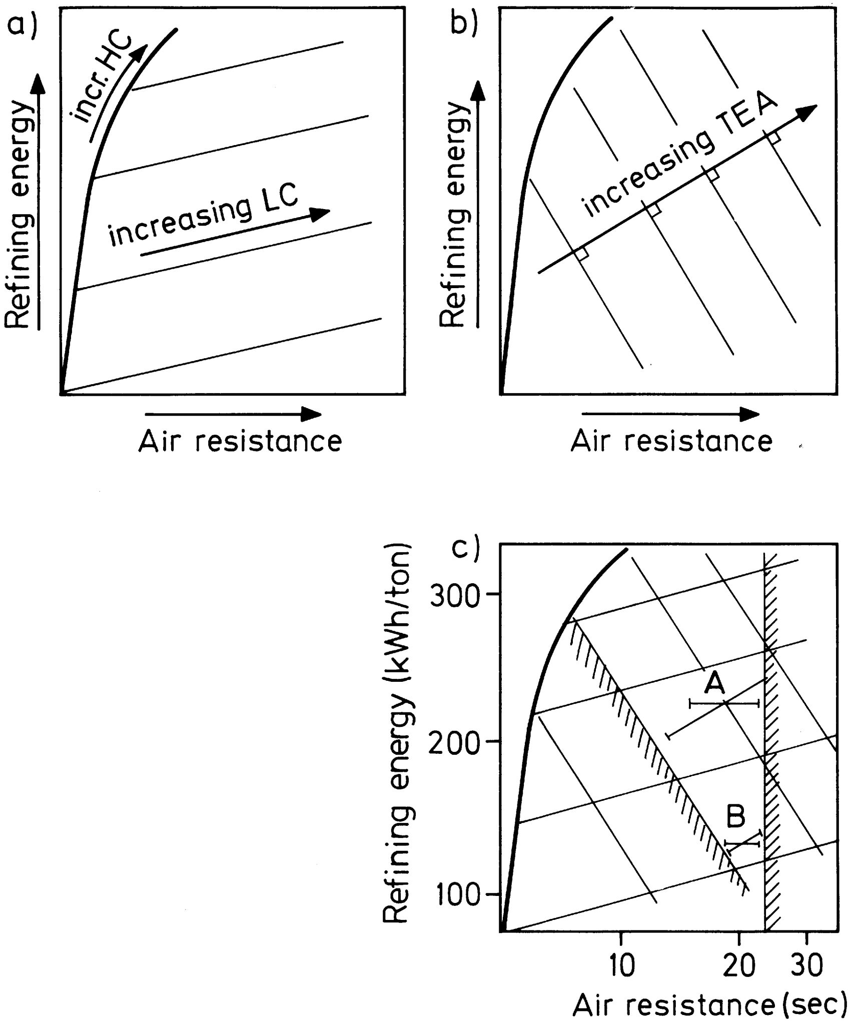

Fig. 8a The principal relation between refining energy and air resistance when a combined HC and LC treatment is applied.

Fig. 8b Isocurves for tensile energy absorption index (TEA) introduced into the diagram according to Fig. 8a.

Fig. 8c This diagram applies the principles of Fig. 8a and b in a real case. In the figure are introduced the quality limits for air resistance and tensile energy absorption index. Points A and B represent different target points for control.

The error bars in Fig. 8c indicate the safety margins. With large variations in tensile energy absorption index and air resistance, large safety margins (A) are required. If these variations can be reduced through better control, then less margins are needed (B) and significantly less total specific energy required. Therefore, if closer control of quality parameters can be achieved optimization becomes possible. In this particular example, the energy input can be balanced against quality data. In another situation, a balance against production rate might be relevant. It should be remembered that the situation depicted in Fig. 8c is "dynamic", i.e. it depends on the potential of the pulp to develop strength. Therefore a good control system must take changing pulp quality into account.

A control philosophy was built up where the air resistance was controlled mainly through the LC-stage and the tensile energy absorption index through the HC-stage.

An air resistance control loop was built to compensate for the pulp variations. Here the measurement of kappa number, fiber diameter and freeness was used to control the LC-stage and the signal from an on-line porosity gauge was used for feed-back control. The porosity gauge was calibrated against laboratory determinations, carried out once per reel. This control scheme lowered porosity variations by 50 %.

A similar approach was applied to the control of tensile energy absorption index, and was shown to significantly reduce the variations. Here, the HC-stage was controlled through a statistical model based on pulp quality measurements and with feed-back from laboratory data.

Because of non-linearity, the variation in tensile energy absorption index from the HC-stage diminishes as the energy input increases. This offers a way to deemphasize the effect of varying pulp quality in situations when the means do not exist for a closer control of the type indicated in this case. The advantage of a high energy input in the HC-stage is a certain degree of self-stabilization, thus compensating for lack of controllability. The sacrifice is of course that more energy is used.

Which of the two control strategies is best, must be determined for the particular case. Clearly, if the operators have to control the process without the tools just mentioned, they tend to use the most stable approach - at the expense of energy cost. So, here we have an example of a choice between stability and controllability.

Because the disturbance patterns in the pulp furnish were so complicated, much work was done to develop statistical models predicting paper propertis from fiber data emanating from the pulp quality measurements. For example, a model predicting porosity was developed and then integrated into the control loop described earlier. Fig. 9 compares predicted and actual values from one such model.

These empirical statistical models have the limitation of being valid only for the particular mill system studied. In the future it would be desirable to use more general models, which are based on fundamental principles. We think sufficient knowledge is presently lacking to produce such fundamental models. In fact, it is doubtful if enough knowledge exists concerning the relationships between furnish parameters and parameters describing the finished paper to even specify the on-line sensors required for an effective control.

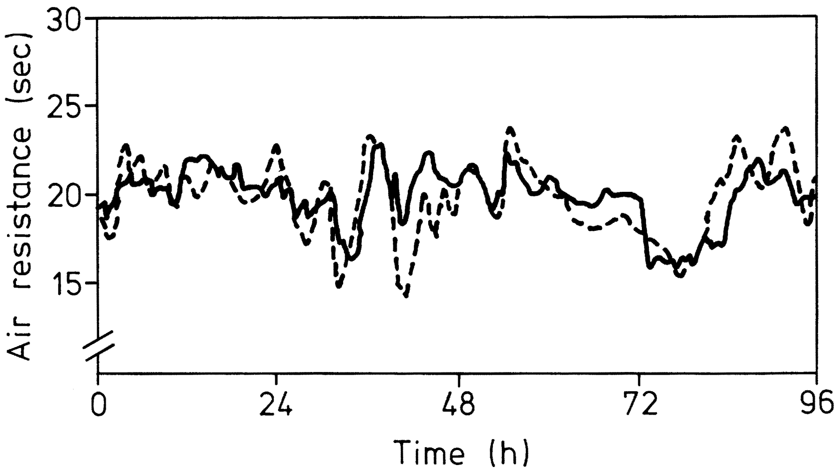

Fig. 9 Air resistance data for sack paper. Comparison between model prediction (——) and data from reel testing (---). The model uses measurements of freeness, fiber diameter and kappa number of the furnish.

From a controllability point of view, the case discussed above illustrates the following:

- the new sensors yielded previously unknown information about disturbances in pulp quality thus helping trace their causes.

- through the process knowledge gained, it was possible to establish a control of the refining operation with the end-product quality as target. This control also took variations in pulp properties into account. The controllability obtained opened the way for optimization and energy savings.

- refining is a controllable process, but possess a difficulty in that several paper properties are affected simultaneously. In this particular case, HC-refiners presented an additional possibility to increase the controllability, since they mainly affected the tensile energy absorption index.

- it was possible to develop empirical models that could predict variations in paper quality and which could be used for control. These models should be improved, however, and preferably be based on a better fundamental knowledge.

Case 3: Wet-end and retention control

Many important properties of the finished paper are established in the wet-end system. It is therefore of great importance to understand and control the chemistry of this system. This field is becoming more important with increased use of fillers and chemicals. The retention on the wire and in white-water cleaning is intimately dependent on the wet-end chemistry. Retention is also influenced by the forming metod, the head-box consistency and the basis weight. When speaking of retention, we are not only interested in paper fibres, but also of fines, fillers, dissolved and collodial substances. The chemistry in the wet-end is also influenced by broke addition, strength additives, size, slime etc.

So, the wet end is no doubt a complicated system with strong feed-back coupling. The system also contains time lags and mixing volumes. The consequencies of a disturbance or an intentional change in this system are not easy to foresee and control. Obviously, better means of monitoring the system must be at hand if the controllability is to be improved. In order to achieve this, certain items must be monitored like ionic strengths, conductivity and pH. In order to characterize the wet-end charge conditions (which are important for formation and retention) the z-potential, streaming potential and titration of cationic demand are often utilized. With some exceptions, many of the methods just mentioned are used only in a laboratory mode. However, several developments of on-line sensors are in progress.

One such area for development is on-line sensors for measurement of fiber and filler retention and of fiber and filler consistencies in the head-box and white water. STFI has developed a system, proven in several commercial installations, which is able to separately measure the consistency of fibers and fillers. This equipment is based on a combination of an optical sensor (which is sensitive only to fibers and not to fillers) and a density gauge (which measures total consistency). Thus, when the fiber consistency is known, the filler consistency can be calculated. The system compensates for the contribution to total consistency of dissolved organics. Compared to optical sensing of the fillers, as in other systems, the density gauge has the advantage of being independent of the light scattering properties of the fillers (which can vary with size distribution, shape, type etc). Also, the density gauge is independent of the flocculation stage of the fillers.

In this example, we wish to present observations made when using this sensor to monitor retention and to make other wet-end studies. We found many examples of how the concentrations of fibers and fillers in the short circulation affected the papermachine runnability. For example, measurement of ash in the finished paper does not address the important subject of filler content in the short circulation. At low retention, high contents of filler build up in the short circulation loop and if the retention for some reason suddenly increases, the filler content in the paper will also increase quickly, possibly causing a web break.

We have found that by monitoring variations in consistency and retention, we can dramatically increase the chances of following changes in the wet-end chemistry and to understand relations between different parameters. Such knowledge greatly increases controllability. Fig. 10 shows an example of how changes in pH, basis weight, wire speed and dosage of retention aid influence filler retention measured on-line on a fine paper machine. Certain changes are quite rapid. It was obvious from speaking to personnel in the mill, that these detailed on-line measurements of filler retention revealed process interdependences that were not apparent to them.

Fig. 10 clearly demonstrates the predominating effect of pH-variations on filler retention. The study showed that different types of disturbances could cause moderate pH-variations which influenced filler retention to an extent that an effort to control it through retention aids would be ineffective. It was therefore necessary to first introduce better control of the pH, something we have seen on many other machines.

Once the wet-end system has been stabilized (e.g. pH-control) and process studies have been performed, it is possible to begin controlling retention and to find out which retention level gives the best quality and runnability. In our own work, we are approximately in this position, and control projects are presently being conducted.

From a controllability point of view, this case demonstrates the following:

- new knowledge was established through process analysis. In this case a new sensor was needed to yield enough information.

- pH-control of the wet-end is a key factor for further wet-end and retention control.

- there is a need to make better knowledge available to the operators - the system is very complex.

- reliable instrumentation exists to make on-line measurements of fibre and filler retention and consistencies.

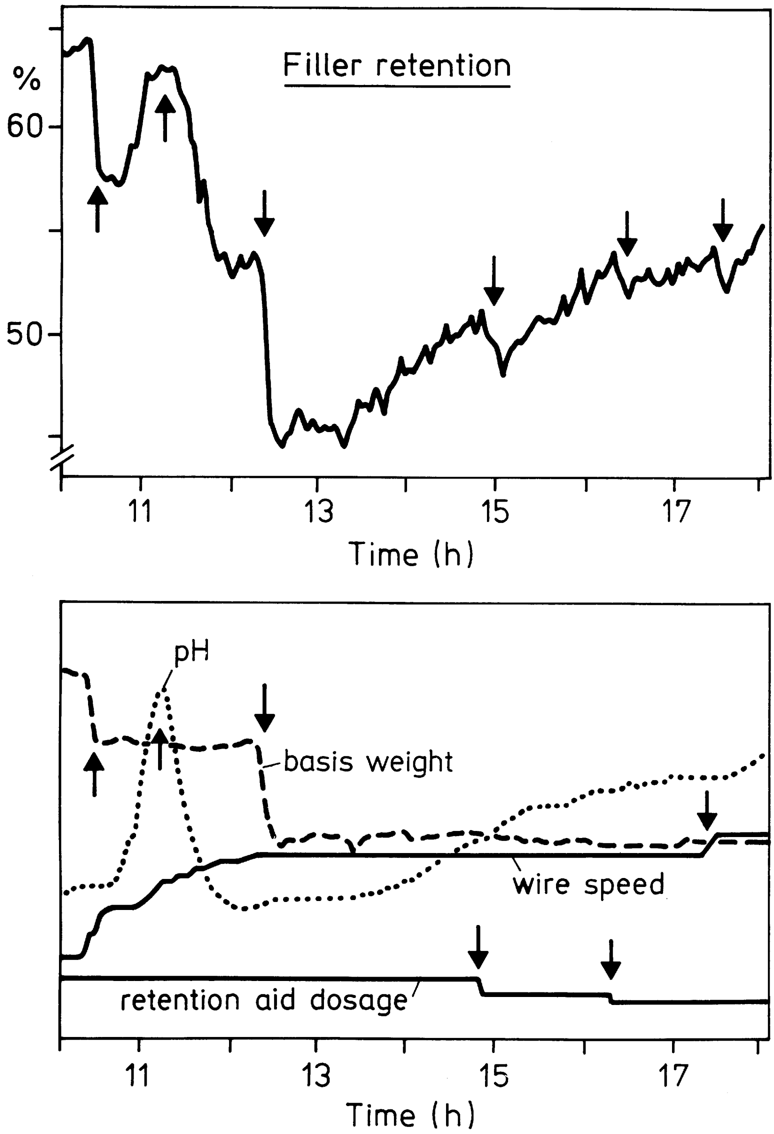

Fig. 10 Data obtained with the STFI retention sensor on a fine-paper machine. The figure shows how filler retention is influenced, besides by pH, also by basis-weight, wire speed and dosage of retention aid.

THE PROCESS

After having described three cases with relevance for our discussion on controllability, we now return to the more general discussion. We have earlier (cf Fig 2) identified the major factors contributing to controllability and we now start to discuss the first of these, viz. the process and its actuators. We will carry out this discussion in a rather general way.

The paper-machine system is obviously the key to controlled paper making. We can conclude, that paper making today is a highly technological operation, where market demands on quality are steadily increasing and where efficiency demands have also increased. This progress has been achieved mainly through:

- the application of computer control systems
- the application of actuators, particularly for cross-direction control
- process developments, including surface treatments and machine clothing
- changes in furnish composition

Recently, the process developments in paper making have advanced at a significantly higher rate. Still, these developments have not significantly changed the process and it cannot, as an over-all judgement, be claimed that the observability or the controllability of process equipment have really improved. As described below, our possibilities for CD control have, however, undoubtedly increased in essential aspects.

If we look back 15-20 years, many viewed lack of control as a failure by the paper maker. These people felt that deficiencies in the system should not be "controlled away", but that the system should be designed to be inherently perfect. This thinking is now out-dated but we still live with some of its consequences (e.g. in terms of equipment not designed to be controllable). Today, the accepted view is that the paper making system is so complex that computer control is a necessity. The need for control is enhanced by the fact that the process is subjected to time variations through wear and through variations in incoming raw materials.

If a system is to be controlled, it must have observability (through sensors and humans) and it must have controllability (through actuators or self-adjustment). It must also be designed and furnished with raw materials in such away that control is at all meaningful. Our intention here is not to analyze the different parts of the paper-making process in detail with respect to controllability (and observability) but instead to make some more general statements.

In the past, the paper making process was not designed with controllability in mind. This was realistic, because at the time tools for close control did not exist, so it was better to design for stability (cf Case 2). However, when the need for closer control became obvious in the 1970's, the major equipment suppliers appeared slow in adapting to these needs. This had the effect that in CD-control it was the suppliers of control systems and independent, smaller equipment manufacturers who furnished the paper machines with actuators.

In Case 2 we dealt with refining and touched upon the limitations in controllability that arise from the fact that several furnish or paper properties are simultaneously influenced by a particular actuator or by a particular process step. By combining two types of refiners - HC and LC - it was possible, in that case, to circumvent the problem of interactions reasonably well and to obtain quality control (tensile energy absorption index and air resistance). Another way of obtaining better quality controllability in refining would be to use, beside the energy input, a varying edge-load through varied rotational speed. One can then chose more fibrillation or a more cutting action. Today, the tackle must be changed if the nature of the refining is to be changed. A more flexible refining process like this should be even more interesting if suitable on-line measurement of the refining result was established.

Many head-boxes are now being delivered with closer slice-screw spacing and new head-boxes are now designed and equipped for CD-control at delivery. Process limitations related to the head-box can be found in multi-layer formation, where there is no possibility to effectively control the basis weight of individual layers. If multi-layer forming with a single headbox was to emerge for more paper grades, we would have to temporarily accept that the individual layers can not be controlled (perhaps in MD if feed-forward consistency control could be improved).

The press section must be considered underdeveloped from the controllability point of view. First of all it influences several important paper qualities in an interrelated way (scientists still argue about the exact models for water removal and for its effect on final density). Secondly, the possibility for high resolution CD-control in the press section seems quite limited. Press-roll shells cannot be bent sharply enough; so called "zone-control" is extremely broadband. The development trend is perhaps even in the opposite direction. This underlines the importance of having an even profile before the press section. It can also be remarked, that the use of load scheduling in the press section in order to optimize the development of paper properties is not very well developed. Again, this goes back to our lack of fundamental understanding of the paper making operations.

Also the drying section is underdeveloped when it comes to quality control. It is well known that the paper mechanical properties are highly influenced in the drying section and that both MD- and CD-conditions are important. Increased controllability would thus call for a more sophisticated control of moisture and tension in both MD- and CD-direction through the dryer. The latter would, as an example, require means for restrained shrinkage in the CD-direction.

From a production efficiency point of view, there is a tendency towards closed draws which decreases the observability of the process. As an example, even if we had a sensor for dryness profile after the press section, there is no space for it. This illustrates a more general point, viz. that the trend today is to make the process less observable. Modern, twin-wire formers is another example och this.

From a more general point of view, increased consideration of controllability means that cross couplings between different process lines are avoided. Separate white-water systems for the paper machines is one example. Unnecessary residence-times in storage chests should be avoided, and so forth.

Our experience from quality control (Case 2) showed that proper managing of the wood raw material and pulp mixing is very important. Mixing raw materials is one way to create stable conditions, but from a controllability point of view it would be better to process quality-graded raw material which should then result in more even pulp properties and better paper quality.

If we return for a moment to Fig. 1, we concluded there, that there are still significant "islands" in the frequency domain that are not under quality control - particularly in the MD-direction. The major reason is of course the process design. One important restriction is the time lag in the machine between the head-box and the dry end. A secondary reason is lack of suitable sensors and the fact that sensors can not very well be introduced earlier in the machine.

A further restriction in controllability stems from the dynamics introduced through chest volumes. These volumes are largely there to stabilize the process (to compensate for lack of full controllability) and to make the process less sensitive to short term variations. As a result one has:

- increased the time needed for grade changes
- reduced the possibility to trace disturbancies backwards in the process
- reduced the possibility for the operators to learn and understand the process.

Some time constants are very long and one could argue that no response time should be longer than, say, 1/4 of a shift. Otherwise it will be difficult for the operator to learn from his own control actions.

Controllability is also a matter of actuators. The development in the CD-control field is exceptional and many new actuators have appeared. These actuators are introduced because of market demands on quality and because of the fact that the paper machine in itself is not able to fully control the properties. This is due to inherent deficiencies in the process but also to variations with time (wear, clogging, temperature effects, etc). These actuators are introduced also because of a need to de-couple the essential properties dry weight, moisture and caliper (final density). Unfortunately, many of the process steps affect more than one property (so also many actuators) and frequently the control goal is different for each property. The web edges are important in this respect, since the two paper rolls at the edges of the reel represent a significant part of the production. A special control strategy for the edges is worthwhile, because many of the over-all profile problems are actually associated with the edges. The edge control strategy must be carefully blended into the over-all profile strategy to avoid upsetting.

So we have to conclude that the CD-actuators are necessary tools to improve the controllability.

It must always be remembered that CD-actuators very often compensate or obscure other more fundamental deficiencies which should be solved in another way. Control through actuators can also lead to increased costs. If, for example, an actuator remoistures the web, it may also mean increased drying costs.

It should be observed, that correction of the dry-weight profile through adjustment of slice screws may mean that flows on the wire are redirected. This may have a negative effect on important paper qualities, since the fiber orientation is effected. Today's CD-control systems do not consider effects on mechanical (or optical) properties when adjusting for a better dry-weight profile. This is a field of development that should receive more attention in the future.

The fact that important paper properties are affected in many positions along the machine (and even in a way that is not fully understood even to the experts) and that a certain key parameter is often influenced by many different parameters, affects the controllability. An example of the latter was seen in Case 3, where filler retention was influenced not only by the retention aid but also by pH, basis weight and speed. The closing up of the systems has, of course, increased the complexibility from this point of view. Difficult dynamic behaviour can arise.

The problem that control actions tend to compensate for a problem rather than cure it, can be counteracted by more extensive diagnostic systems and by "on-line" process analysis. This is an area of great interest and importance and it will be discussed somewhat later. If this area is improved, it will undoubtedly increase the controllability of the paper making process.

When the process is stable, the task then is to handle smaller variations in order to maintain quality specifications. If the machine has a good basic design relative to the product one intends to produce, it is a good help. If not, one may have a situation where certain quality defects can never be coped with through control. If, for example, the forming unit has a tendency to produce pin-holes, it is not a problem that control systems should or can handle. If, as another example, the basic design results in poor retention, this might be improved through control (e.g. more advanced wet-end chemistry control). But such control may affect the formation or the dewatering properties. So, there will be a prize to pay for a deficient design.

When major grade changes are being made, at start-up or shutdown or when a sheet break is a fact, the requirements on controllability are large. If our industry is moving towards more "flexible production", "customer orientation", "just-in-time delivery", then this will call for good controllability in situations where the set points for the process are changed. This is an area where much remains to accomplish. Maybe, this situation should be considered more in future process design.

To sum up this section, we want to emphasize the following:

- generally speaking, recent development in process technology has not increased the observability and controllability of the paper making process. In fact the opposite has occurred.

- several CD-actuators (basis weight, moisture and caliper) have significantly contributed to increased controllability.

- since essential paper properties are influenced by the various unit processes in a complex way, one could wish for process developments that can circumvent this. Improvements here are probably dependent on a better fundamental understanding of the paper making process.

- systems design from controllability viewpoint is important (residence times, time lags, cross-couplings etc).

SENSORS

There are four ways by which we obtain information about the process performance:

- feed-back from the market
- laboratory data
- (in-process) sensors
- human observations

For the last two ways to be successful, the observability of the process is important and we have earlier pointed at existing limitations caused by the process design. The signals from the sensors can either be used for closed loop control or serve as input to the operational crew. The sensor signals can be subjected to various degrees of signal conditioning (statistical treatment, mathematical calculations, combination with other signals).

In-process sensors belong to one of three basic groups. The first represents sensors that measure fundamental parameters like temperature, pressure, level and which are of interest to many process industries. The second group consists of sensors that measure quite fundamental and general parameters but where conditions peculiar to our industry make the sensing particularly difficult (consistency, moisture, caliper and basis weight). The third group represents sensors that measure quite specific parameters, often related to the product quality (tensile strength, fiber orientation, z-direction properties, retention, furnish composition etc.). It is clear that the most urgent development needs for the paper industry lie in the third group.

The arguments for in-process measurements are clear and they were illustrated in Fig. 7. There is no doubt that variations in pulp quality are normally too rapid to be addressed through laboratory analysis. Thus on-line (in-process) sensors ahead of the paper mill serves both the purpose of feed-back control for more even pulp quality and (in the integrated mill) the purpose of feed-forward information to the paper mill. Also paper properties vary and a reliance on laboratory measurements (even when speeded up as much as possible) means that an essential control potential is lost (cf Fig. 1).

Let us briefly review the present situation regarding on-line sensors for paper properties.

The following measurements can be regarded as well established:

basis-weight
moisture
caliper
ash content
colour
hole detection

The following measurements can be regarded as partly established:

formation
gloss/surface roughness
opacity
porosity
coat weight
roll hardness

The following measurements can be regarded as in need of further research:

mechanical/strength properties
printability
z-direction properties
fiber orientation
non-traversing (instantaneous) CD-profile measurements

It is obvious from this listing that we are far from having a complete spectrum of well established on-line sensors and this gives us certain control limitations. This appraisal applies mainly to mono-layer paper structures. When addressing multi-layer structures, whether formed from one or several head-boxes, we are extremely limited when it comes to the measurement of the individual layers. Thus the possibility to carefully control these layers individually is almost nonexistent.

Why are we lacking important sensing possibilities when the needs have been genereally felt for a long time? Beside the measurement problems being difficult, we believe that a development team must possess deep process knowledge, ability to invent new measurement ideas, capability to convert such ideas into reliable equipment and ability to support the first industrial installations. These conditions are not always available and many sensor development projects are therefore destined to fail even if the correct measurement need was formulated.

Secondly, it is very costly to solve some of these advanced sensor problems and, with an intensively competitive but relatively limited market there often is no assurance of recouping the research and developing costs. Clearly, the overwhelming development effort has been so far put into improving the basis weight, moisture and caliper sensors that are used in MD and CD direction control systems.

There is also a third factor to consider. It is one thing to desire a method to measure on-line a certain property, but it is another to know exactly how the information shall be used for control. This has to do with the complexity of the process.

It may be relevant to discuss in greater detail some areas in need of further development:

1. The traversing gauges of today typically travel 500 m in the MD-direction, while travelling across the web. This means that MD-variations may affect the observed CD-profile which in turn can influence the performance of a CD-control system. If MD-variations happen to exist within certain critical frequency ranges, the interference may even be so large that the function of a CD-control system is wiped out. It is therefore of interest to obtain in the future a more "true" CD-measurement.

2. The trend towards more complex furnish mixtures and sheet structures and a more complicated wet-end chemistry, means that variations in pulp properties become even more difficult to trace. Measurements on the finished paper only reveal the sum of all effects with the influence also from the paper machine added. For this reason, new on-line measurements of specific furnish properties and of chemical parameters are urgently needed.

   The pulp measurement system developed at STFI (Case 2) is one way of approaching this problem. A weakness, so far, is that it is not clear just what properties of the pulp should be measured in order to predict in the most efficient way certain sheet properties. An advantage with this approach is that a measurement of for example fiber length or fines can hint at the process step where a disturbance originates. For example if the refining is more cutting than it should be.

Another approach with the same aim and which is being tried, is to have a robot which simulates the paper making process, i.e. takes pulp samples and makes sheets which are directly and automatically tested. It is still not proved, however, if such a system can simulate the paper machine well enough; if the robot is not quantitative, it must at least be able to detect deviations from a given set-point. The advantage with this approach is that sheet properties are measured, i.e. end-product qualities. On the other hand, the measurement provides little direct information on what has gone wrong when deviations are detected.

3. The laboratory testing should be regarded as an integral part of the total control. This is because we have for many paper properties no on-line sensors and we will not have for a long time. So, despite the time-delay, it is important to use laboratory data as well as possible. It can be remarked, that certain paper properties can not be measured even in the laboratory. One example is z-direction properties. Before such measurements are developed for on-line use, it is natural that they are first developed for laboratory use.

As a final remark, we wish to point out that new sensors are easily requested. In the end, however, it must be economical to use them and in our experience their control potential must be clearly demonstrated. The high requirements on a sensor to stand the mill environment (chemical and physical influences), to be "operator-friendly", to exhibit high availability and to be easy to service, makes it difficult for advanced equipment to become accepted. Since advanced equipment will be needed to solve some of the remaining measurement problems, this is a difficulty. It is likely, that even in the future, the advent of new sensors will be a slow process. Still, new sensors gradually appear and they undoubtedly will contribute to a better controllability.

INFORMATION TECHNOLOGY

Giant steps have been taken within the information technology area, particularly on hard-ware capacity. Today, computer technology is so intimately connected to control, that control without computer support is almost forgotten although it is indeed very important in paper making (cf section PEOPLE). In this section we want to illustrate how various aspects of "information technology" can contribute to the over-all controllability (cf Fig. 2). We also want to identify some development needs.

Advanced control technology

Insufficient inspection of PID-controllers has turned out to be a problem within process industries. It can well occur, that conditions change without the necessary readjustment of controller settings. A controller can then even start to oscilliate and itself cause a less controllable system without it being observed. If this happens, the performance of the total system of course decreases.

The development and application of adaptive controllers is interesting in this context. The self-tuning PID-controllers that have appeared in recent years, combining conventional PID-controllers with self-tuning ability, might be of special interest. We believe that a procedure where the tuning is initiated manually is to be preferred, since this makes sure that the conditions when tuning are right. Self-tuning controllers that are operated in this way should lead to robust systems that are well accepted by the mill personnel.

Today, the instrument department is normally responsible for the tuning of controllers. Perhaps in the future, the shift going personell should be responsible for this task. This would seem natural, since they have the over-all responsibility for the control of the process. Self-tuning controllers open up a good possibility here.

Process analysis

A large part of our knowledge concerning relations between raw materials, process conditions and paper quality originates from laboratory experiments. This symposium illustrates this. When control systems are developed and the controllability of a process is studied, it is necessary to study the unit processes and their interactions under mill conditions. Even if it is not so easy to plan and conduct such experiments, they are necessary. The principle relationships (cf Fig 8a and b) may be known from the laboratory but the quantifications must be made in the mill (cf Fig. 8c). An important tool for this is process analysis with the aid of computer programmes.

Today, techniques to collect, store and present data are well developed. There are also statistical packages available that can be used to treat the data. But there are important features missing that makes process analysis more cumbersome than desired. If, for example, in a sequence of data, some data are missing, which easily happens, present systems for process analysis can not automatically handle this. Neither can they handle a situation when sequences of data, that are to be analysed together, have been taken with different sampling intervals.

Earlier, trouble shooting was a way to analyse the process once a problem was there. An important trend today is to have more and more of "early-warning systems" integrated on-line. They can be used for example for the planning of maintenance (e.g. monitoring of vibrations). In the future early-warning systems should preferably contain elements of process analysis. They should reveal such information that today is not seen early enough, e.g. emerging clogging of a felt or a malfunctioning drying cylinder effecting the CD-profile. We believe this is an interesting area for development.

Simulators

The use of simulators - "stand-alone" or built into on-line applications - is unusual in our industry. Most frequently, they are used for training and as an engineering tool.

A problem that we have touched upon is that the controllability is often limited by the complex process response to control actions. It can then be difficult to follow up the performance of a control system. In this situation, simulation can help. One example of such an application from our own work is the use of a simulator in the STFI CD-control package referred to in case 1. When the optimal slice adjustments have been calculated, the effects on moisture and basis weight profiles are simulated and presented to the operator. By comparing expected effects with the actual effects it is easier for the operator to follow up and learn how the control system works and how the process reacts. It is also easier to trace process problems which should not be cured through CD control.

Knowledge based systems (KBS)

The development of information systems opens up a possibility to make information available to many people in the mill. It is interesting to note that today such systems are regarded as a positive factor. Earlier, the risk that people should feel supervised by such systems was often discussed. More and easily available information makes it easier to delegate responsibility and to increase job satisfaction. We will return to this under PEOPLE.

To make more paper-making knowledge available to the operators is an interesting field for KBS. Efforts are now being made to test such systems. As an example, one tries to make a papermakers handbook available through a computer and by using an efficient operators interface. Part of this can be to list the possible disturbances that can influence a certain quality parameter. One problem with such systems is to keep them updated. In principle, however, these tools should make it easier for the operators to take correct actions and in this way they contribute to the controllability. Up till now, training has been the main application for KBS-systems.

So called expert systems (one type of KBS-system) have received much attention in recent years. They are structured in such a way that the data base is separated from the knowledge base. This should make it easier to add new knowledge to the system. First, one tried to start from the knowledge of the operators. Problems arouse, however, with incomplete and sometimes incorrect knowledge. In later work with expert systems, one starts with design knowledge, i.e. persons who have designed the process system put their thinking and process charts into the knowledge base.

However, even the latest expert systems have limitations. One problem is to verify new rules against old rules. A function for this is lacking. This makes it difficult to verify the over-all performance of an expert system. This also means that one may end up with a system which is very sensitive to disturbances and which can even arrive at erroneous conclusions - something of a chaotic system. Our judgement is that much R&D still must be done before expert systems become a useful technique in paper making. Undoubtedly the approach is interesting.

Computer control systems

This is, as everybody knows, an area where a lot has happened. As long as the development is very dynamic, it is also difficult to develop standards. This is perhaps the reason why computer systems used in the mills give such a "scattered" impression. Different systems which have different human interfaces and different ways of communicating exist in the same mill. Not seldom, it can in one mill exist different and incompatible systems of the following kinds:

- digital instrument system
- PLC-system
- digital drive system
- basis weight/moisture control system
- CD control system
- information system
- role handling and order systems

etc.

Of course, for good controllability, it is important that information can be easily transferred from one system to another. One can not say that the vendors have done too much to help this. On the other hand, the techniques exist to establish this communication (at a cost) and it is also up to the buyer to put forward requirements. Standardized communication has been talked about as long as the computers have been around. One has also talked about joint requirements from the paper industry visavi the vendors. This has not come about and it is probably not realistic, since our industry is relatively small from the vendors point of view in comparison with other industries.

A trend is that the same vendor can now offer most of the functions listed above - often with a powerful instrument system as a base - and he then, of course, secures good communication. A problem is that the buyer wants to integrate new applications with unique hardware and software into his system. This is important since there are many suppliers who specialize in certain applications, where they are unique and may even have solutions protected by patents.

Quality control

Increased attention is put on quality and evenness in quality. We have emphasized that many times. This has led to an increased interest in defining quality targets and tolerances and one wants to involve the operators in a "quality thinking". One of the reasons behind this is of course that most of the important end-product qualities are not the ones that are directly controlled on-line. So, people have to be involved.

In North America, there has in the last years been a lot of interest in the concept SPC (Statistical Process Control). The concept was introduced already in the 30's. The idea here is to use statistical tools to follow up important quality parameters and to present the data in such a way that they lend themselves as a support for decision making and problem solving. The idea is also that SPC should provide the different categories of people involved in the paper making with a tool to carry out jointly a discussion and analysis.

In the Nordic countries this concept has not been much used so far. Still, there is, of course, an awareness of the importance of quality. The likely approach will be to integrate some SPC-type of analysis in the existing on-line systems. This means for example that laboratory data are integrated in the information system. This information is in some pilot installations integrated with information gained from process analysis and with information residing in KBS-systems.

It is clear that the development of tools which can promote quality control is of greatest importance.

THE PEOPLE

The human resources, particularly the operators, obviously represent a very significant part of the paper making operation (Fig. 2). This was evident also from our discussion of different control situations earlier. Through the actions - or lack of actions - by the operators, the production results can be greatly effected, both with respect to product quality and production efficiency.

The situation of the operators in the paper mill is not an easy one. They have to superintend the process (keep quality targets), optimize the process (efficiency), find faults in the process, perform grade changes, start-ups and shut-downs. They have to cope with:

- increasing quality demands
- increasing efficiency demands (speed etc)
- a more complex process, which also varies with time
- a process with limitations in controllability
- a process with limitations in observability
- varying pulp quality

The demands on knowledge are large and it is no wonder if an operator sometimes have difficulties with priorities and if he sometimes feels that he is not master of the situation. This is not a good situation, since automatic control (despite of steadily growing number of applications) only covers a part of all the control needs (Fig. 1). Therefore, the human organization around the machine all the time has to take control actions and can thus very significantly effect the production result. Here, it should be recalled that the profits are made in the marginal tons.

It must be kept in mind that anywhere near full automation is not likely to ever be reached, e.g. due to the nature of the process system, lack of sensors and due to the variations in raw materials. There will always be numerous situations where the attention of the operator is needed.

In order to take advantage of the potential for improved quality and efficiency that exists and in order to make it possible for the operator to make his contribution, there are things that must be improved.

One improvement is to make the paper making process more observable through more and better sensors and to make the process more controllable. Another improvement is to give the operator the best possible chance to learn and understand the processes. As part of this we must supply him with more and better knowledge support, involving information regarding the machine status and its trends. This is helped by diagnostic systems, on-line process analysis and SPC-type of systems. The knowledge support should also include computer based process-knowledge, adopted to the particular paper machine. This knowledge should help the operator with his decisions in difficult situations. And there are many such situations in paper making. It is reasonable to believe that today, insufficient knowledge often results in erroneous actions.

To have a knowledge support of the kind indicated, may seem as a dream - but still this road has to be entered. It is easy to point at some development needs, if we want to advance in this area:

- we have to have, preferably model based, descriptions of process interactions. Here one may remark that some of these interactions are not fully understood today even by the experts. To demand that they are fully understood by the operators without knowledge support is of course impossible. So, improved fundamental knowledge of the paper making process is a key to improved understanding also by the operators.

- we have to develop better tools for on-line process analysis with the ability to inform the operator about important process changes.

- we have to combine and concentrate all the information available to the operator, so that he has a reasonable chance of over-view. The trend towards better operator interfaces should continue, which in turn puts requirements on data communication.

- we need more simulation models, which the operator can use to educate himself about the process and to test suggested control actions.

The operators, who directly take the control actions, also interact with other parts of the human organization. It is a much discussed subject what the total organization should look like considering relations to maintenance, order/planning, market, development, other parts of the mill, supervisors etc. Although this subject is often brought up, it seems that few hard facts are established. The same can be said for studies on how the operator behaves in his working situation, particularly under stress (too much or too little to do) and with respect to his attitude to the job and how he becomes motivated. It seems that this is an area which deserves more studies.

We are of the opinion that the capacity of the human beings are not fully utilized. One sign of this is that many functions in today's information systems are not being used by the operators. Another is that great losses can easily occur at start-ups. It is a challange to change this. The operators need to understand the process better and to get better knowledge support, and this is more important the more complex the process becomes.

It is very important that the operator feels motivated. We list here a few activities that could increase motivation:

- active participation in the specification and purchasing of new equipment, information systems and control systems
- practising in departments that deliver information and process flows to him
- more direct contact with the users of the products
- information of results in economic terms
- further education, preferably on-site.
- more time left for "thinking"; today all the time is needed for the actual running of the process.

An important question for the future is the educational demands on persons responsible for the control actions on a large paper machine. As already said, the demand on knowledge is considerable and it remains to be seen how much of it can be put into computer-based knowledge systems. Another important question is if and how this industry will be able to recruit the people needed in competition with other industries. At least in Sweden this is a question which presently receives much attention.

CONCLUDING REMARKS

In this paper we have taken a broad approach to controllability. Even if paper production today is carried out at high efficiency and with good quality, it is no doubt that there are strong needs for and a clear possibility for better performance. An increased controllability is one of the most important tools for this. We have argued that many components contribute to controllability. We divided these into: the process with its actuators, the sensors, the information technology and the people.

In order to improve controllability in the short run we feel that most progress can be made in the "soft" areas i.e. by better use of existing information and by better utilization of the people (supported by the necessary tools). In the longer run, new process design, which considers controllability demands, and new sensors have the potential to yield better controllability.

Some of our main points in this paper have been:

- we still lack essential controllability due to inadequate process design (closed systems, residence-times, paper properties are effected in a complex way through the process etc).

- new measurement possibilities are essential to improve the observability and thereby controllability.

- the human organization has a key role in controllability. Full automation is utopia. The operators have an increasingly difficult task. Their motivation is important.

- knowledge-based systems is an interesting area. Such system can be of great value, but much development is still needed.

We have pointed at some important areas for R&D if a better controllability of real-life processes is to be achieved. Increased fundamental understanding of the paper making operations and their interactions is very essential but the knowledge developed must also be useful when developing control systems for actual processes. This means that all the important aspects must be covered and that the knowledge must be formulated in a useful way, e.g. in the form of process models. This is not always the case today.

It is our opinion that work on increased controllability is one of the most important and most exciting areas of development within the field of paper making.

This paper is not a review in the normal sense. It could perhaps be called a discussion paper. We have deliberately avoided references. By doing so, we have not given credit to those who have earlier addressed the topics of this paper. We wish to apologize for that.

Transcription of Discussion

CONTROLLABILITY OF PAPER MAKING

H. Karlsson and L. Eriksson (Review Paper)

***Dr. B.A. Nazir Wiggins Teape R&D Ltd**

You have placed a lot of emphasis on the use of information technology in process control. An argument is sometimes made that full use of information technology and a large numbers of sensors could produce mathematical models that could be used for control. Do you agree with this argument and if so does this mean that we will not need the physical and chemical models produced by the paper scientists?

L.Eriksson

That is a very pertinent question and the answer is not simple. Overall I would say the answer is "yes" to the first part and "no" to the second part.

I will elaborate a little. I think it is quite possible, in certain situations, to get a long way by using many sensors and developing statistical models of the process and product. Such models do have limitations when they are not based on a thorough understanding of the process; their dynamic range is limited and they lack generality. Obviously the use of physical models is advantageous,there can be no doubt about that, but that assumes that we have such physical models.

I think it is interesting to note that historically when vendors started to design systems they found that the easiest way of doing that was to apply the machinery of statistical analysis and modelling because that can be applied to any process. One can apply process control without knowing much about the process, that has happened many many times, but that does not give us the best control system. By way of example we have seen this at STFI in the CD control where we were working in 1976 to 1977. We based this on a physical model of what was happening on the wire. The ensuing system had far better performance than the commercial systems of the day that were based on statistical modelling.

We can also turn the argument around. We do not always have the physical knowledge necessary to build control systems. Much of our understanding is based on laboratory experiments and all too often this is not closely related to what is useful in the mill. In these cases perhaps paper scientists should get out to the mills and use the sensors and statistical tools to confirm that their finding are useful for control.

At present we lack much information about process relations. If I were to say to a person in the audience "I want to control a particular strength factor in the finished paper. Please tell me which material and process variables to measure to make a predictive model?" I think do not think I would get a useful answer, so there is still a lot of fundamental knowledge lacking. In these cases statistical modelling is the only tool which is available to us.

There are many answers to your question but I am sure that we must always strive for a good physical model since it will always be the best.

M.I. MacLaurin

Thankyou for that answer. It occurred to me that if we are going in for lots of models in the future, we not going to run into problems of keeping them updated. I wonder whether you have any comment to make about that?

L. Eriksson

Yes. Of course updating models is a very important issue. I will hand the question over to my co-author Hakan Karlsson because he has lived with this problem more than I have in recent years.

H. Karlsson

From the control engineers point of view we can cope with updating data when we are in closed loop control, here it is very easy to see if the model is wrong.

It is important to note that the complexity of the process is such that we will never close all loops. What we are talking about when we refer to a knowledge based system, is a database containing a lot of knowledge relating to variables which are not in closed loop control. This database should be available for use by the plant operators and they need good information on which to base their actions. This is a much more complicated problem than control, it is far more difficult to develop and update this type of knowledge and this is the major problem which faces us today, particularly in the area of mathematical relationships and models. This is a very good area for theoretical scientists to be working in today.

Dr. R. Grant Consultant and Pulp And Paper International

This question is addressed everybody here and is related to mathematical modelling. Now that Derek Page has made the suggestion that we use standard starting materials for our experiments, we can now see that, had his suggestion been made at the first symposium 32 years ago, our knowledge about stock preparation and other areas of papermaking would be better than it is today. Perhaps there is an early warning for us here with regard to mathematical modelling which, thanks to computers, is on the increase. We saw yesterday two diametrically opposed opinions between experts on both the conceptual side and the mathematics of models. We saw another instance following the paper by Dr. Popil. Is there support for earlier discussion in the derivation of these fundamental models and possibly the need for greater ongoing collaboration between experts? I fear if we miss this early warning we could be building a mountain of mathematical models that are confusing to the majority and irreconcilable between the minority.

M.I. MacLaurin

That is a very interesting thought Roger, we cannot open this to everybody but do you have any very quick comment to make on this before we pull the rug out on this session?

L.Eriksson

No brief comment.

J. Mardon Omni Continental

Dr. Eriksson has omitted to mention the seminal paper by W.H. Cuffey (Ref. "Some factors involved in basis weight uniformity". TAPPI 40. No:6 190-6A (June 1957)).

In this paper Cuffey clearly describes the variation in basis weight resulting from the adjustments of one screw.

(Ed. Note. This comment was submitted after the session).