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FEX FOR FUNDAMENTAL RESEARCH IN PAPER-MAKING

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Abstract

During the early 1970's the old experimental paper machine at STFI was left too far behind by technical developments to be of any great use for basic process research. In the mid 1970's, therefore, the planning began of new equipment at STFI. The aim was to design the experimental system required for a basic process research programme during the period 1980 - 2000.

It has to include all process units involved in recirculating material flows. This means that stock preparation, wire section, press section and backwater system should be included, while drying can be performed off-line.

The wire section should include the two basic twin-wire forming principles as well as a Fourdrinier section. In the wire section it should further be possible to form multi-ply products, either from a multi-ply headbox or from several headboxes. The roll width in the wire section will be 800 mm, which means that headboxes up to 500 mm width can be applied. The press section should avoid open draws and include double felted as well as single-felted nips. To simulate industrial processes running according to modern environmental standards, a filter should be used to recover suspended material from the excess back-water, which could then be re-used for showers, dilution, etc.

The dynamic properties of the FEX System were calculated using computer simulations. As a result it was found that 2 tons of pulp will be needed to run the system into equilibrium. It

was decided that the storage capacity in the stock preparation plant should allow the system to be run into equilibrium four times on one batch of pulp.

An experimental paper machine often has to produce more data than paper. The FEX System is therefore heavily instrumented, and the requirements of the different measurements often had a strong impact on the design of the system. A central minicomputer is to administer a number of microcomputers which will do the actual job of process control and data collection and processing, and also automatically start up and shut down the complete system.

Increased use of multi-ply forming and paper-making additives are two important development trends in the paper industry, and extensive research within these areas is planned.

Background

Since the 1940´s the availability of the experimental paper machine, XPM, at the institute has created a tradition at STFI for studying the paper-making process at pilot plant scale. During its active time, XPM was used for numerous projects involving process evaluation and process development technology . Many newly graduated engineers were engaged in projects on XPM for a few years, before taking their new knowledge into the industry.

During the later 1960´s, however, XPM was starting to lose its usefulness as a basic research tool, as it could not be kept level with the rapid developments of modern technology. During the 1970´s it also became more difficult than before to attract students at the Royal Institute of Technology in Stockholm to specialise in paper technology as an alternative to such popular new subjects as energy, biochemical or computer technology. Towards the mid-seventies it thus became obvious that a new experimental machine was needed both for research and educational purposes.

When Alf de Ruvo took over as research director of the paper department at STFI in 1974, he soon initiated discussions of how best to replace the old experimental paper machine. Seven years have evolved from the initial ideas in 1974 to the first parts of the new system being put into position in 1981, with an expected start up in mid-1982. It would not be appropriate in this context to describe in detail the many phases through which the project has passed, and the hard work which has been put in to make the FEX system a reality. If, in the beginning, we had been aware of the time and effort required to carry out this project we would certainly have hesitated. Suffice to say that the first years of planning under the harsh chairmanship of Borje Steenberg were extremely hard, but also very useful. It should also be pointed out that people within the paper industry have been most willing to help, and therefore must be given much of the credit for the final positive decision in 1980 by the Swedish Pulp and Paper Association and the National Swedish Board for Technical Development to launch the project.

In the following sections, firstly the main specifications for the new experimental paper machine, called the FEX system, which have gradually evolved from the original ideas, will be described.

Secondly, two areas will be dealt with, in which work done during the planning stage has already contributed to the fundamental knowledge of paper making, namely the dynamics of white-water systems and the basics of twin-wire forming.

Finally, the possibilities within two important research areas for the FEX system, multi-ply production and increased use of paper additives, will be briefly discussed.

The FEX System

An important aim of the new machine is to achieve higher machine speeds and higher production rates per unit machine width than contemporary industrial units. Furthermore, modern technology, like different types of twin-wire forming, should be provided for, as well as multi-ply production. To simulate conditions corresponding to industrial systems, a closed white water system with recovery of solid material from the waste water has been designed. We further require that the system be designed to be able to run to equilibrium four times on one batch of pulp without recirculating the sheet from the press section.

Below is a short summary of the main technical data for the FEX system.

Stock preparation plant (See figure 1)

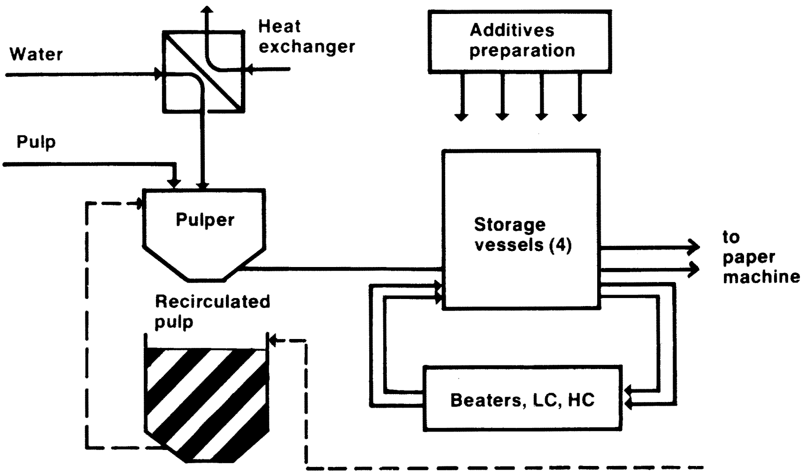

Fig 1—Stock preparation plant.

This includes the following features: batch pulper to be fed by dry pulp and heated water (maximum 70^{o}C) to make it possible to run the white-water system at elevated temperatures: equipment for low-consistency and high-consistency refining: storage capacity for 10 tonnes of pulp in five tanks, either as separate components or as ready-made stocks for feeding the machine through the two stock lines: preparation plant for adding four non-fibrous components, including filler.

Headboxes

The minimum width was determined by the sample length required for paper testing in the cross direction. To this the different, sometimes overlapping, edge effects from drying, pressing, dewatering and headbox flow should be added. The minimum headbox width was set to 300 mm, and this width was used when calculating maximum flow rates required.

There will be three 300 mm wide, high-speed, high-consistency headboxes for single- and three-ply forming, and a 500 mm wide, medium-speed headbox for Fourdinier forming.

Wire section (See figure 2)

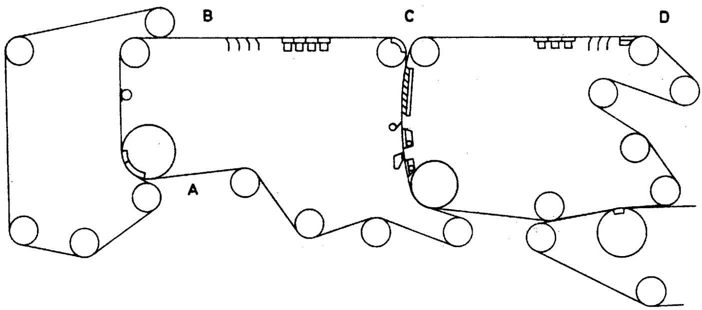

Fig 2— Wire section
A Twin wire forming, constant pressure.
B Fourdrinier.
C Twin wire forming, pulsating pressure.
D Fourdrinier.

Of flexible design to allow for future modifications it includes the following features:

a. Different sections for twin-wire forming with constant and pulsating dewatering pressure respectively, as well as two Fourdriniers.

b. Machine balanced for 3000 m/min and drive arranged for initial speed range 250-2500 m/min.
c. Roll width 800 mm and wire width 650 mm.

Press section (See figure 3)

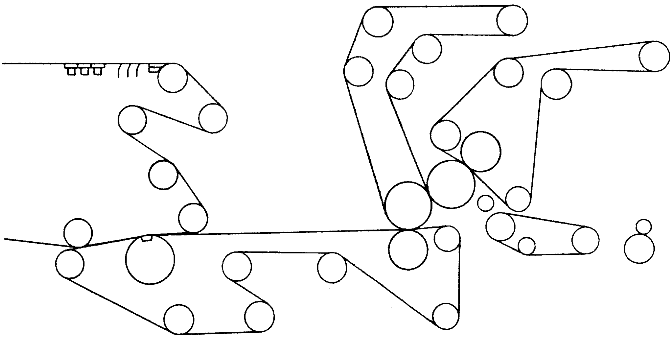

Fig 3—Press section. Pick up felt, double felted nip, two single felted nips, transport felt and sample rolling station.

This section is to comprise the following equipment: one double-felted and two single nips with 150, 200 and 200 kN/m maximum loading respectively: a transport arrangement will carry the sheet from the third press nip across an open section for profile measurement of basis weight and moisture to the roll sampling station: roll width 800 mm, felt width 500 mm, and sheet width 300 mm.

Drying

Drying, whether of rolls or of individual sheets, will be performed off-line.

White-water system (see figure 4)

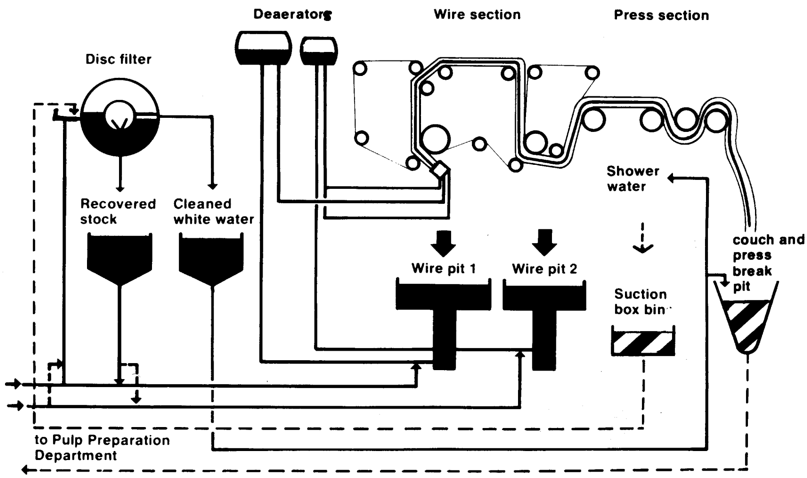

Fig 4—White water system.

This, one of the most important sections of the machine, comprises two separate short circulation loops including mix pump, coarse screen and de-aerator. The maximum flow rates are to be 10 and 5 m^3/min respectively. Figure 5 shows the maximum slice opening using different headbox widths at 10 m^3/min flow rate. There are to be three feed pumps, one for each flow in three-ply forming. Excess white-water will be cleaned in a disc filter containing six discs, using either of the two stock lines to supply sweetener pulp. This pulp is returned to the stock line after passing through the filter. The maximum re-use of the clear filtrate will be made for showering purposes, and for re-broking the sheet after the press section.

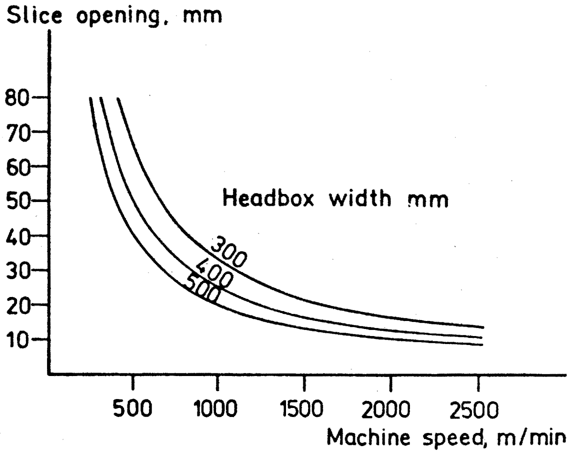

Fig 5—Relationship between machine speed and slice opening at different headbox widths with maximum flow rate 10 m^3/min.

Measurement and control system (see figure 6)

The computerised measurement and control system will include.

* central operator's panel with two full-colour displays to show actual process configuration including data for process variables
* distributed control units for digital process control and for generation of automatic sequences for start-ups, grade changes, and shut-downs
* additional computer for extensive data logging, play-back functions, and special purposes.

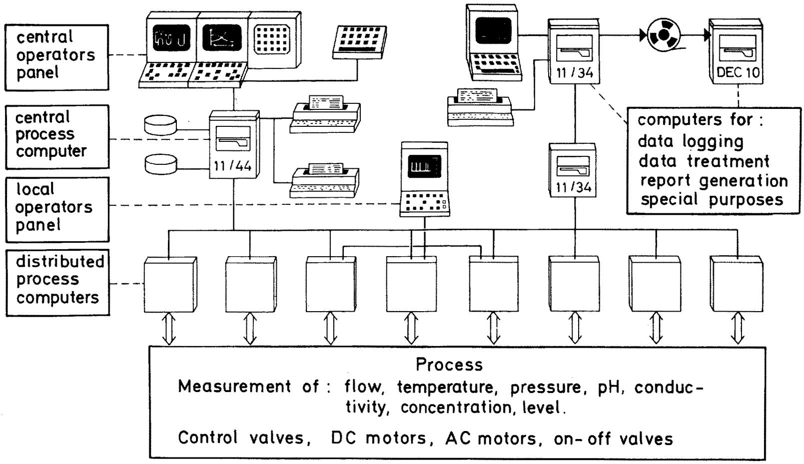

Fig 6—Computerised measurement and control system.

The extensive measuring equipment will include flow-meters for the determination of complete flow balances, and numerous transmitters for the measurement of pressure, temperature, conductivity, pH, and concentration.

Dynamics of the white-water system

Earlier experimental paper machines have generally been equipped with completely open white-water systems, or they have re-circulated the stock after its passage through the machine. Using either of these two methods it has been possible to run the white water system to `equilibrium' conditions consuming a rather limited amount of pulp. However, the equilibria reached were not representative of modern industrial plants, which use comparatively closed white-water systems.

In the FEX system the aim is to provide a white-water system closed enough to be representative of industrial conditions. It is also essential to design the system so that true equilibrium conditions can be reached during experimental runs.

Analytical simulation models

To evaluate the dynamic properties of a white-water system including both the short and the long circulation loops, analytical methods (using Laplace transforms) were initially used during FEX planning[1]. The white-water system was simplified by representing each of the circulation loops by one single volume with ideal mixing, see figures 7 and 8. Some important results were obtained using this mathematical model.

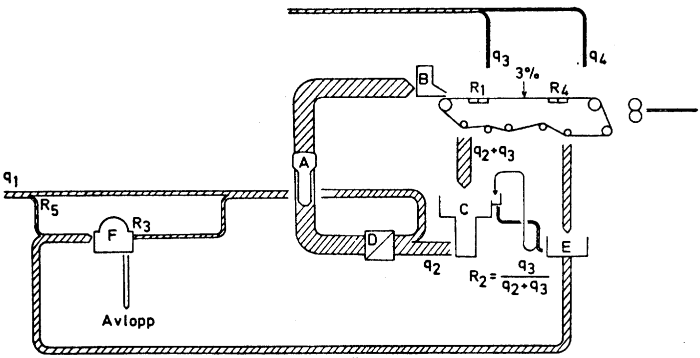

Fig 7—White water system for dynamic analysis, analytical method. q flow rate, R retention. Ref. (1).

The larger the volumes and the lower the retention values and flow rates the longer the time to reach equilibrium. The lowest retention will be achieved for dissolved and colloidal material not subject to any physical filtration effect on the wire. These components will simply follow the water and the retention values will then be determined by the relative (not absolute) water flow rates.

The stock consumption to reach equilibrium is determined only by the water volumes and the retention values, but not by the flow rates in the white-water system.

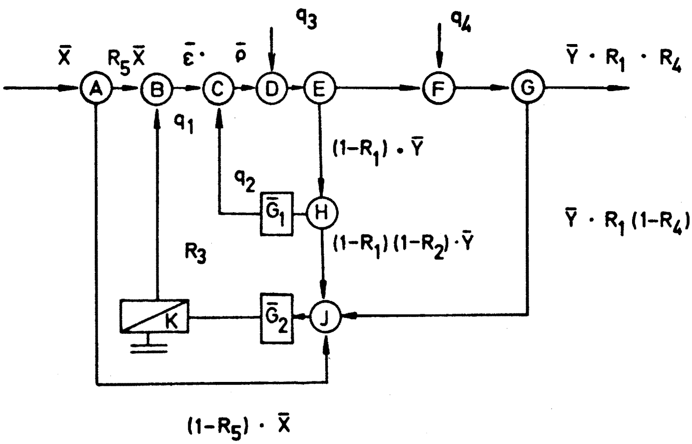

Fig 8—Analytical (laplace transform) model for dynamic simulation. (Compare fig. 7). Ref. (1).

When running an experimental paper machine the time consumed to reach equilibrium is generally less important than the amount of stock consumed. Consequently, to determine the most critical (that is slowest) dynamic conditions in the white-water system, it will be enough to specify the inherent volumes and the relative flow rates (retention values) but not the actual production rates. This increases the flexibility for future running conditions using a predetermined size of the stock supply.

The analytical model was utilised to make coarse calculations of the dynamic properties of the system when running single-ply products. Based upon these results, the stock supply was dimensioned for four runs to equilibrium on one complete batch of stock.

Numerical simulation models

There are some important restrictions inherent in the analytical simulation method. It can only be used to solve linear differential equations (which means that, for example, retention may not change with basis weight) and the method becomes impracticable when the number of mixing volumes exceeds two. To be able to simulate more complex white-water systems, numerical simulation programs were applied.

The GEMS program for simulating steady state conditions was developed to simulate pulping processes. For use in the FEX planning it was modified to include also some important paper making unit processes(2). The SIMNON program for dynamic simulations was first applied to paper-making white-water systems within the FEX project(3). Both the GEMS and the SIMNON program consist of individual programs for the different unit processes, which are then linked together to simulate a specific system. This structure makes it easy to modify the simulation program when the white-water system is changed.

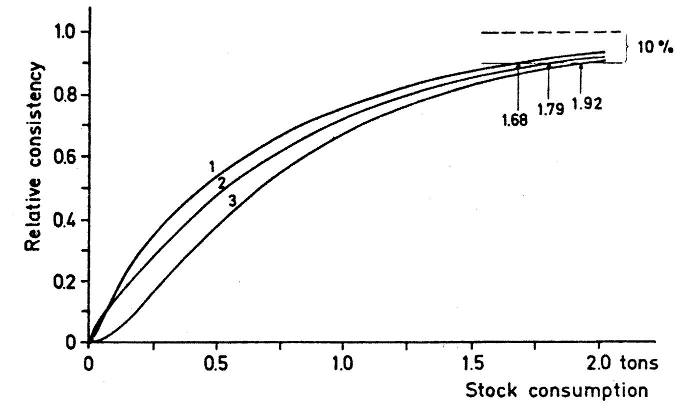

Fig 9—Build up of consistency of solved material using numerical simulation method.
1 Short circulation 1 (large)
2 Paper
3 Short circulation 2 (small)

The steady state flow values calculated using the GEMS program, together with the volume specifications for the different components in the white water system, are used as input data for the SIMNON program, with which the dynamic progress of the process is calculated.

Simulation tests were performed for multi-ply forming according to the process design shown in figure 4. Some basic data for the process are collected in table 1. Figure 9 shows the build-up of consistency of dissolved and colloidal material after start-up of a water-filled system. The three curves represent the consistencies in the paper and in the wire pits of the two short circulation loops respectively. The stock consumption to reach 90 % equilibrium for the paper amounts to 1.8 tons. If a minimum of 90 % equilibrium is required also for the concentrations in the white-water system, the critical concentration will be that in the smaller of the short circulation loops, for which 1.9 tons of stock will be required for equilibrium. It was initially surprising that the dynamics are slower in the smaller than in the larger of the two short circulation loops. The explanation lies in the connection to the disc filter. The stock feeding the smaller of the short circulation loops has previously been run over the disc filter to provide sweetener stock, and therefore the composition of the stock when reaching the short circulation loop will vary due to the dynamic properties of the disc filter loop.

Figure 10 shows the effect on the dynamic situation either of reducing the volumes in the system or of increasing the fresh water consumption.

A 22 % reduction of the volumes specified in table 1 will cause an 18 % reduction in stock consumption to reach equilibrium in the paper.

An increase of the fresh water consumption to 30 m^3/tonne will decrease the stock consumption by one third, but at the same time the equilibrium consistency of the critical components in the paper will also decrease by one third. This verifies an initial statement in this section that an open white-water system will reach its equilibrium faster than a more closed system.

Basis weight 300 g/m^2
Three-layered product

Stock volume flows required:

sweetener stock,	3 %	consistency,	0.95 m^3/min
outer plies,	3 %	"	, 0.75 "
centre ply,	3 %	"	, 0.75 "

Retention values for dissolved material:

outer ply 1,	10.9 %
outer ply 2,	14.0 %
centre ply,	16.0 %
disc filter,	45.2 %

Fixed volumes:

disc filter	8.3 m^3
deaerator 1	2.3 m^3(including piping in short circulation 1)
deaerator 2	1.7 m^3(" " " " " 2)

Variable volumes, m^3:	alt I	alt II
clear filtrate tank	2.3	1.1
cloudy filtrate tank	2.3	1.1
wire pit 1	4.7	3.3
wire pit 2	3.1	2.2
suction box bin	2.0	1.0

Table 1

Data for dynamic analysis of the white-water system

The GEMS and SIMNON programmes have also been used to simulate the dynamic conditions of a complete industrial paper making system(4).

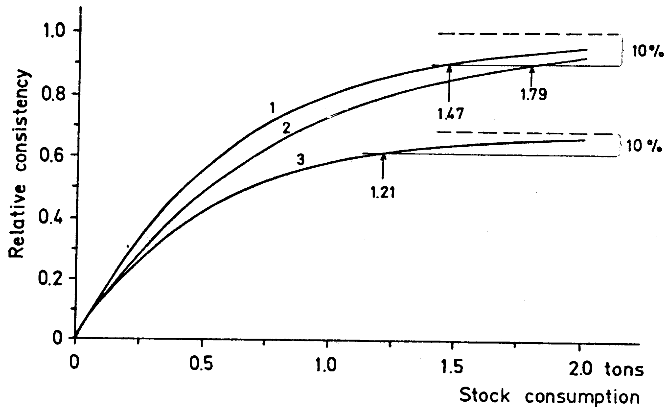

Fig 10—Build up of consistency of solved material using numerical simulation method.
1 volumes alt 2 (table 1), no fresh water
2 volumes alt 1 (table 1), no fresh water
3 volumes alt 1 (table 1), 30 m^3/min fresh water

Twin-wire forming possibilities

The design of the wire section has undergone vital changes since the initial plans of 1974. At that time, the Bel Baie and the Papriformer typified the two main technologies for twin-wire forming. According to the literature, the main difference between the two methods was the size of the forming zone radius. In the Papriformer version the radius was around 0.7 m while in the Bel Baie case it was in the range 8-10 m. This was supposed to mean that the dewatering pressure, T/R (wire tension divided by forming zone radius), was about ten times lower for the Bel Baie former(5). It was further claimed that the more gentle drainage created a more even fibre distribution in the final sheet.

In the beginning, therefore, the wire section of the FEX machine was planned to include formers in both ranges. The Fourdrinier section was added mainly for comparison purposes.

During the progress of the FEX project, the twin-wire forming process was analysed in some detail. The conclusion was then reached that there was a fundamental difference between the Bel Baie and the Papriformer forming methods, and it was suggested that the dewatering in the Bel Baie former was caused by a series of pressure pulses, each related to the deflection of the wires over the individual foil elements[6]. This is today the generally accepted explanation for the more even fibre distribution obtained in a Bel Baie former over what is usually achieved using the roll forming principle of the Papriformer.

This new understanding initiated a change in design of the FEX wire section. In the new design, twin-wire forming according to both basic principles is included: even dewatering is achieved using the roll forming principle, and pulsating dewatering by using stationary deflector elements, see figure 2. Combinations are also possible. Deflector elements can be introduced in the vertical section following the roll former. Curved suction boxes can be introduced into the central twin-wire nip, as a complement to the deflector elements.

After some rearrangement of the wire section it will also be possible to apply initial Fourdrinier forming followed by a twin wire nip.

Important research areas

Of the many important research areas which are stressed by the development trends within the paper industry and which will therefore be attacked using the FEX system two will be briefly discussed here, namely multi-ply production and paper-making additives.

Multi-ply production

The use of multi-ply products will increase in future, due to their inherent possibilities of more efficient use of different raw materials. Many mechanical as well as optical properties can be improved by hiding components in the centre of a sheet or by concentrating them on the surface.

However, multi-ply forming will mean increased investments in process equipment and increased running costs, which have to be offset by the savings of raw material. It is therefore of vital importance to investigate the sophistication required from forming principles and the degree of white-water separation necessary.

In the wire section of the FEX machine it will be possible to form two sheets against each other according to four basic principles:

* Simultaneous forming of two sheets using a two-ply headbox: positions 1 and 2 in figure 11 (top).

* Using a secondary headbox to form a sheet onto an already formed sheet, with drainage through the existing sheet: positions 1 and 2 in figure 11 (bottom).

* Using a secondary headbox to form an additional sheet against an already existing sheet, with dewatering away from the sheet: positions 1 and 3 in figure 11 (bottom).

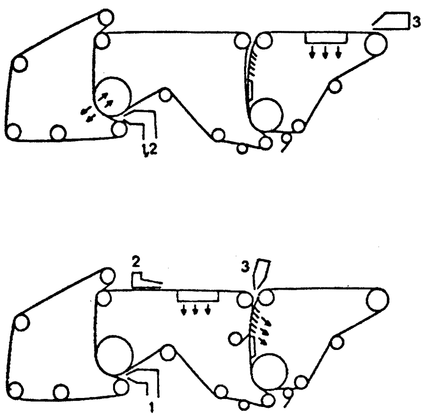

Fig 11—Alternative multi ply forming methods in wire section.

* Two sheets formed separately and couched together: positions 1 and 3 in figure 11 (top).

The four principles are arranged in the order of decreasing ply bond, complexity and therefore cost.

In combination with any of the forming methods it is possible to use one single or two separate white-water systems. The choice will affect both production economy and product quality. It is furthermore important to consider other effects, especially pressing and drying efficiency, to be able to make a complete evaluation of the economics of multi-ply production.

Paper-making additives

A substantial increase in the future use of additives is to be expected. The additives may consist of mineral (or organic) fillers or of one or more chemical components.

A wide range of properties can be manipulated using various additives, like

wet and dry strength
optical and printing properties
bulk and stiffness
hydrophobic properties.

Additives can also be used for increasing the efficiency of the different processes, for instance to aid retention.

To give a true picture of the relevant effects of additives in an experimental paper machine it is important to use a comparatively closed white-water system, and it is furthermore impossible to recirculate the production from the machine. Both these requirements are fulfilled in the FEX system.

The locations and means of introducing these additives are very important. Some components should be added as separate layers in a structure, some are best mixed into one of several layers, while some can be evenly mixed into the entire sheet. The fine scale mixing at the point of addition is generally quite inadequate. The amounts of additives required can be decreased by using better mixing efficiency. These are important areas for further development.

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Transcription of Discussion

Discussion following paper given by Prof. B. Norman

Dr. J. Mardon, OmniContinental, Canada

Is there not the danger that the running costs of a piece of equipment like FEX, unless it is separately funded, will draw off funds which would normally go to other parts of the Institute, and thus put them at a disadvantage?

Prof. B. Norman

It is quite natural that the flow of funds changes with time and current demands. I agree that there will be an increased flow of funds into paper process problems as a result of FEX. We anticipate that the FEX investment shows the way forward, and that such projects are necessary to stimulate continued financial input to the Institute.

Mr. I.K. Kartovaara, Enso-Gutzeit Oy, Finland

You said that the pulp volume required to reach equilibrium depends on the retention and total volume of the system. For 50% retention what is the relationship between pulp and system volume? Does it matter whether materials are added just before the headbox or in the chest? Do these materials reach equilibrium at the same times?

Prof. B. Norman

If you feed a stock volume of 3 to 4 times the white-water volume into the machine then an acceptable state of equilibrium will probably be reached.

Your figure of 50% first-pass retention does not give the whole picture since the retention of fines is lower than that of long fibres so the fines take a longer time to reach equilibrium. Addition immediately before the headbox speeds up the process compared with addition at the machine-chest, because that way it isn´t necessary to consider the dynamics of the machine-chest itself.

Mr. E.J. Justus, Beloit Corp., USA

This is not a question, it is a correction. Dr. Norman showed an imagined trajectory of a wire around some stationary elements. We at Beloit were not so naive as to assume such a trajectory. The wire actually travels around the shoe in short straight-line segments. Our experience on the roll formers and on the early Bel Baie formers where we used a solid shoe was that we did not achieve optimum formation. On Fourdriniers we have always attempted to have a certain amount of shear in the sheet during the forming. The activity on the wire accomplishes this shear. The action of travelling over the individual blades is to improve the formation and the experience on over 60 of these units says that they do indeed give excellent formation: we believe this is due to the action of the chordal travel over the forming zone.

Prof. B. Norman

I agree with you 100% that the pulses improve the formation.

I do not agree with you though when you say that you had this information at the time.

At the 1975 Water Removal Symposium, Dave Gustafson claimed a curved shape in his presentation of the Bel Baie former. I quote "The forming shoe blades are set so that they support the No. 2 wire on a radius".

In February 1978, I gave a seminar at Beloit Research to some ten or fifteen people. No-one believed in my suggested model, and Jan Bergström (research director) even said that they had measured the pressure along the forming zone and found it constant.

Mr. E.J. Justus

The Black Clawson Unit, where the sheet is formed on blades, has always produced excellent formation and I think that many of us were cognisant of that fact at the time. We knew what we were doing when we built the Bel Baie, though we did not necessarily tell everybody who visited us.

session 7 discussions

Prof. B. Norman

Next time tell your people in the research lab, that will help!