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THE INSTALLATION OF A COMPUTER ON A FINE PAPER MACHINE

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Synopsis The paper examines the various stages in a project to implement control of a papermachine and its associated stock preparation plant using a digital computer. The project is looked at from the initial economic feasibility through to the commissioning and implementation stage.

A general description of the computer system and the control strategy employed is included. Particular mention is made of those aspects of the project not immediately associated with the control of the process, yet making important contributions to the whole system.

Reference is made to the more significant problems faced during the project, giving when possible indication of lessons learned for future applications.

Introduction

IT IS generally accepted that the availability of on-line measurements and conventional control devices has had a considerable effect on the profitability of the papermaking process. It is also widely believed that the digital computer has a further significant contribution to make by its application to the control of those interacting process variables that remain largely uninfluenced by conventional devices.

The full potential of improved control is difficult to estimate in advance, especially as many benefits are of an intangible nature. The more obvious areas of economic interest are—

1. Saving in fibre costs.
2. Improvements in operational efficiencies.
3. Reductions in broke at breaks and grade changes.

The intangible returns are largely associated with the computer used as a learning tool and as a means of centralising control and information.

Under the chairmanship of Dr D. B. Brewster

Economic justification

DURING the early part of 1965, Bowaters carried out a series of feasibility studies aimed at justifying the introduction of a digital computer for control purposes on to one of the U.K. papermachines. The studies covered a number of machines, producing a range of papers from fluting to quality coater base. The results of the studies were, in the main, very favourable and this was particularly true for No. 16 machine at Sittingbourne, manufacturing a range of base sheets for blade coating. This machine was therefore chosen for Bowaters' first computer control project. No. 17 machine, which is situated alongside No. 16, was soon to switch to a similar range of papers and it was therefore recommended that allowance be made early for its eventual inclusion in the entire control system.

Table 1 summarises the comparative benefits estimated for four different machines. There is considerable variation, but each would probably justify a computer control system of one size or another. Calculations for the purposes of the feasibility studies were based on the *shift sigma technique*, which is discussed below.

Typical production practice is to control product quality to some target value and to place upper and lower sample acceptance limits at two standard deviations (2σ) above and below this mean. The normal distribution curve has the property that 5 per cent of its area lies outside the 2σ limits, thus 5 per cent of production normally falls outside the specification limit. If process control is improved such that the standard deviation of the quality distribution is reduced to half its previous value, then the mean quality level can be altered

TABLE 1—SUMMARY OF COMPARATIVE BENEFITS

Area of development	*Mechanicals*	*Fluting*	*Newsprint*	*Fine paper*
	Financial gain	*Financial gain*	*Financial gain*	*Financial gain*
	£	£	£	£
1. Substance control—reduction in materials demand due to lowering of average substance	No claims	13 618	No claims	28 000
2. Moisture control—increase in average moisture content	5 560	5 720	10 500	No claims
3. Furnish control—reduction in chemical pulp content	No claims	No claims	10 500	10 000
4. Machine efficiency—increase in output due to reduced time/broke losses	29 540	20 660	32 940	88 500
5. Machine speed — increase in general average resulting from raising of lower limits	4 600	41 600	7 200	61 500
	£39 720	£81 598	£61 140	£188 000

N.B. It has been assumed that the additional saleable tonnage will be sold according to the present mix for each machine by an amount equal to the original standard deviation without more than 2·5 per cent of production falling outside the specification limits (Fig. 1).

The argument can be extended to aspects of process operation that do not involve specification limits. In this case, limiting factors are provided by the physical limitations of the plant. If process operation can be stabilised so that its standard deviation is halved, then the mean operating level can, as before, be moved by an amount equal to the original standard deviation without exceeding any of the plant limitations.

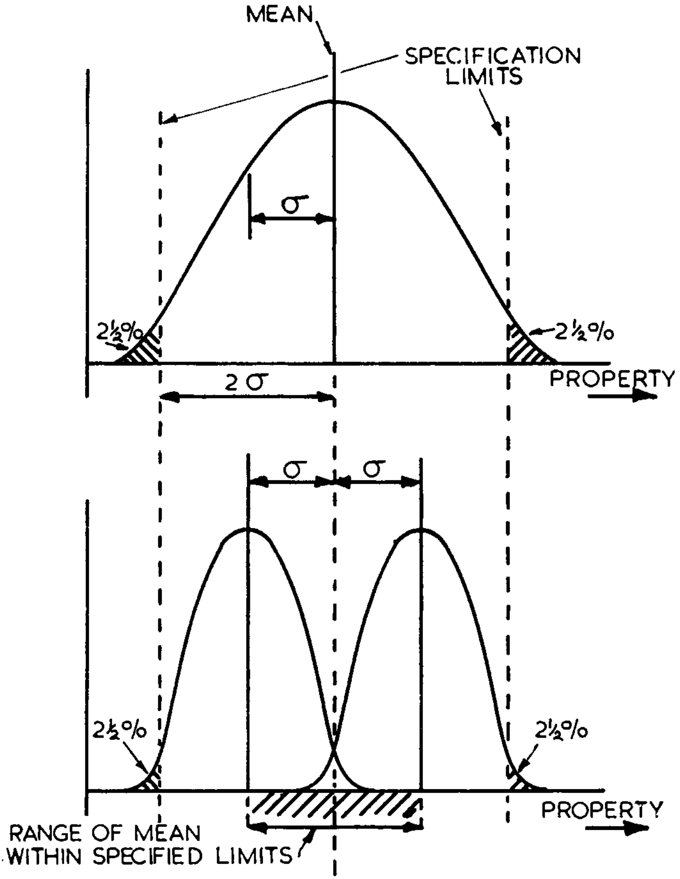

Fig. 1—Normal distribution curves

There are usually different economic penalties for different mean operating and quality levels. Thus, in the calculations for the feasibility studies, the economic implications of a shift in the mean were combined with estimates of current standard deviations to yield estimates of potential savings in the various areas of machine operation. Fibre savings were anticipated from improved control of basis weight, moisture content and loading proportion. Other economic values were determined on the basis of improved papermaking efficiency and a reduction in lost production through web breaks and grade changes. No value was placed on intangible benefits.

Alternative techniques for analysing the economic viability of computerisation are available.(1) In general, the more successful involve the comparison of process operation with achieved best performance or with theoretical limits. One approach that Bowaters have used attempts (unlike the shift sigma method) to look beyond the economic benefits of improved regulation of the various process stages by estimating the likely increase in process performance optimisation rate arising through the use of a computer.

This performance optimisation—which is, of course, going on throughout the life of a process as the natural outcome of increasing operating experience and knowledge—should show itself as an improvement in process profitability. Any major change to the plant or operating strategy will cause a discontinuity in the rate of optimisation and no such change should be considered successful unless the optimisation rate is increased.

It is necessary to analyse the performance of a process in economic terms and in ways that will reveal shortcomings and indicate areas of potential improvements.

The full description of the performance of a process involves a variety of interrelated factors such as quantity produced, purity, customer satisfaction with product quality, raw material costs and supervision costs. The most satisfactory single measure of process performance is one that measures the instantaneous profitability. This will be termed the *performance quantity* (PQ) and it can be expressed in terms of all the values and costs involved in the process—

$$\begin{aligned}\text{PQ} = {} & \text{Value (Products} + \text{Customer satisfaction} - \text{Returned products, etc.)} \\ & - \text{Costs (Materials} + \text{Labour} + \text{Maintenance, etc.)}\end{aligned}$$

The performance quantity as defined provides the best measure of process performance. In some cases, other criteria may seem more appropriate—for example, cost per unit production or production rate. Such sub-targets may be misleading, since they tend to ignore those factors that at particular times in the life of a process may become of extreme significance.

Performance trends may be studied by plotting the PQ for a plant for a number of past years. To be meaningful, the calculations must be carried out with fixed raw material and labour prices, etc. The prices and values in the current year are normally chosen for convenience. The procedure can be justified only when the plant and operating strategy have been unaltered during the whole period.

The growth of the PQ for most complex industrial processes without external disturbance shows a logarithmic rise. This is due to a sharp rise in performance as the plant is run up, followed by a steady rise, but with decreasing rate, as the plant operators gradually optimise the performance. Any major change to the plant or operating strategy will cause a discontinuity with another logarithmic curve rising from the time of change.

The logarithmic rise will have the equation—

$$PQ_t = PQ_m(1 - e^{-t\ T})$$

where PQ_t is the instantaneous PQ value at year t,
PQ_m is the maximum theoretical PQ value or ceiling and
T is the time constant of the curve in years.

Curves of the component parts of the PQ may be plotted to aid interpretation of past performance variations. These components of the PQ can be broken down and presented as a diagram showing the flow of cash through the process, culminating in the final profit. Such a diagram is helpful when locating areas of the process that make a major contribution to the PQ.

Data collected by the accountants can usually be presented directly as a cash flow diagram. The items that contribute directly towards the production of the product—such as raw material and steam costs—can be separated from fixed costs such as rents, insurance and management overheads. Other items such as labour, maintenance and warehousing must be investigated at the source and a decision made on whether or not extra production will cause an increase in costs. This separation into fixed and throughput-dependent costs enables the profit associated with extra production to be established. If the extra product can still be sold for the original selling price and if the fixed costs are high, the profit per unit for the extra production will usually be much greater than the mean profit per unit.

A typical application of the performance quantity technique is illustrated by Fig. 2, which was generated in the course of a recent computer feasibility study. The past performance of the process involved was studied for the period 1962–67 and a PQ growth curve calculated that showed the expected logarithmic rise (Fig. 3). During the early part of 1968, a major process modification was implemented, thereby introducing a significant discontinuity to the curve. It was possible, of course, to determine the theoretical maximum for this post-1968 curve and, by assuming a growth rate similar to that of the

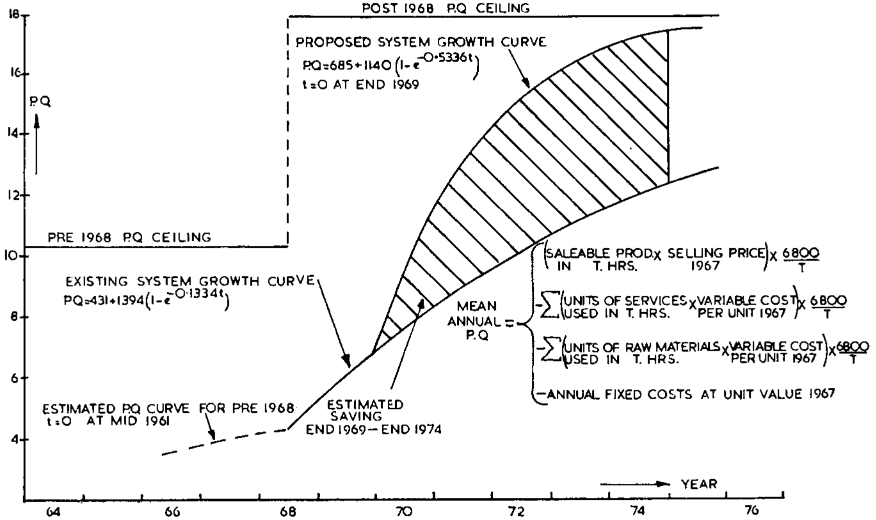

Fig. 2—Growth curves showing potential saving

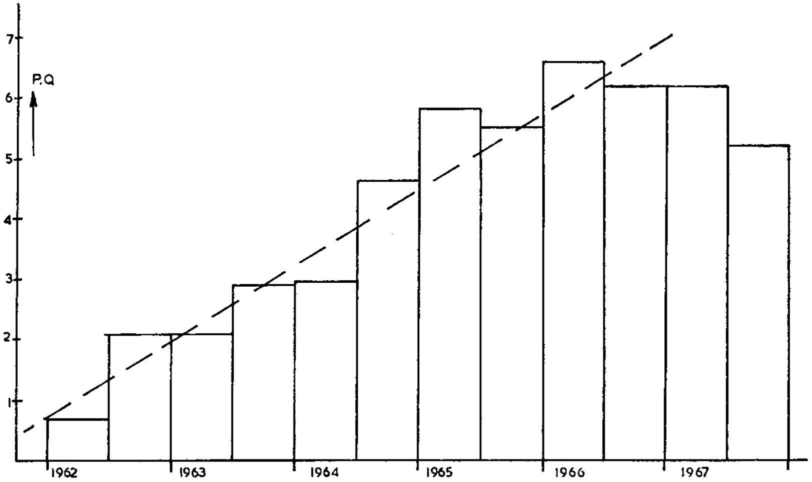

Fig. 3—Performance quantity trends 1962–67

pre-1968 period, the current performance curve extrapolated to 1974 was determined.

The study assumed that a computer system would be installed and available by the end of 1969. It was considered that, as a result of this computerisation, the process would be optimised at a faster rate. Firstly, process stability would enable process relationships to be established more quickly and would also make the assessment of performance at a particular operating state considerably easier. Secondly, an organised approach to optimisation, preferably involving frequent assessment of the PQ, would speed the rate of optimisation. It seemed probable that each of these factors would increase the rate of optimisation by at least a factor of two, hence both together should effect a fourfold improvement. The computer system would not directly affect the theoretical maximum PQ.

A growth curve for the process with the proposed computer system was therefore determined for the period 1970–74. The area between this curve and the post-1968 curve indicative of current performance was determined and this represents a sum of money equivalent to the increase in return over the years to be obtained by the computerisation.

Selection of the computer system

FOLLOWING the decision to proceed with the computerisation, various manufacturers were approached and invited to meet Bowater management and technical personnel. At that time, experience of computer control within the organisation was negligible and therefore the company was looking not only for a hardware/software package, but for a manufacturer interested in participating in a joint project that, although designed to be economically viable, was also to have a research and development aspect. It was our opinion that several computer manufacturers could provide the quality of hardware and software packages required, but we thought that it was in our best interests to purchase from a supplier who had the type of organisation and individual personalities best suited to match our own. The intention has always been that this first installation should lead into a long-term program, involving the application of computer control to some extent or other to each of the papermachines in the U.K. group.

The choice of actual system was therefore a secondary consideration at that time. Nevertheless, the more obvious details of software and hardware design were looked at and, as our understanding has increased, their significance has become more obvious. It is the less obvious points, however, that are now of particular interest to us and are those upon which we place greatest emphasis in our plans for the future.

In selecting hardware, along with details of core cycle speeds, instructions range, etc., we would consider carefully the following—

1. Degree of modularity.
2. Design for easy extension and modification.
3. Likely reliability and failure rate.
4. Quality of maintenance back-up and supply of spares.
5. Type of output stations and their compatability with standby equipment.
6. Type and quality of peripherals, especially operators' consoles.

The selection of software is considered more difficult, especially in the light of the apparently high rate of development and change. In general, however, it needs to be flexible and designed to be used by process engineers, not skilled programmers. Therefore, we would look for the following features—

1. Modular executive program.
2. System of autonomous packages.
3. Engineer-oriented language.
4. Simplest acceptable approach to a problem.

After some consideration, Bowaters selected a CON/PAC 4060 computer coupled with Kent interface equipment. The system was purchased with the standard monitor executive, together with various functional and interrupt driven programs, including one for direct digital control (DDC), which were written by the manufacturer's programmers. Bowaters chose at that stage to employ no full-time programmer of their own, but to set up a joint systems team with the manufacturer. The team was totally responsible for the project and consisted of two people from each company. This team has since been increased to include additional Bowater personnel during the commissioning and implementation stages.

Computer specification

Central processor Parallel arithmetic unit with 16 384 (extendable to 65 536) 24-bit word core store, having a 1·6 μs cycle time.

Locations up to 16 384 are directly addressable.

Above 16 384 words relative addressing permits preassembled programs to be located anywhere in the core store and be obeyed without address alterations.

Odd parity is written on transfer into memory and checked during read-out.

Seven index registers were available.

Program load was wired in.

Automatic priority interrupt system Continuous sequential scanning of 48 priority levels (extendable to 64).

Both inhibitable and non-inhibitable types available; the latter for use generally as pulse counters.

Operator communication system Digitronics paper tape reader—photoelectric sensing, 100 characters/s, seven channels plus parity.

Westrex paper tape punch—100 characters/s, seven channels plus parity.

2 IBM model 735 typewriters—15·5 characters/s.

Peripheral buffer capable of handling up to 8 items.

Programmer's console.

Operator's panel.

Process communication system Analog input scanner controller, low level amplifier with common mode rejection, successive approximation analog-to-digital converter capable of handling up to 1 024 inputs with up to 8 group advance.

Multiple contact output controller, capable of handling up to 32 groups (extendable to 64) of decimal outputs (4 per group), binary outputs (16 per group) or analog outputs (1 per group).

Digital input controller capable of handling up to 64 groups of 23 bits plus error bit.

Automatic stall alarm

Automatic sequencing of computer shutdown and start-up

Total project strategy

THERE are three categories of control function that will benefit a papermachine. Firstly, those aspects of present practice that will be improved by more precise control and that can easily be automated. Secondly, those aspects that hold out promise of large returns based on development and the use of optimisation and integrated control techniques. Finally, those aspects that will yield only to the most powerful computer techniques just now being fully exploited in the field of process control.

With these ideas in mind, it was decided that a phased approach should be adopted towards the project. Five phases were planned and orders were placed during August 1966 for phases 0 and 1, together with the necessary facilities for easy extension at a later date. The phases were—

Phase 0—The planning and preparation phase

Phase 1—Implementation of control functions of immediate benefit using established techniques.

Phase 2—Development of new papermachine controls and application of steady state optimisation techniques.
Phase 3—The inclusion of associated finishing processes.
Phase 4—Application of advanced techniques.

Phase 0 was expected to last about 12 months (the time for delivery of the hardware). The first quarter of this period was given over by the systems team to the detailed design of the control system in terms of computer inputs and outputs, which was essential for the building of the hardware configuration. For the rest of the period, the team was involved with all the planning and preparatory analysis that needed to be completed before delivery of the computer. They controlled the project using a PERT analysis updated on a monthly basis. Through this, the various activities associated with programming, hardware manufacture, instrument selection and installation, cabling and numerous building and erection tasks were co-ordinated.

In addition to the basic task of designing a control configuration, all other aspects of the total computer system required to be considered and suitably phased into the project. As decisions here reflected the entire philosophy of the project; these aspects represent an important part of the total system and are therefore worthy of mention at this point.

The standby system

The existence of a reliable standby-to-computer system is considered essential and full consideration was given to all possible system types. These range from the fully redundant system, employing a second computer, to an entirely manual system in which, in the event of a computer failure, the operators are left with merely *raise/lower* facilities. It was agreed that the standby system should match in complexity the computer/plant system, although it should also be economically justifiable in itself. The design was tied therefore to economic calculations based on estimates of computer *mean time between failures* and *mean time to repair.*

The chosen design(2) is an external digital system (that is, non-supervisory) based on three levels of standby control. Important control loops are provided with full two-term or three-term, bumpless controllers, less important loops with more simple two-term, manual set point controllers and the remainder with purely manual controls. In order to minimise production losses, the system includes automatic transfer facilities, with switching to standby control being effected by various hardware and software links. Manual transfer is retained for emergency use. There is an ‘all or nothing’ philosophy, whereby no single loop can go to standby alone. Each loop, however, can be separately manually adjusted through the computer. Standby control on No. 16 machine is through stations situated around the plant rather than as a whole in the computer control room. It therefore involves the full machine crew.

There are six bumpless controllers acting on the following loops—

Stuffgate flow
Stuffgate consistency
Flow box head
Second dryer section pressure
Third dryer section pressure
Fourth dryer section pressure

Each controller, which is situated in a convenient local control station, has its set point automatically updated by the computer until it is brought into use when either a computer/local switch is adjusted to allow overriding local control or automatically in the event of computer system failure. Control constants are adjusted at the controller.

There are ten simple controllers acting on the following loops—

Rough chest consistency.
Broke chest consistency.
Fine chest consistency
Stock flow to proportioner
Broke flow to proportioner.
First fine chest level.
Second line chest level.
Flow box level.
First dryer section pressure.
Fifth dryer section pressure.

The controllers are situated in the interface cubicle in the computer room, but manual set point adjustments are made at local control stations. The controller output shares a path to the plant with the normal computer output.

The standby controllers represented in themselves a new type of control for the machine operators and it has therefore been necessary to implement a training programme that has included a period of continuous running with the equipment in use.

Operator information

Particular importance was placed on the need to compensate the machine operator for removing him from the machine floor. Therefore, considerable care was taken in the choice of design and facilities of the computer rooms.

Two rooms are provided—the computer room and the control room (Fig. 4). The former contains all the computer and interface hardware, tape preparation and editing equipment and other general facilities for technicians and programmers. The other room is intended essentially for the purposes of controlling the computer/plant system and is used primarily by the machine operator.

There are five television cameras sited along the papermachine and a further one in the quality control laboratory. The operator can therefore survey the process from the control room by switching among these cameras, using three monitors situated in the room. There is also an intercommunication system,

Fig. 4—General view of computer rooms

allowing up to a seven-way conversation, which covers the full papermaking process. The intercommunication control is situated on the main control desk, together with the operator's panel and a single typewriter (Fig. 5). This typewriter provides a permanent record of all actions taken through the operator's panel, together with alarm conditions and any logs that may have been put out either automatically or on demand. There is a range of special short length logs available to the operator specially designed to enable him quickly to ascertain the state of his plant. The use of abbreviations and mnemonics here is minimised to reduce the risk of confusion. Of particular interest are the alarm log (which lists all loops currently in a state of alarm) and a series of sub-logs, each giving data about perhaps only six or seven variables.

Although functionally adequate, the manufacturer's standard operator's panel was redesigned for both ergonomic and aesthetic reasons. For this task, the systems team was joined by an industrial designer.

The panel (Fig. 6) is divided into two sections. The left side facing, which has a blue background, is given over essentially to control functions and the other side, which is white, to information functions. Lamps, switches and buttons are variously coloured; data displays make use of correspondingly coloured floods. A special feature is the use of a dual flood for data input using the *check/execute/cancel* switch, whereby the value is checked using an orange background that turns green once the change is accepted or cancelled.

Fig. 5—Operator information and control station

There are three digits available for addressing and each address can refer to either a fully functional control loop or a simple software logic switch. In the former case, the following ten functions are available—

Measured value (MV)
Desired value (DV)
Maximum change in DV allowed (△DV)
Three control parameters (P,I,D)
Two absolute alarm levels (HA, LA)
A control alarm band (CA)
Manual positive valve positioning (MPP)

Each loop can be switched on or off individually, whereas depending on the status, either the DV or the valve can be stepped by various preset amounts. Usually, only the *on/off* feature applies to logic addresses, although MV or some other function may be used to relay data. A set of reference sheets is available to act as a directory to panel addresses (Table 2).

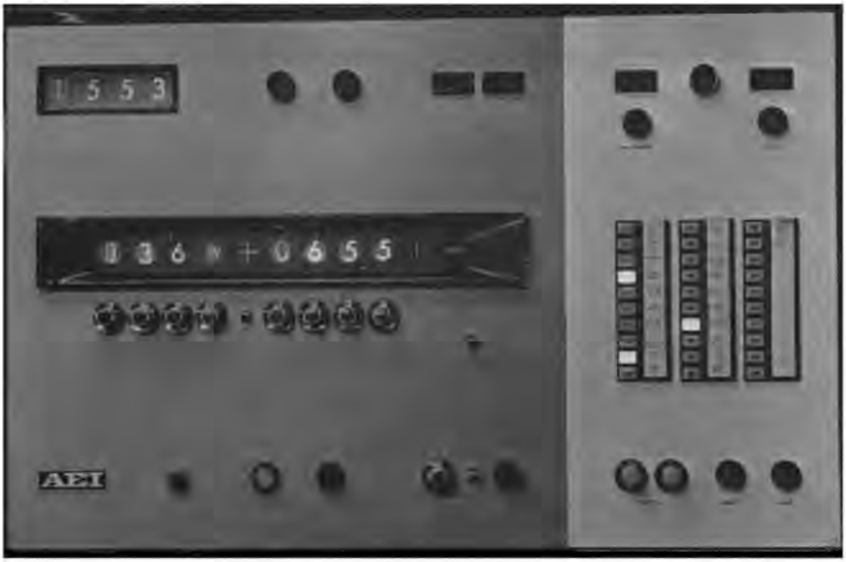

Fig. 6—Operator's panel facia

Other features of the panel include a digital clock, alarm lamp and buzzer, keyswitch protection on most functions, a *type displays* button and selection of up to 30 logs. Switching to computer control can be effected only through the panel; manual switching to standby control can also be achieved in the event of an emergency. There is a *not accept* lamp that is illuminated in the event that some panel action offends a wide range of safety checks.

Management information

A comprehensive range of operating records and efficiency reports was developed and designed to eliminate the need for other records for this particular machine. Typical of these are—

The papermaker's log A list of instantaneous measured values of all variables of interest to the papermaker, with those out of specification typed in red (Fig. 7).

TABLE 2—TYPICAL PANEL REFERENCE SHEET

Code	Title	Normal DV range	Scale	Units	Alarm group	Log code	Slave loops	Master loops	Notes
S.0 0.	Rough chest level	0–136	—1	Inches	1	0			
S.0 1.	Rough chest consistency	3–6	−2	Per cent	2	1		S.23	
S.0 2.	Broke chest consistency	3–6	−2	Per cent	2	2		S.28	
S.0 3.	Stock flow to proportioner	0–1 000	0	gal/min	2	3		S.32	
S.0 4.	Broke flow to proportioner	0–400	0	gal/min	2	4		S.29	
S.0 5.	Alum flow to proportioner	0–100	−1	gal/h	2	5		S.30	
S.0 6.	Size flow to mixing pump	0–200	−1	gal/h	3	6		S.31	
S.0 7.	Second fine chest level	0–196	−1	Inches	1	7			Overflow at 194.5
S.0 8.	Fine chest consistency	3–6	−2	Per cent	1	8		S.34	
S.2 0.	Hydrapulper water	0–15 000	+1	Gallons		21			
S.2 1.	Hydrapulper clay (cor.)	0–1 000	0	Gallons		22		S.22	1 box = 100 gal
S.2 2.	Hydrapulper clay	0–1 000	0	Gallons		23	S.21		
S.2 3.	Rough chest cons. comp.		−2	Per cent		24	S.01		
S.2 4.	First Shartle power	0–400	−1	kW	2	25		S.25.S.39	
S.2 5.	First Shartle power/flow ratio		−2	kW/gal/min		26	S.24		
S.2 6.	Second Shartle power	0–400	−1	kW	2	27		S.27.S.40	
S.2 7.	Second Shartle power/flow ratio		−2	kW/gal/min		28	S.26		
S.2 8.	Broke cons. compensation		−2	Per cent		29	S.02		
S.2 9.	Broke ratio	0–50	−1	Per cent		30	S.04	S.33	

Fig. 7—Typical papermaker's log

The engineer's log A full list of current status, set point, measured value and control equation constants stored for all control loops (Fig. 8).

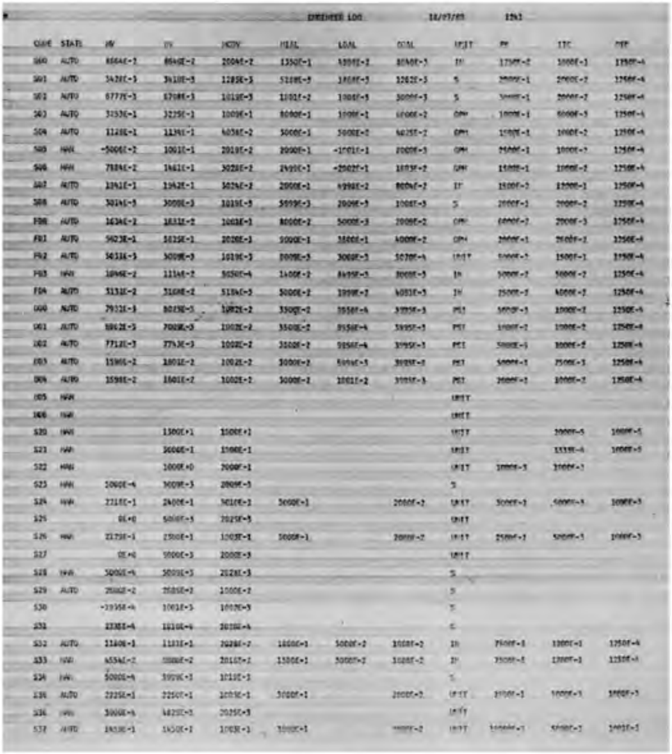

Fig. 8—Typical engineer's log

The shift or grade summary A summary of the average basis weight, machine speed and deckle, calculated production, a broke analysis and the average values and standard deviations for numerous process variables over the last shift or making.

Profile logs Typewriter plots of the cross-machine values of basis weight, moisture content and slice position (Fig. 9).

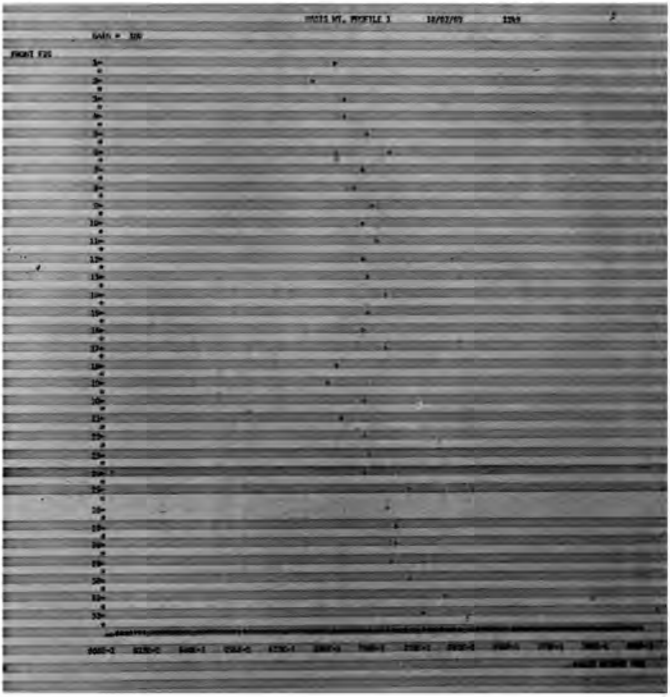

Fig. 9—Basis weight profile log

Trend logs Typewriter plots of up to four process variables at any time, sampled at one of four sampling intervals and containing the most recent 32 sampled values (Fig. 10).

Operator training

A programme for operator training was drawn up that, because of the lengthy time scale involved, had to be carefully planned in order to maintain interest.

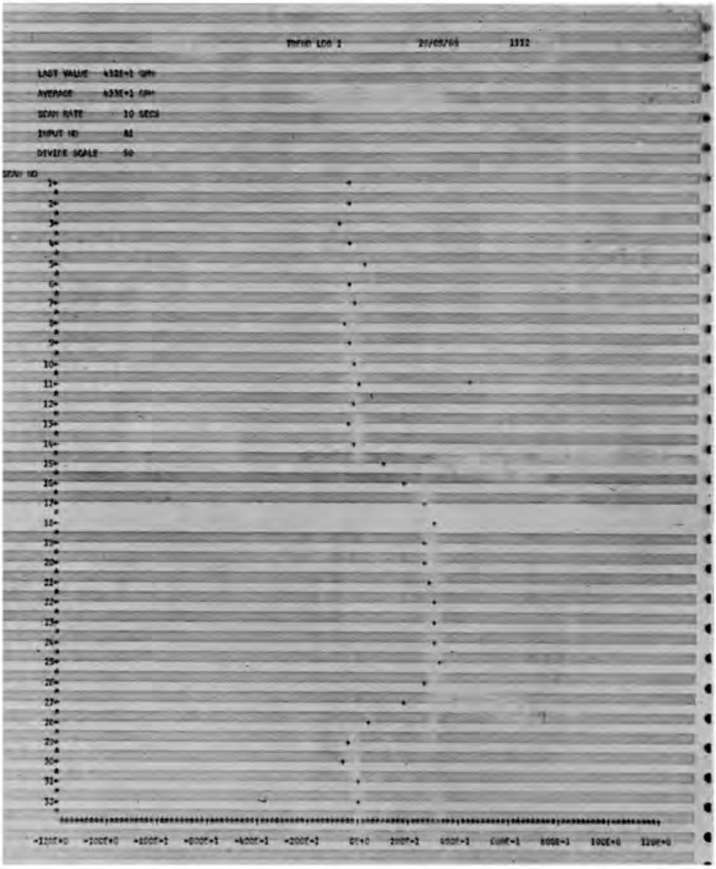

Fig. 10—Typical trend log

An operator's manual written by the systems team was presented in the first instance to the operators and supervisors, section by section, at a series of lectures. In general, these were given by the mill training officer. The sequence of 15 lectures was—

1. Introduction to a typical control loop.
2. Control room facilities.
3. The information and data system.
4. Simple on/off and manual controls.
5. Special and emergency routines.
6. Direct digital control.

7. Control of the vertical pulper and the proportioning system.
8. Control of consistency and the refiners.
9. Control of the flow box and speed and draw.
10. Control of basis weight and moisture content.
11. Manual standby facilities.
12. Simple standby control.
13. Bumpless standby control.
14. Start-up and shutdown.
15. Fault procedures.

Each lecture was given six times to allow full coverage from each shift and typical attendance was 12 men per lecture.

The programme of lectures was commenced in March 1968 and continued through to June. Following this, the manual was modified in light of comment and response. A copy of the final version was issued to each senior operative and supervisor during October-November, when a programme of panel instruction and practice was also carried through by the systems team. The manual is not designed for minute-to-minute use, for which reference sheets are of more value, but as background information, During December, detailed on-line instruction in the use of the standby system was given. Since January 1969, the machine operator has been responsible to some extent or other for the computer/plant system. Planned instruction continued through to June with full shift support being given by the systems team and extra cover by production personnel when necessary. It is anticipated that retraining and updating of the operators' understanding will be necessary for some considerable time, especially while changes or extensions to the computer system are being made.

Special routines

A range of special routines was developed aimed at providing a wide range of system checks. The group termed *Emergency routines* was designed to carry out some sequenced routine in the event of a dangerous or unusual condition arising on the plant such as certain stock valve closures, wire shuts and paper breaks. Others are more concerned with possible defects in the computer hardware or software. These latter routines were designed to be extremely searching and are in-line with the fail safe philosophy adapted for the project.

Instrumentation and cabling

The systems team joined with the instrument engineer in the selection and siting of instrumentation. In general, a policy of standardisation has been adopted. The task of instrument and cable scheduling was taken on by the systems team, together with the responsibility for ensuring that correct calibrations are maintained. Advice was obtained from the computer manufacturer on best cabling practice, as mistakes here are likely to be especially difficult to clear up.

All inputs and outputs to the plant are linked through a marshalling cubicle situated in the computer room. Each line is capable of being broken at this cubicle for the purposes of testing and maintaining plant safety. All inputs are capable of being relayed to a multi-point recorder also situated in the cubicle.

The control system

THE control system is based on the use of a standard DDC program used in conjunction with special programs written for control functions requiring a more complex approach than simple DDC allows.

The No. 16 machine control system comprises 106 control loops, only 19 of which are simple DDC. In addition, about 50 other measured variables are fed into the computer for purposes of logging and later phases and there is the ability to switch in excess of 30 pumps and actuators.

The DDC program calculates control outputs in a form suitable for output to the interface equipment based upon a two-term or three-term incremental control algorithm of the form—

$$\Delta VP = KA_1(\theta_n - \theta_{n-1}) + A_2\theta_n\tau + \frac{A_3(\theta_n - 2\theta_{n-1} + \theta_{n-2})}{\tau}$$

where ΔVP is the valve position increment,

suffix n refers to the nth sampling interval,

K is a function of the gain,

A_1, A_2, A_3 are constants and

τ is the sampling interval.

All changes to the control constants may be effected as keyswitch-protected options through the operator's console. More fundamental changes, such as the selection of control terms, are made on-line through the computer console via the block of storage associated with each loop. The program accommodates cascade control loops, prevents integral saturation and employs both input and output filters. Associated software enables each measured value to be checked for high and low alarm levels, control alarm levels and has various manual action facilities.

The complex control loops come under the following nine headings.

Pulper control

The addition of water and clay through pulse meters is controlled so as to present uniform stock to the first consistency controller and to the refiners (Fig. 11).

The operator is responsible for the addition of a constant total weight of fibre at each charge and the computer supervises preset water and clay additions initiated by a *batch commence* button. Once the additions are completed, the computer shuts the water and clay valves and illuminates a *batch complete* lamp on the pulper panel. For purposes of wash-down, the operator has local manual control over the water valve. This overriding control is available, however, only within each batch and the full preset quantity must be taken. There is a density meter situated in the clay ring-main and this is used to facilitate computer corrections for density variations by adjusting the DV of the clay addition loop.

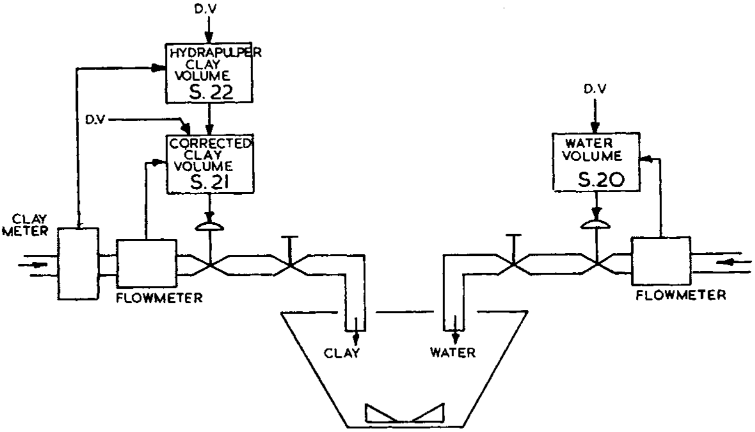

Fig. 11—Hydrapulper complex loop

Compensated consistency control

The simple consistency DDC loops, which are located on the rough stock, broke, fine stock and at the stuffgate are compensated for fluctuations in stock flow and temperature (Fig. 12).

The computer allows for easy adjustment of constants for calibration of on-line measurements and of the compensation curves, each of which is defined by an origin, flow or temperature increment and eighth incremental corrective factors over the range of flow or temperature concerned. The compensation is applied to the set point of the consistency loop.

Refiner control

The refiners can be controlled (Fig. 13) so as to maintain either the ratio *refiner load/stock flow* or the temperature differential across the refiners.

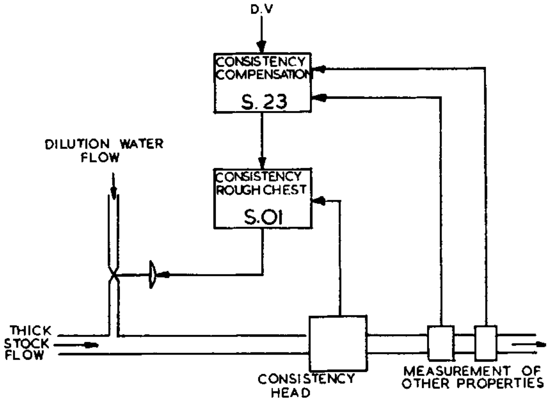

Fig. 12—Compensated consistency complex control loop

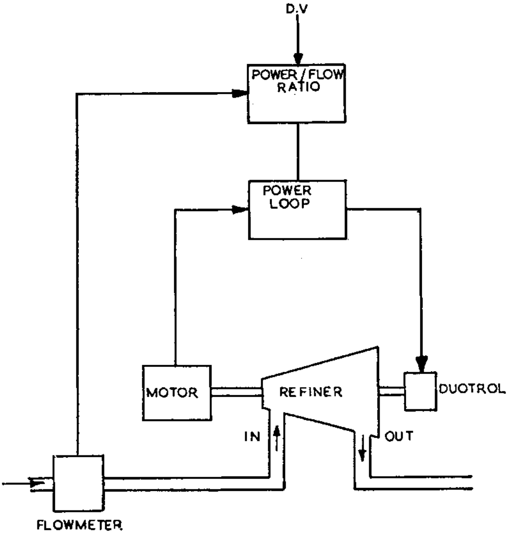

Fig. 13—Refiner complex loop

The control action takes the form of *raise/lower* signals to automatic plug positioners. Although these are equipped with suitable limit devices, the computer system critically surveys each output and checks for safety. Automatic back-out by computer is an important facility.

Proportional control

The flows of stock, broke and alum into the fine chest and size at the mixing pumps are controlled to obtain proportions specified by the operator (Fig. 14).

The chest level cascades to the stock flow and the broke and alum components are, in turn, ratio-controlled to this. Size is ratio-controlled to the stuffgate flow. The simple DDC loops on the various flows can of course be maintained independently of the complex loop.

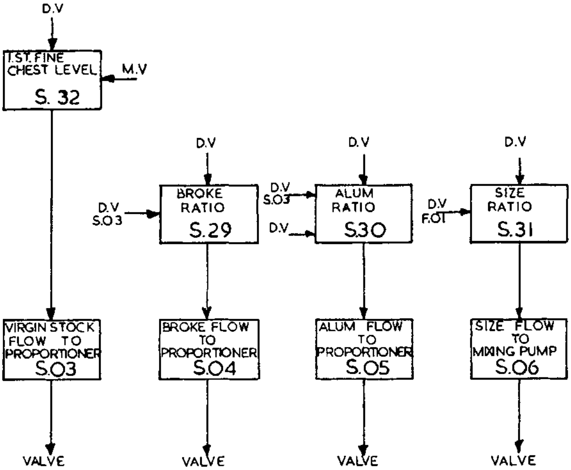

Fig. 14—Proportioning system complex loop

Flow box control

The closed, pressure flow box is controlled to enable the operative to adjust the stock consistency and efflux ratio independently The flow box is equipped with an adjustable slice (Fig. 15).

Various control configuration options are available and can be easily implemented by adjusting the complex loop-addressing format. It is possible, using simple DDC to supply set points to the head, level and slice controls alone.

Cross-machine slice gap adjustment

The cross-machine slice profile is adjustable through 31 individual adjuster motors, each capable of receiving *raise* and *lower* signals as required. There is a built-in safety check being continuously carried out, which prevents an excessive adjustment between two adjacent units. A display of the actual profile is available as a typewriter plot and plans are being prepared for closed loop operation in a later phase.

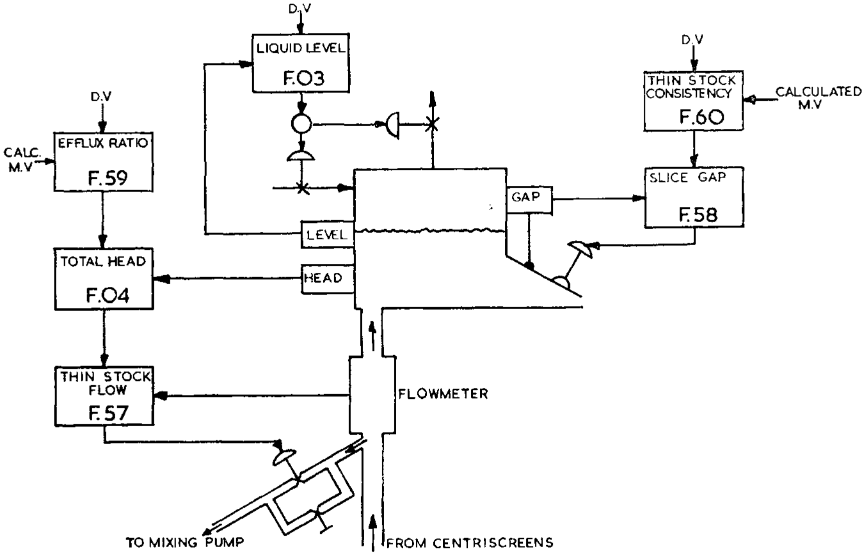

Fig. 15—Flow box complex loop

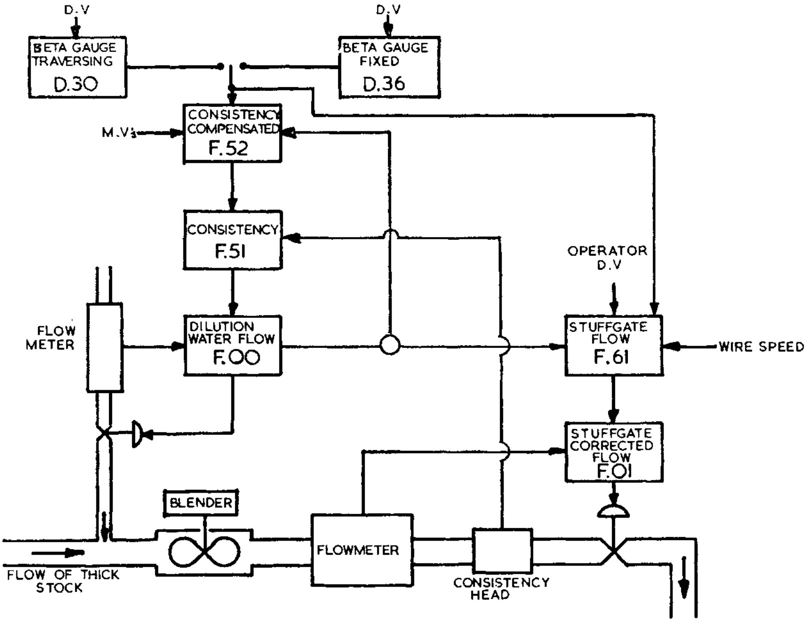

Fig. 16—Basis weight control complex loop

Basis weight control

Basis weight is measured by sensor heads at both the reel and before the size press. Although it is normal for both gauges to be traversing, control is available for the fixed head condition. In this case, the substance measurement is presented to the control system as a filtered, mean value and, for the purposes of traversing head control, as a traverse average (Fig. 16).

The trimming control action is through adjustments to the set point of the stuffgate consistency control loop, which cascades to a simple dilution water flow loop. The flow of thick stock at the stuffgate is initially set up for the current grade and is automatically tied to machine speed. If a change in basis weight DV is made, then the stuffgate flow set point is adjusted accordingly. Similarly, it is adjusted if the consistency control moves to a preset control range limit. In this event, an equal percentage adjustment is made to the consistency control set points.

An automatic calculation is done to check beta-gauge calibration. This is obtained from the weight of the steel core, weight of the full reel, sheet width and a precise measure of the length of paper on the reel. There are a series of checks carried out to ensure that the calibration is reliable. In addition, there is a laboratory data input channel that enables the latest laboratory value and the internally corrected value of, basis weight to be compared. If these differ markedly, a warning message is printed out.

Moisture control

The sheet moisture content is measured at both the reel and before the size press and is presented to the control system as a filtered, mean value. Moisture control is effected by means of adjusting the set points of the machine dryer sections (Fig. 17).

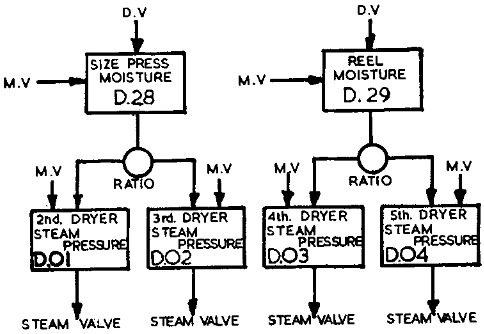

Fig. 17—Moisture control complex loop

The main dryers are in three sections and size press moisture control is through the second and third of these. The two sections are also ratio-controlled, thereby introducing an additional degree of flexibility. The two sections of the after-dryers control reel moisture in a similar manner.

Speed and draw control

The machine speed is controlled by a simple DDC loop operating on the main drive motors, whereas individual sectional draws, monitored by pulse interrupts, are controlled to preset values by means of adjustments to cone and pulley units. Sectional speeds are available as measured values (Fig. 18).

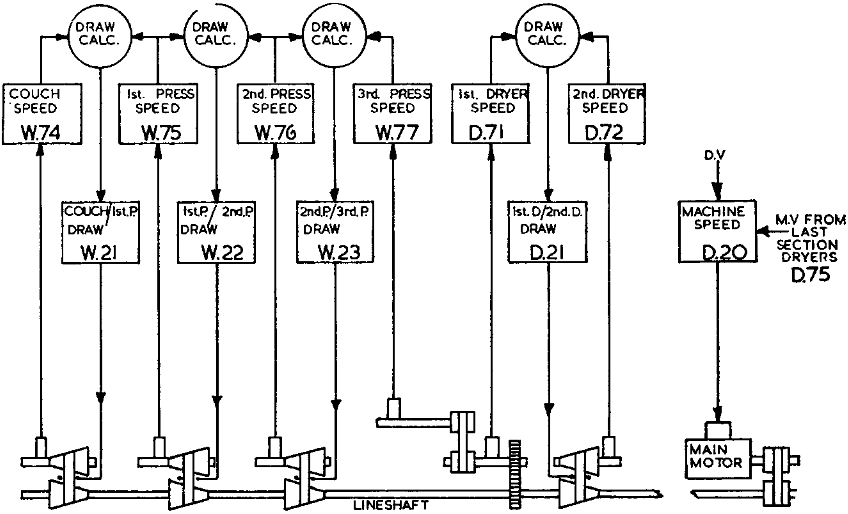

Fig. 18—Speed and draw complex loop

The speed of the first main dryer section, which acts as the master speed section, remains in constant ratio to that of the main lineshaft. On either side of the master, there is sectional draw control, with adjustments being made to that section furthest from the master. Under normal circumstances, the response of this system is slow and it acts as a trimming control. The local manual adjustments have been retained, but when the automatic system is working they only have a short-term effect. If an emergency draw condition is detected, for which the trimming action would be too slow, there is a facility for locking out the normal draw control and introducing a form of feedforward control that resets the entire speed and draw system.

Phase one

ONE problem during the early planning stage was the prediction of the duration of phase 1. It was possible to obtain estimates for hardware testing and proving, program testing and for the initial system commissioning, but the time necessary for the tuning of the system seemed more difficult to predict. In fact, phase 1 was planned to last 12 months from the date of delivery of the computer hardware, expected during August 1967.

The first major delay to the project arose, however, through late delivery of the computer. Arriving during the first week in January 1968, it was some 18 weeks late. This therefore largely invalidated the need for the PERT analysis, which otherwise had been extremely valuable, once it was generally accepted by the various groups associated with the project. The software was ready well in advance of delivery, but had to wait on the hardware before it could be tested. This need not have been the case had a suitable simulator been available at the supplier's site.

All further delays in the project have largely been due to hardware faults, which were particularly common during the period immediately after initial hardware commissioning. At the time of writing, availability since completion of hardware testing has been only about 70 per cent, but has fortuntately maintained an acceptable level over the last six months since the major sources of difficulty were overcome. Software has caused little or no delay. Systems work has gone according to plan, except for a period of delay caused by a total changeover of personnel on the supplier's side. This naturally involved the project in some loss of continuity and momentum. One other delay arose through the need for an additional reassembly of programs as a result of limited working space.

In general, hardware faults have first shown themselves intermittently and have therefore been difficult to isolate and repair. They seldom took long to put right once they were located, but the delays they brought about were damaging to both progress and morale.

Analog inputs and scanning difficulties have been responsible for many of the delays and have resulted in a modification to the low level amplifier and a number of grounding alterations. The delays were greater as a result of the unfortunate failure of the analog-to-digital converter, normally accepted to be a reliable piece of equipment.

In all, some 6½ weeks have been lost through arithmetic unit faults, but they have not been apparent for some considerable time and it is hoped that they were largely the teething problems of a new system. It seems very likely that their frequency was unduly exaggerated by the relatively high ambient temperatures common in the control room before the present cooling system was introduced.

Parity errors have accounted for a large part of the total delay. In general, these have been in data areas and could quite safely have been ignored. The computer system in any case checks for such errors and we have chosen that this check should stop the computer system, thereby enabling some action to be taken. It appears now that they are becoming increasingly less of a problem; unfortunately, the reason for this is not completely clear.

Comment on hardware faults would not be complete without reference to the high failure rates of peripherals, especially typewriters, which alone have accounted for several lost weeks of systems work.

Computer hardware, interface and peripheral equipment installation and and testing commenced immediately on delivery. During this period, the systems team commenced testing of the standby system in readiness for the phasing out of conventional controllers. Plant inputs and outputs were made available to the computer through the marshalling cubicle and all lines were checked for continuity. All this work terminated in early April 1968 with a week of testing, using a series of standard routines designed to check out fully the complete hardware system.

On completion of this first stage of phase 1, the programmers commenced their task of testing and initiating the software, starting with the basic organisational programs and following up with the various system programs. This work facilitated the systematic testing of all plant inputs, both digital and analog and involved the early proving of all basic alarm, console and information logging programs. Once these operated in a satisfactory manner, all inputs were linked permanently to the computer, measured values were accurately set up and the computer's basic data system was brought into full-time use. This availability was fitted into the operator training programme, which was proceeding in parallel.

Thereafter, specific functional programs (of which 18 were written) continued to be brought into use one at a time and, once proved by the programmers, they were commissioned by the systems team. When appropriate, checks were made on the output lines at the marshalling cubicle before they were linked through to the plant. One of the first programs handled was that one associated with the standby switching, which was essential for the well being of the production unit during later stages. This was followed by the program controlling the numerous special routines. The DDC package was then made available and each loop was tested, brought on-line and tuned individually. At this stage, the standby system (which had been fully com missioned) was totally phased in and became the first line of back-up to computer control. Training of the operators in the use of the standby system was immediately completed.

Numerous other activities were of course going on during these early commissioning stages. Important among these were instrument and cable scheduling, instrument proving and calibration, program modifications. Preliminary testing of the complex loops was also being carried out and serious effort was directed to these during December. The original phase 0 estimate for their implementation was 20 weeks.

Comment

THE commissioning of the complex control loops is nearing completion 18 months after delivery and coincides with the writing of this paper in June 1969. In light of the significant delays experienced in the early stages of phase 1, the progress of systems work has been quite good. The project team is particularly pleased by the degree to which the computer system has been accepted by mill personnel, particularly the machine operators.

Although practically every part of the system as designed in phase 0 has been seen to work and a large part is freely available for use, there are areas of disappointment. Speed and draw control testing has been difficult to fit into the production schedule, slice profile instrumentation has failed to keep working and compensation data has proved difficult to obtain. Altogether, the expected performance of the computer system is not immediately forthcoming and work is continuing on the tuning of the individual control areas. It is hoped that this will be effective by the end of the year and that the benefit to the process will be self-evident by that time.

The whole project has of course been a learning exercise for Bowaters and, now that higher system availability can be expected, this process must continue, although it may appear to slow down progress. The present stage of the project has been reached with only about 10 man-years of Bowater effort, plus a similar amount from the manufacturer; the Bowater team has recently been enlarged, particular effort is being put into the task of tuning and day-to-day responsibility for running the papermachine through the computer rests with the operatives. It seems likely that the tuning process may continue for some considerable time, especially as the long-term benefits of the computer, as a learning tool and means of freeing the operative from tedious control duties, become more significant.

A number of lessons have come out of the Sittingbourne exercise that will not be forgotten in future projects. The value of energetic project management cannot be overemphasised. Computer installations are all-embracing in that they inevitably involve all departments within the production unit concerned. Therefore, particular care must be put to organisation and information distribution if the whole project is not to founder through petty jealousies or local incompetence. Worthy of mention again, at this point, is PERT or critical path analysis, which is invaluable to a computer project.

A planned programme of operator training together with a reliable and relatively comprehensive standby system have proven to be useful in maintaining interest during early days and a source of confidence throughout.

The value of operating records and reports can be greatly overstressed. They are very heavy on computer storage and, except in the concept of the fully automated mill, should be reduced to a useful minimum. The paper industry should be striving for the fully automated mill.

The total dependence of a computer system on instrumentation has been confirmed. It is unwise therefore to commence a computer project, without this fact being generally accepted and the necessary action taken to ensure that good quality hardware and technical support will be available at all times.

It is intended that a full evaluation of the benefits of the computer system should be carried out at the right time. Bowaters have little doubt, however, that a suitably designed computer system will be an asset to each of our papermaking streams and this project has done much to clarify our thinking for the immediate plans for later phases at Sittingbourne and for at least one other machine in the U.K. group.

References

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2. Cyprus, H. D., Morley, R. L. and Hitchin, D. F., 'Standby to a computer control system': *Paper Tech.*, 1969, **10** (5), T93–T101

Discussion

Mr R. G. Nagro May I congratulate you on your paper and your computer system. You stated some estimates of the expected system payout. After having had some working experience, would you like to modify those or support them or is it still too early to tell?

Mr H. D. Cyprus I take it you are referring to the estimates shown in Fig. 1. I would not change them, except possibly to raise them somewhat. We have certainly not yet achieved those returns. This is partly reflected in the troubles we had last year; it also affects our lack of expertise, which is still being developed. I cannot see why we should not achieve those levels.

Harking back to my comments on performance quantity, I am not convinced we did not do ourselves, the management and the project a disservice by looking at it in this light—by isolating the return on improved regulation of basis weight, proportions of the constituents, etc., yet I cannot think of an alternative.

Mr J. Mardon My first point on Mr Cyprus's paper is my great difficulty in accepting the idea that one first chooses a computer, then undertakes the planning preparation phase. This seems to me a negation of what I might term the classical approach. First of all, the planning phase; then one should choose the pieces of equipment suitable for the specification when it is drawn up. I would appreciate Mr Cyprus's comments on that.

The second point is to say to Mr Nagro that the idea of having on-line access to the computer without in any way impairing its functionality for control has been taken into account in the design of the Bailey 855.

Mr Cyprus There seems to be a measure of misunderstanding. The planning and preparation phase that I referred to under the heading phase 0 was in fact detailed preparations and detailed planning in line with the decision to go ahead with this particular system. Of course, the company, working with more than one manufacturer, did a preliminary preparation and planning phase. This went on for some time before the decision to buy this particular system and it decided for us the general detail, for example, whether or not to buy a computer, whether an analog or digital, whether small, large or medium sized, etc. Phase 0 was detailed planning and detailed preparation, which must be done after deciding what equipment to use. Otherwise, I agree with your comments.

Mr W. D. Hoath Mr Cyprus mentioned that they had their own learning to go through in computer installation. What were the problems experienced? Were they hardware, software and how well did they keep within their budget costs? On the standby equipment, he is having to cope with several manufacturers. Was this a problem in itself?

Mr Cyprus With respect, I will not go into the detail on the first part of the question, because the answer lies fully in the paper. The troubles we had did not affect our costing, but I think the reason for this is maybe the way we organised the budget initially.

We had no great embarrassment because of different manufacturers. We know our instrument suppliers well and there were no delays through them. Although our interface and standby equipment was manufactured by one firm, it came as part of the supply from another firm in a satisfactorily phased manner. To be fair, the hardware was delivered late and therefore this may well have hidden problems that we might otherwise have had.

Mr M. I. MacLaurin Some of you may have heard me speak on the subject of computer project assessment earlier this year in New York.* Since that time, we have gained further experience in this area and, were I to speak again on the subject, I would be less assured of the practicability of the method I described, despite its theoretical merit.

The basic problem is not so much in comparing how well the papermachine performs now compared with the pre-computer period, but more in identifying how much of this improvement may properly be attributed to the effect of the computer.

Mr Cyprus I agree totally with you. It seems to me pointless to compare the 1965 performance (when we did our initial study) with running today. As I have suggested, this has no meaning. We must define a parameter, the performance quantity (which takes into account all those factors influencing performance) and monitor it continuously. Normally, it should show a logarithmic rise and a step to a higher level if some factor contributes significantly to the well being of the process. We have developed this growth curve for No. 16 machine for the last six years or so and will maintain it, hoping to see an effect attributable to the computer.

An alternative might be to take the computer off for a month, then put it back on, hoping to show the improvement. I consider this to be an impracticable proposition.

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* *Tappi*, 1969, **52** (8), 1 480—1 483