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THE FUTURE OF PROCESS CONTROL IN THE PAPER INDUSTRY

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History and philosophy of control systems

THE past decade has witnessed a major advance in the use of process control systems by the paper industry. Before that time, very few variables were controlled automatically, many instruments were either indicating or else, if controlling, were operated in the manual mode much of the time and the degree of instrument reliability and accuracy in the average mill did not promote operator confidence or use. Pneumatic controllers performing simple control loop strategies were the norm. Making paper was an art and frequently different papermakers would operate a machine in quite different ways to make the same given grade of paper. Fairly broad tolerances in paper specifications were accepted in the trade, since few machines could achieve or maintain very stable operations.

The economic pressures that developed during the fifties created two incentives to achieve improved process control—the trend to lower basis weights and the increased quality demands by the customer on the one hand and the need for greater operating speeds and machine efficiencies on the other. The rapid advances in electronic instrumentation, control system reliability and computer technology stimulated to a large extent by the space programme appeared to offer the elements of a solution. In several companies, this need for improvement in uniformity was broadly recognised and the early promises of utopia offered by the computer manufacturers captured the imagination of process engineer, paper salesman and company executive alike. In such a climate, optimism overstated the positive and ignorance overlooked the negative.

In 1961, the first installation of a digital process computer on a papermachine was heralded with much publicity, then quietly abandoned two years later. Another abortive installation was made in 1962 and seemed to this observer to have been primarily conceived as a paper sales promotional tool.

Under the chairmanship of D. Attwood

Several systems, coming on line in 1963, emerged during a period of scepticism and only after a radical departure from the initial control strategies suggested by the suppliers were they finally able to demonstrate the potential economic value of the process computer. Most of these installations are still in operation today. By 1969, over 70 digital control computers have been placed in operation or are on order by the paper industry—over 50 in North America and the balance in Europe. The majority are used to control papermachine operation although there are now several installations in the pulping and bleaching plant areas.

The most conclusive evidence that computer-based control technology will be the dominant theme in the future of process control in the paper industry is the growing number of companies operating multiple installations. Even though many accountants still debate the partition of economic benefits between systems engineering, improved instrumentation and computer control, the tangible improvements from their combined use have been recognised by operator and customer alike and have made computer-based or computer-compatible process control systems an accepted feature of most recent high-speed machine and pulpmill installations.

In spite of this proliferation of applications in an industry that, in the past, has been slow to embrace major developments with a high technological content, the present day state of development still exhibits very many signs of immaturity. The high cost of engineering analysis and software generation has shown to date little sign of reduction on successive installations. Instrumentation, hardware, software and control strategy are still rapidly evolving and the earlier ignorance of process technology that created the art of papermaking mythology has now given way to a belief by some that each new computer installation requires a brand new control strategy and an original software package. The long and expensive gestation period that precedes an installation, together with the shortage of skilled process and computer analysts to carry it out, have been the two major restraints on the growth rate of this new technology.

As a means of looking into the future, I have chosen to review the recent development of process control in the paper industry and to project some of the emerging trends and control concepts.

The early philosophy of the computer process control exponents was 'measure everything possible, feed the results into the computer, statistically analyse the signals, then calculate the appropriate corrective control changes'. It was assumed that these indiscriminate statistical models derived by regression and correlation analyses would substitute for our lack of understanding of the true process variable relationships. Perhaps the first significant finding of the early workers in computer process control was that, on a typical machine for much of the time, there was such a great amount of variation of a random or unpredictable nature that this type of statistical model was useless for control improvement. In computer lingo, excessive white signal noise gave garbage in, garbage out. One of the first criteria the Mead team established in the data-collecting phase of their work was to calculate an instantaneous material flow balance for the system and only if the balance closed within 5 per cent was the system sufficiently stable for the readings to be of value in developing a statistical control model. At this stage of the program, we became so submerged in data that it proved beneficial to re-evaluate the objectives of a process control system.

Objectives of a process control system

THE objectives of any process control system are threefold—(*1*) a uniform product, (*2*) a product with certain given quality specifications and (*3*) manufacturing it in the most economical manner possible—in short, stabilise-standardise-optimise, in that order.

A paper or pulp mill process contains some elements with very short transportation lags, some with very long ones and, in addition, some controllable process variables have very fast response times and others very slow ones. To achieve product uniformity under these conditions requires a system designed to operate in a *stable* manner—that is, we desire changes in a variable to occur only as the result of a deliberate control decision and that there be no—or, in practice, very little—uncontrolled or random variation. We cannot design a control system that can change process variables quickly enough to offset rapid, random variations in the process feed flows or composition. Stability for the most part must be designed into a system. It can usually be achieved more easily and at lower cost in a new installation than by modification of an existing one. The most appropriate first use of a computer on an existing machine is to locate and determine the causes of instability so that they can be corrected. This work is the role of the process engineer and must precede that of the control engineer.

Product specifications are frequently based upon tests simulating final use requirements. In these and many other instances, it is impossible continuously to measure the product specifications during production. Measurement and control of these properties depends therefore on the identification, measurement and control of other variables that have a high degree of correlation to the specified properties. The absorption coefficient for beta-rays, for example, is substituted for basis weight. There are two classes of variable—*process variables* such as roll and wire speeds, flow rates, material ratios and temperatures and *product variables* such as opacity, colour, surface texture, strength and porosity. Control theory assumes that, for a given machine, there is a relationship between a given combination of process variables and the resulting set of product variables—establishing the former set determines the other. Any set of process variables creating the desired product specifications is called an operating *standard* for the grade. The role of the control system is to adjust the process controls about the desired process standard to compensate for varying material inputs or other changing boundary conditions.

If a given grade can be produced by a number of different *standard* conditions, the final function of the control system is to select the most economical *standard* set taking into account the economic parameters associated with the specific order. Usually, a given grade can be made over a range of speeds, at each level of which there will be one or more operating standard sets. The economic parameters will include such factors as component raw materials costs, machine efficiencies as a function of speed, the cost of alternate ways of achieving a desired property and the costs associated with getting on and off the grade.

The unique role of the digital computer, in contrast to other control instrumentation and hardware, is its ability to contribute towards the attainment of all three control objectives. It can aid in identifying instability, memorising and achieving process standards, checking measured product characteristics against stored specifications and, finally, in selecting the optimum process economics.

The progress to date in the paper industry has been mostly towards achieving the first two objectives. In many cases, the early improvements achieved were a result of improved process stability rather than of computer control *per se*. In the control field, standardisation programs have been quite successful. Control algorithms (mathematical models) designed to imitate the behaviour of an experienced operator have also been successful and acceptable to the operators. Advanced control strategies based on sophisticated control theory have had limited application to date and it is only in the last few years that they are beginning to find a useful place as we gain a better understanding of process dynamics and the interrelationships of process variables. Process optimisation is beginning to appear in the bleaching plant area, where the incremental steps of brightness obtained from successive stages can be varied according to the prevailing cost of the different chemicals used. In no case, however, have we achieved the sophistication of the optimising function found today in certain food and petrochemical plants.

Process design—the pre-process control

THE important role that process design makes to subsequent control success has been emphasised above. A major change is taking place as a result of this realisation in the design of new mills. The prior emphasis of the chemical engineer on treating a system as a succession of essentially unrelated unit processes has given way to the systems engineer and an emphasis on process dynamics, interactions between variables and total systems behaviour. In this respect, the control system is no longer 'hung on' the process after the basic design is completed; instead, the system is designed with specific control strategies in mind.

How has this influenced paper or pulp mill design? In many ways—original layouts are made with instrumentation in mind, piping layouts and flow meter locations to ensure accuracy, gaps in the papermachine to accommodate traversing hardware, modification of flumes, silos, suction box separators, etc. to facilitate flow measurement. This trend will increase as we begin to control for additional product specifications. The advances and flexibility of control achieved by magnetic flow measurement has made this a preferred method for metering and proportioning feed flows. The improved control of flow and mixing that the magnetic flow meter has permitted has allowed the reduction or elimination of intermediate process chests, whose purpose was not that of storage, but of variable smoothing. This trend has the advantages of reducing transportation lags, elimination of many random consistency variations caused by inadequate agitation and economic savings both in capital, operations and pollution treatment, since the intermediate chests were either dumped to sewer at a grade change or increased the amount of off-quality paper produced at a grade change.

Recent findings in dryer research are drastically changing the approach to moisture control. The previous approaches of overdrying and remoistening or of segmented cross-machine drying at the end of a machine for uniform moisture profiles are being replaced by the use of controlled crown wet presses and more carefully designed dryer ventilation schemes. The prevention of product profile non-uniformity throughout the process is a more satisfactory and economical solution than the use of controlled cross-correction devices after non-uniformity occurs.

Other major advances have been made in the control of hydraulic instabilities from flow valves, pressure screens, head boxes and other mechnical and hydrodynamic devices in the system, all of which in the past have produced variations beyond the corrective ability of a control system.

System analysis has changed the design approach to such auxiliary components as whitewater savealls and broke systems. Both have been shown to cause previously unsuspected disturbances in the uniformity of the product, when operated in a conventional manner and disturbances in filler, drainage and porosity attributable to these sources persist for a long time after the original upset—a break, for example—has been corrected. Process design changes have minimised these variations and, in one case at least, resulted in a substantial increase in effective saveall capacity.

I believe the impact of a system approach to pulp and papermill design has only just begun and that the increasing political and social pressure for both air and stream pollution abatement will end up by requiring the paper or pulp mill design engineer to include these operations in his design strategy. Stated in an unconventional manner, a prime role of the systems engineer is to design out variation and cost and to reduce the need for sophisticated process control systems before the process is built.

Instrumentation—sensors and control elements

THE present trend in instrumentation is from the mechanical and the pneumatic towards the electronic. The sales of electronic instrumentation in 1968 exceeded those of pneumatic for the first time and, by 1973, it is forecast that the switch to electronic will be close to 90 per cent. The major advantages favouring electronics have been compact size, flexibility, reliability and decreasing prices. The use of solid state and now of integrated circuitry has been a significant factor in this switch. The reduction in cost of integrated circuits—approximately 50 per cent/year—has been so significant that new approaches to instrument maintenance have become possible. The present difficulties of converting pneumatic instrument men to electronics will be overcome in the future by reducing the cost of electronic assemblies to the point that it is more economical to replace entire assemblies with spares than it is to try to correct the failure. This approach, with manual back-up, appears to have prevailed over the alternate approach of 100 per cent circuit redundancy. This trend will lead also to an increased use of standardised electronic plug-in modules.

Monolithic circuits have gone a long way toward overcoming another papermill problem—atmospheric corrosion of electronic circuitry. This factor will permit the gradual relocation of much of the control hardware closer to the process, particularly as the hierarchical approach to computer control comes into use. The traditional process instrument had either a pneumatic or an analog output. Even many digital sensors such as pulse tachometers displayed their readings in analog form. One of the major cost items and continuing source of trouble on the earlier computer systems was associated with the conversion and multiplexing of analog input signals. Fig. 1 shows a typical computer control loop today. In this instance, a digital process (namely, the absorption of beta-rays) is converted to an analog signal, then electronically massaged to take care of source decay, standardisation, etc.

Because of the high cost of analog to digital conversion and a requirement of some computer manufacturers to keep this function closely tied to the remote computer, the signal is multiplexed along with the other inputs. On the

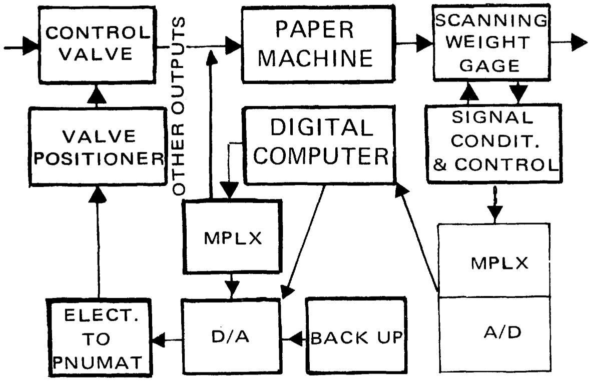

Fig. 1—A typical computer loop for analog instrumentation showing conversion and multiplexing steps required

output side, the reverse steps are taken and extended in this example to an extra pneumatic conversion in order to operate the valve positioner. One company is already offering a beta-gauge in which digital logic and circuitry are used through the input stages and many of the instrument functions are taken over by the computer. Fig. 2 shows such a simplified control loop. Similar approaches are also being developed for moisture and optical measurements.

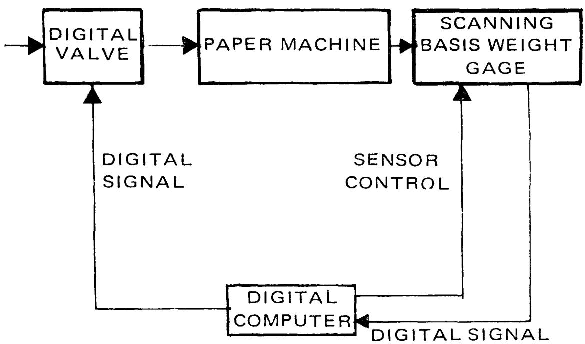

Fig. 2—A digital control system illustrating the simplification possible with digital instrumentation

This seems a logical direction and will probably expand, particularly in association with direct digital control.

Some process variables are unique to the paper industry and some have proved difficult in the past to measure reliably. Examples include freeness, consistency, formation and, in addition, product variables such as on-line porosity, printability and strength parameters. The ability of the computer to calculate often makes it possible to deduce some variables not readily measured directly from other more available measurements, also to make corrections to the results for errors caused by known process interactions. The impetus of the computer has generated a market that is attracting a steady stream of new or improved sensors for the paper mill. Taken together, these factors have greatly reduced control limitations imposed by the lack of suitable instrumentation.

Pneumatic power is still preferred for primary motive power on most valves. The inherent problems with electric control motors in a mill environment has limited their application. Digital and electronic valve positioners are finding use in DDC systems, however, so that the control loop can now be digital right up to the final stage. There would seem to be no particular economic incentive to eliminate the pneumatic power function.

Computers

LOOKING now to computer trends let us consider the stages through which we have progressed.

Stage 1—A conventional analog control loop is shown in Fig. 3. It could be either electronic or pneumatic. Its control modes are limited to gain, reset and rate, which are manually set, usually by the instrument engineer. The control point is manually set by the operator.

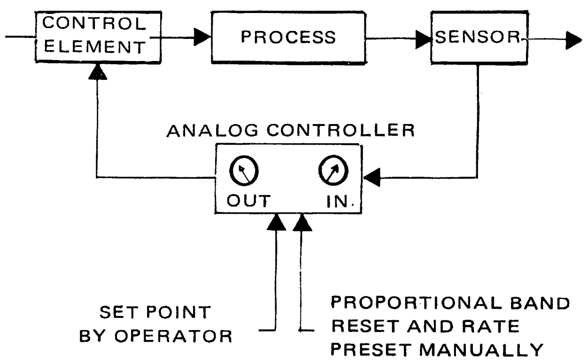

Fig. 3—A conventional analog controller with manual set point and three-mode control

Stage 2—The first application of the computer substituted the computer for the operator (Fig. 4). The analog control mode adjustments were still set manually and performed their normal task, but now the computer adjusted the set point according to a preprogrammed strategy. This approach is called *supervisory control.* Economics dictated a single computer to handle all controllers and the computer design required a remote air-conditioned location. Fig. 1 illustrated the problems of coupling each control loop to the computer and the economic compromises made to solve them. Early improvements in computer design occurred as the early modified electronic data processing units were replaced with units designed expressly for process control. Better performance and lower costs were the result.

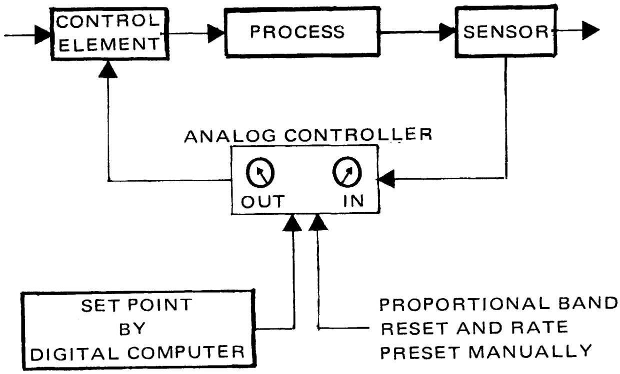

Fig. 4—Supervisory computer control

The first successful strategies were aimed at operator imitation—for example, recording the operator's manual settings when the machine was producing paper to specification and recalling these automatically whenever the same grade was run again. Immediate advantages were realised from this 'standard' approach, since the computer had an infallible memory. The next step was to analyse the operator's strategies for grade and speed changes, then to program the most successful ones into the computer. During computer failure, the system returned to conventional operation. There are still many computers operating in this manner and it is probably the most straightforward system for an existing machine, since it may be added to the existing control system incrementally. Besides, it allows two or more machines to be handled by a single computer.

Stage 3—Type A, DDC (Fig. 5). The next major step has been to direct digital control. In this mode, the function of the analog controller is replaced entirely by software within the computer. The counterparts to the gain, reset and rate controls are now defined within the computer program and the control point is entered into the computer by the operator or generated internally by a programmed strategy. In its simplest form, type A, the control constants are preset by the programmer. Interconnections between control loops are made internally by software and can be easily modified by a

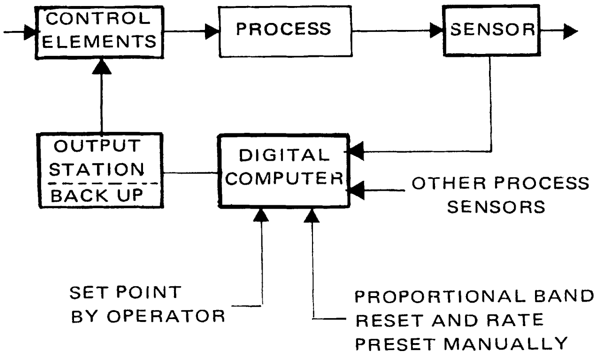

Fig. 5—Basic direct digital control: a digital equivalent to the analog centre of Fig. 3

program change. Instrument maintenance is reduced, since the hardware is greatly simplified.

There are two basic disadvantages to this approach—

1. Since only a single computer substitutes for all the analog controllers, the control action in every loop is now non-continuous. Each loop is served sequentially by the computer on a programmed cycle of one or two seconds. DDC is practical, because the high speed of the computer allows all the control functions to be serviced in a fraction of a control cycle, usually 30 per cent or less and so leaves a substantial portion of each cycle for other computational purposes.
2. Since all loops are dependent on one computer, a failure of it affects all control loops. This possibility is remote in practice, since computer reliability has proved greater than that of the papermachine itself. Yet DDC control valves and other DDC output devices are designed to retain their last position in case of a failure and an auxiliary analog back-up system is provided on some systems for a few key variables in addition to manual operation on all variables.

A type A system is the control equivalent of a mixed stage 1 and stage 2 supervisory system. The ratio is commonly 80 per cent stage 1 and 20 per cent stage 2. Although it was initially projected that a type A, DDC system over a minimum size would be cheaper than a conventional analog controller system, this does not appear to be true in practice because of the provision of back-up systems. It is unlikely that a type A system could be justified economically, unless it was later intended to modify it to a type B system.

Stage 4—In a type B, DDC system (Fig. 6), the full potential of the DDC approach is achieved. The 'frozen' control system of type A with fixed control parameters is replaced by a 'fluid' control system, in which not only the parameters, but the control linkages as well can be selected dynamically to suit the operating conditions. Thus, a different control configuration could be used during breaks for grade changes, even for different grades. Most of the new computer systems over the next five years will probably be of this type.

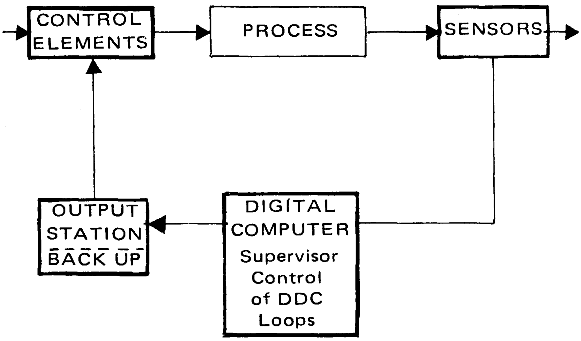

Fig. 6—Direct digital control with supervisory control of the DDC loops—that is, the DDC equivalent of Fig. 4

The most obvious feature of a DDC system is the absence of a control panel covered with controllers, limit warning lights, etc. They are replaced by a single display unit that on a command to the computer displays all the appropriate information of the selected loop. Loop parameters are changed at this same console. Since controllers can be viewed only one at a time, a computer-operated program must in the case of emergency record the identity of each loop in the sequence it goes out of limits to assist the operator in re-establishing control. This departure from familiar procedures necessitates a careful operator-training program. Current developments in cathode ray tube display systems will undoubtedly become commercial in the next few years. This will allow a wider choice of display features and, with the use of colour, a graphical differentiation of critical information. Such systems have been widely used in the space program and cost is the controlling factor in their use for industrial installations.

In stage 2, the role of the computer was strictly supervisory. It could organise its operating priorities according to their importance. Its active memory was largely available for computational procedures and the transfer time of data between active memory and disc storage was not a critical factor. In a DDC mode, a considerable portion of the active memory is set aside for the DDC control function, since there would be insufficient time on a large system to move the DDC package back and forth to disc or drum storage during each control cycle. This has two disadvantages—a given computer cannot handle as large a system as if it were used in a stage 2 system and, secondly, it requires the computer to give priority to the control function at the start of each cycle. This latter fact means that computations not completed in the open time of one cycle must be interrupted and possibly moved in and out of storage for completion during the next.

Stage 5—Hierarchy of computers (Fig. 7). The continued reduction in computer hardware costs promises that the next stage of computer system will consist of a central supervisory controller, much like the role of the computer in stage 2 served by one or more dedicated mini-computers located close to the process, each one of which will provide the DDC control function for a given subsection of the system. All computational operations associated with the supervisory function—models, standards, strategies, etc.—will be performed in the central computer and its output will adjust the control parameters and control points in the DDC units. Such a arrangement will have added value in those subsystems containing digitally based instruments, since the slave computer will also be able to handle the computional processing of the raw signal and standardisation routines. A further possibility is that it will eventually be possible by careful design of subsystems to standardise these subsystem hardware and software packages and so permit a distribution

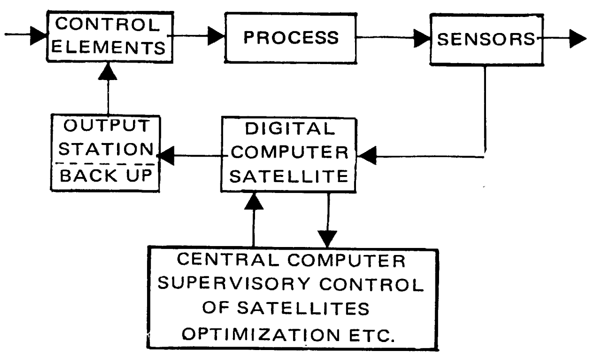

Fig. 7—Hierarchical computer control—a central computer exercising supervisory control over one or more satellite computers handling the DDC function

of development costs over many installations. The specific control models and strategies that define a machine's individuality and a company's proprietary technology would then all be contained in the central computer.

The biggest unknown in anticipating the rate and extent to which these new systems will be adopted is the relative economic return that arises from each new level of control complexity. The first gains in computer control are the largest and come from a few simple control strategies. Further gains are smaller and more costly to achieve. The cost picture is changing as hardware costs decrease rapidly and software costs stay relatively constant. This trend will increase the incentives for seeking ways to standardise subsystems of a control package so that they are suitable for a large number of customers and so justify the lower cost of a common hardware control package.

On many older machines, where major speed increases are not available to justify the costs of a computer system, it is probable that preprogrammed mini-computers will be used as part of a packaged control subsystem. The customer will have no special preparation or software maintenance to contend with and the system will be bought as a complete standard instrument control system. A basis weight, moisture content control package of this type has already been offered and other suitable subsystems would include head boxes, continuous digesters, savealls and refiners. These packages could be designed to be compatible with the hierarchy system in order to achieve wider application.

Mathematical modelling and control strategies

In the previous discussion, frequent reference has been made to models and control strategies. Control actions and their effects do not take place instantaneously. There are some delays in the control system itself and much larger ones in the process. Under these conditions, Attwood has shown that manual and analog control actions tend to be too frequent and drastic, resulting in a permanently unstable condition.

At least two kinds of model concept are used in process control studies. One approach attempts to describe the process mathematically in such a way that the interdependence of all the significant variables is explicitly stated. It is assumed that such a model (if available) would provide the basis for developing control actions unambiguously. The large number and the complicated interrelationship of papermaking variables makes such a *variable model* an impractical dream at this time. The second approach develops empirical relationships to describe the way in which small *changes* in one or more variables effect *changes* in the other significant process variables—that is, it is a *variable derivative model.* If the independent variables are subject to process control action, then such a control model describes the expectation of the process' response to the control actions. In manual operation, the model is a mental one and imprecise. In an analog system, it is usually a pneumatic or electronic network. In the digital computer system, it is defined in mathematical terms. The value of the model is the closeness with which it predicts the actual response of the process, *not* the degree of resemblance it bears to the physical system. It is used to plan a program of control actions that will move the process in the shortest possible time to a new control level or restore it from a random disturbance and minimise longer term oscillations.

Most of the variables on a papermachine are interrelated to several others. This means that a change in one variable will cause a change in several others. Unless these interactions are taken into account by the control system, a control level change in one variable will cause disturbances in several other variables and may cause the entire process to oscillate for a long period. Analog control systems are able to deal only with simple interactions. Two analog techniques that have been used are cascade and ratio or product control. Examples of their use have been in dryer controls and stock metering, respectively.

The computer has permitted more sophisticated use of models. Dahlin has described a technique to decouple the interactions between two variables and applied it in a basis weight and reel moisture control system. In another version, Rounsley combined decoupling with a predictive strategy. A mathematical model in the computer keeps a real time record of the system's response to all previous control actions and can therefore recognise new disturbances by comparing the model response to the actual response and, if a difference exists, take appropriate action immediately. Moisture control with these techniques gave a fivefold reduction in variation compared with a more conventional analog control system.

To date, little success has been reported with feedforward control. For example, feedforward basis weight control based on thick stock consistency, stock flow rate and stuff gate control has proved too insensitive, owing to poor consistency measurement and an inability to model all the variables influencing the fibre retention on the Fourdrinier machine and the presses.

Significant improvement in basis weight control has been obtained on one of our machines using an approach that is possible only with the aid of the computing ability of the digital computer and is illustrative of the technique of adaptive modelling. The example is based on three observations—the extremely reliable and accurate readings possible with modern basis weight gauges, the relatively slow changes in retention factors on the wet end and the relatively faster fluctuations in consistency of the thick stock supply to the machine. The equation relating the major variables (but ignoring time delays) is—

$$\begin{bmatrix} \text{thick stock consistency } \times \\ \text{thick stock flow rate } \times \\ \text{wet end retention factor} \end{bmatrix} = \begin{bmatrix} \text{oven-dry basis weight} \times \\ \text{machine speed } \times \\ \text{deckle factor} \end{bmatrix}$$

In this equation, basis weight is measured accurately and is a critical product property. Machine speed, deckle factor and stock flow rate are all relatively constant and usually fixed during a production run. The short-term basis weight fluctuations that occur are primarily a result of random consistency variations, which, because of the time lag, are measured too late to be corrected by a feedback control loop. The retention factors usually drift slowly as a result of slow system build-up, etc.

The control strategy developed was to decouple total basis weight and moisture content at the reel and use the oven-dry basis weight reading in a feedback control loop to set the thick stock flow control valve or stuff gate. This is conventional so far. The consistency reading signal is measured by the computer and corrected for known interactions of flow rate and of temperature by means of statistically derived models—say its corrected value is C_1. An apparent retention factor is calculated by substitution of measured values in the above equation. The instantaneous retention factor calculated will fluctuate as a result of the errors caused by the time displacement of consistency and basis weight measurements. A smoothed average retention factor calculated from successive readings, however, will give a very accurate estimate because of the slow time dependence of the factor with respect to the sampling frequency. This average value can then be substituted in the equation and a corrected average eonsistency reading C_2 calculated.

The consistency controller is now arranged so that the control set point is adjusted to maintain C_2 at a desired level and the instantaneous correction signal to the dilution valve is determined by the error signal $(C_1 - C_2)$. In this way, the basis weight signal in effect provides a continuous recalibration of the system and compensates for drifts in the consistency gauge itself and the machine retention factor. Such a strategy is a form of adaptive control.

This type of updating of model constants by on-line calculation can be done by use of time average readings as in the above case or by off-line control test readings taken intermittently and entered into the computer by the control laboratory, if the variable concerned has a slow rate of drift.

Strategies such as this offer several possibilities not previously available—

1. It is possible to control accurately while using a slowly drifting primary sensor.
2. It allows a desired variable to be calculated indirectly from the measurement of another correlated variable, for which the proportionality factor may vary slowly.

The advantages so obtained will lead to improved control and cheaper measuring devices, as well as to the measurement of variables for which accurate sensors had not previously been available.

The economics of process control

A DIGITAL computer system of the type widely used today is an expensive item. A computer may cost approximately $250 000 (£100 000) and a like amount will be divided between software development and instrumentation. The cost is somewhat the same whatever the application or capacity of the plant. I have already indicated some of the reasons that these figures have not declined as fast as would be expected for a new technology. There are signs that the situation is beginning to change, but I am sceptical that total costs will decline very rapidly, since savings will be largely balanced by increased sophistication for a number of years.

Perhaps the earliest improvements will be for marginal installations, by which I mean those of smaller size or older vintage that could not justify a standard system. Here, we have seen that dedicated mini-computer subsystems may be the most economic purchase with control capabilities restricted to a few key variables and the use of standard control programs already built in. On new larger installations, however, the added capabilities of a more complex system will continue to be justified.

Specialised software houses are claiming that, through the sharing of software programs over many installations, they will be able to offer cost savings not available to the inhouse staffs of individual paper companies. To date, the technology has not slowed down sufficiently for many duplicate sales of the same model system, but this could become increasingly a factor as time passes. They also claim the additional advantage of being unbiased in equipment selection, which will lead to more competitive pricing, although to date the lack of software standardisation between computers, etc. has made it costly to change from one supplier to another for successive jobs. The feast or famine situation within a paper company once the initial installations are made will probably cause a decline in complete inhouse capabilities, particularly as these services become available outside. Smaller internal specialist staffs to update installed systems will be a more economical solution.

Although the pulpmill and bleaching plant have not received as much attention to date as has the papermachine, the indications are that these applications will yield substantial returns from chemical cost savings and they have the added advantage that these systems are not in general as sophisticated or costly and their product mix does not vary as much as for an average papermachine.

Conclusions

IN SUMMARY then, I expect to see the following major trends continue—

1. Increased use of computer-based control systems.

2. Improved and new instrumentation, with wide use of integrated electronic circuitry, digital techniques and a trend to move many of the functions of the instrument into an associated digital computer.

3. A continued expansion of DDC, although for a number of years hybrid systems mixing DDC and analog controller may represent the optimum economical balance.

4. Increased use of dedicated mini-computers either as stand-alone installations or as slave units tied to an hierarchical computer control system.

5. Extensive use of sophisticated models and control strategies, particularly the use of the decoupling, predictive and adaptive varieties. I do not expect any extensive use of feedforward strategies in the near future, because of the highly interactive nature of most of our operations and the successes achieved by other means.

6. A gradual extension of computer use towards the third objective of process control—the economic optimisation of the manufacturing process.

7. The generation of routine production statistics, etc. by the computer system for use by the management information system and a gradual flow of information back from this source for setting up the process variables.

8. A slow trend to standard subsystems of hardware and of software and another trend away from software into hardware for many of the routine and repetitive operations.

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