Preferred citation: M.A. Keyes and R.H. Temple. Automation trends in papermaking systems. In **Papermaking Systems and their Control**, *Trans. of the IVth Fund. Res. Symp. Oxford, 1969*, (F. Bolam, ed.), pp 417–436, FRC, Manchester, 2018. DOI: 10.15376/frc.1969.2.417.

AUTOMATION TRENDS IN PAPERMAKING SYSTEMS

M. A. KEYES and R. H. TEMPLE, Control Systems Division, Beloit Corporation, U.S.A.

Synopsis This paper discusses the current trends in the evolution of hardware for computer control and the implications of these trends for the papermaking industry. This discussion covers, in addition to computer main frames, the development of remote analog signal multiplexing, conversion and digital data transmission, the evolution of graphic displays as operator panel replacements and the elimination of long cable runs from instruments by the use of laser data links.

As an overview of the future, an indepth presentation is given of an integrated papermill computer control hierarchy (of the sort to be expected within five years). In this configuration, the actual process control is performed by a number of free-standing (that is, no special computer room), small (20 in × 20 in × 60 in) computers dedicated to the direct digital control of the process sub-units (for example, grinders, bleaching plant, head box, dryer section and coaters). These first level computers are subservient to a larger foreground/background computer, performing such functions as control parameter optimisation, management information reduction and presentation, as well as on-line optimum production scheduling.

This portion of the paper also includes a discussion of the control techniques and strategies that will be in common use at this date and the additional process variables that will be on computer control (gloss, air permeability, colour and caliper). A part of this discussion covers the future state of the art, which will be approaching the control of the distributed parameter aspects of the process (such as cross-machine moisture and basis weight control).

Introduction

ANALYSIS of current trends clearly indicates that the next few years will produce a maturing of control application philosophy in the pulp and paper industry. A major result of this will be the widespread acceptance and installation of computer-based control systems, because they offer an attractive return on invested capital, not because of the historical glamour motives.

In addition to consideration of the usual goals of higher production rates,

Under the chairmanship of Dr D. B. Brewster improved product quality, lower reject rate, greater flexibility to meet changing requirements and so on, two increasingly important areas of need and, consequently, justification will come to the fore. The first of these is the result of the pressing current need for integrated management control and co-ordination of operations in conjunction with the upgrading and consolidation of personnel requirements.

The second and newer area originates from the increased emphasis placed on working conditions for operating personnel. Limits are being placed by regulatory bodies on allowable long-term noise and atmospheric contaminant levels for plant operating areas. In many cases, it will prove easier to remove the personnel from the process environment through automation and centralised control rather than to render the entire plant environment acceptable for long-term operator residence.

In the past, too many process control computers suffered from reverse justification (that is, install this powerful tool, then look for something for it to do). This approach rejected all sound project planning principles such as careful definition of goals, planning and enforcement of schedules and continuing critical evaluation. The result in a great many cases has been either explicit failure or an internal erosion of confidence and lack of measureable achievement.

Increasingly, control computers are losing the glamour and special treatment of the prima donna and are being recognised as a powerful production tool that must be controlled and utilised by production personnel to achieve the desired levels of operating success. In the end, the 'success' of a project can, after all, be measured only in terms of its net effect on plant operations.

In this environment of increasing acceptance on a rational basis, two outstanding characteristics will be particularly significant. One of these is the fruition of the use of hierarchical control in our industry. A comparative multitude of small computers will be utilised to control individual process areas and units. The use of advanced digital communication techniques will allow co-ordination of these subservient systems with a more powerful central unit.

The second important facet of future advanced control operations of this type will be the increasing relative importance of software, services and application engineering. This is due to the simultaneous realisation by paper users of the potential high hidden costs of software and applications (some pulp and paper users have utilised teams of 5 or 10, even 50 men and have yet met with only moderate project success) and the decreasing costs of hardware. This effect was illustrated in a recent Forbes Survey(1) covering data processing applications. The results of this survey are depicted in Fig. 1. As experienced industry people will concede, there is a good deal more effort in implementing, say, a continuous digester control system than there is to writing a payroll program and making it work smoothly. The result of this realisation will be an increased demand for packaged systems and turnkey applications.

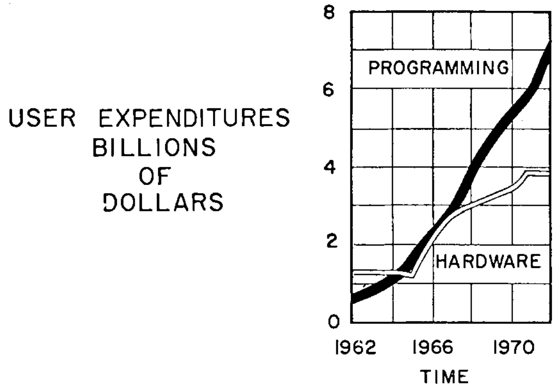

Fig. 1—Increasing relative software costs[1]

Hardware development

To IMPLEMENT modern control technology, the digital computer is by far the most flexible tool available. Many times, it provides the only feasible approach to implementation of an advanced control system. Thus, the much-heralded advent of *medium-scale integration* (MSI) and *large-scale integration* (LSI) digital electronics are having and will have a tremendous impact on control systems. Since, through this circuit technology, electronic components are becoming much less expensive, smaller and more powerful, three basic new types of computer for process control applications are evolving. The first type will be physically smaller than present-day machines, will cost about the same, but will have from four to five times the capability. The second type will have the same capacity as current machines, but will be much smaller and will cost much less. An indication of this direction is seen in some of the present-day aerospace computers, one of which weighs 10 lb, measures 4 in × 4 in × 9 in, with 7 500 words of memory and a 38 instruction repertoire.[2]

The third type has been termed the micro-computer or the 'computer-on-a-chip'.[3] This digital subsystem will functionally replace the current electronic controller[4] with a physically smaller, lower cost, more capable unit. The typical micro-controller will be capable of controlling 4–8 DDC loops and, in a hermetically sealed box of approximately 4 in × 4 in × 10 in, will contain all the necessary logic circuitry, memory, analog/digital (A/D), digital/analog (D/A) and computer interface electronics. This micro-controller will implement a form of the general digital compensation transfer function and will operate asynchronously with respect to any other 'supervisory' digital computers, receiving data from these units only when it is desired to change a set point or a control algorithm parameter. In addition to a projected one for one cost advantage over analog systems, there are other important incentives in using this type of approach such as reduced instrument wiring costs, reliable drift-free operation and simplified master control computer software.

Implication for computer control systems

A SIGNIFICANT implication of these developments for the paper industry is that a given degree of control complexity and scope will be much less expensive in basic hardware. This has both good and bad aspects. It implies that the capabilities of the computer hardware will be much less of a barrier in the future and larger tasks will be feasible. Yet the systems aspect of the work will be no simpler and, in particular, the software and hardware interfacing aspects will continue to be complex. Many new application software packages will be available for purchase or lease from both computer vendors and systems houses. This gain will, however, be offset to a degree by the proliferation of small computer vendors and the specialised or unique characteristics of each installation and computer system.[5-7]

Specialised hardware is being developed to handle certain relatively well-defined functions that will simplify the interfacing problems to a certain extent as discussed above for the micro-controller. In other cases, the control computations will still be performed in a central computer. The digital/analog interface and encoder logic will inevitably move away from the computer mainframe, however. More digital transducers will be available than at present and analog units will more frequently be available with digital conversion built in. Local multiplexers will abound. Illustrating the technical feasibility of local multiplexing, conversion and encoding is the fact that a single MSI chip is available today that performs all the logic and control associated with an A/D converter for less than $100.00.[8]

Another example is a recently announced computer that operates from a *read only memory* (ROM), interfaces directly to a 120 V ac, signals and replaces interlocks, break detector systems and other relay control systems on an even cost basis.[9]

Packaging

ANOTHER major ramification of these developments will be their effect on the area of computer packaging and reliability. The hardware will be more compact allowing totally new packaging concepts. One result even now being offered in prototype is a hermetically sealed enclosure with a positive pressure inert gas atmosphere totally surrounding these new, small machines. The electronics are inherently immune to industrial temperatures and the packaging will render the machine proof against chemical and biological attack, since the process atmosphere is excluded. In addition, this packaging will obviate the need for special computer rooms allowing location close to the process under control. With ruggedisation and enclosures of this type high reliability is guaranteed, washdown hoses and forklift trucks not excepted. The first steps in this direction are indicated by several recent product announcements by major computer vendors.[10, 11] An artist's conception of one of our recent proposed configurations for applications in an area with a corrosive atmosphere is shown in Fig. 2.

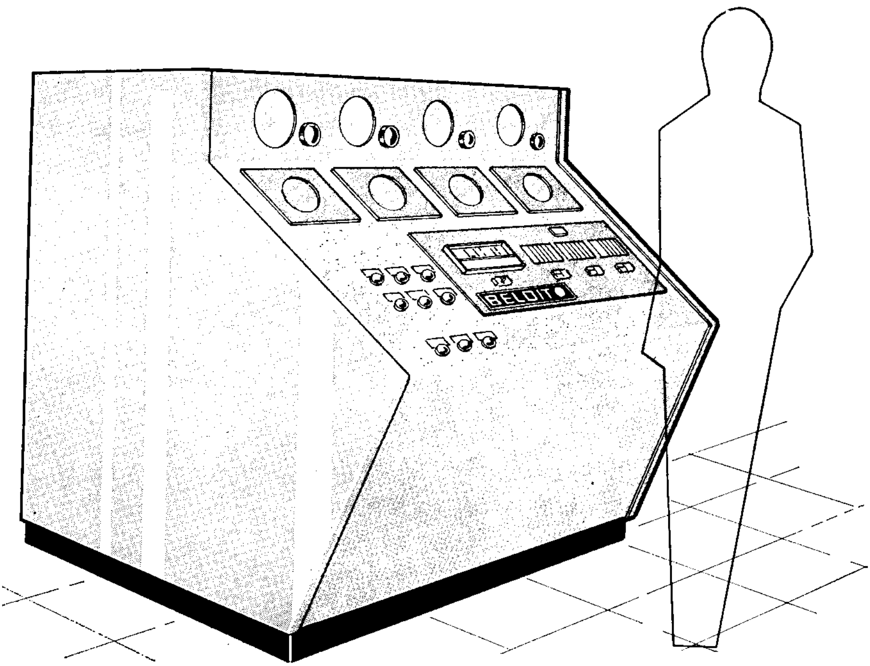

Fig 2—Environmentally protected small computer control system

System reliability

THE reliability of the computer will increase greatly, simply because of its MSI construction and concommitant lack of multi-level interconnections. Industrial type packaging as described will add to these inherent benefits. A side benefit of this reliability, in addition to less process down-time, reduced repair costs and simplified maintenance, will be gross reductions in manual or analog back-up necessary. With micro-computer replacement of present analog systems on new process installations 'back-up', as such will be a meaningless concept. This increase in reliability is not an unmixed blessing. Two problems will result, the first signs of which are evident in the highly computerised petrochemical industry, even in isolated pulp and paper installations. These include the gradual degradation of any analog back-up equipment installed through lack of use and maintenance plus the increasing unfamiliarity of the operators with the non-computer mode of operation, again through lack of use. The first problem can be prevented via an aggressive maintenance programme, the second with a periodic, scheduled half hour or so of process operation without the computer to enable the operating crews to maintain their old skills.

Hierarchical control

THE hierarchical or hierarchically distributed arrangement of computers is being made economically feasible by the advent of small low cost mini-computer and micro-computers and the improved packaging discussed above. Reasons for applying hierarchical control from an application standpoint are threefold. Firstly, wiring costs are reduced and very attractive savings may be realised by locating the computer close to the points being scanned and controlled. Secondly, the system design is simplified and reliability increased by the control and associated programming tasks into logical sub-units and sizing the computer appropriately. Thirdly, this hierarchical or distributed concept of control has the effect of greatly improving the system response time via parallelism, without having to support the cost of the equivalent reduction in computer cycle time. It is interesting at this point to note the recent announcements by major U.S. vendors of mini-computers to be marketed with their conventional large-scale process control computers and to act as remote peripheral controllers.

Digital telemetry

IN CONJUNCTION with and as an extension of this concept of distributed hierarchical control, increasing utilisation will be made of digital data transmission techniques and devices. Telemetry equipment has long been employed in the power and utility industries for remote control from a central location and will be employed in the paper industry in the near future. One U.S.A. user is currently planning to install telemetry equipment to control a bleaching plant several hundred miles distant, utilising excess capacity in the existing central control computer.

Alternatives to conventional hard-wired and microwave telemetry will become available through advances in other fields. One development that we are now examining with interest is the utilisation of lasers for digital data transmission. Laser links will have cost, reliability, noise and flexibility advantages over conventional methods on medium to intermediate ranges (that is, 0·25–10 miles).[12] A prototype installation is in operation at the Case Western Reserve University in Cleveland, Ohio, connecting a central scientific computer to a number of remote scientific terminals. The technology employed is directly transferable to the paper industry with suitable ruggedisation to meet the stringent requirements for industrial applications.

Graphic displays and the operator interface

ANOTHER area of great need where work is underway is that of operator communications and the graphic display of data. To enable an operator adequately to handle a centralised control system of vastly increased scope, two developments must occur. Extensive data reduction and decision making must be done within the framework of the computer hierarchy. Operators must be presented almost exclusively with information by exception. Unless specifically interrogated, the only data that will be displayed is that indicating a process upset, out of limit values or conditions that require his action. This data must also be presented in an easily interpreted graphical or pictorial format whenever possible. Several vendors have already taken the first step in this direction and with their nuclear gauging systems offer single colour

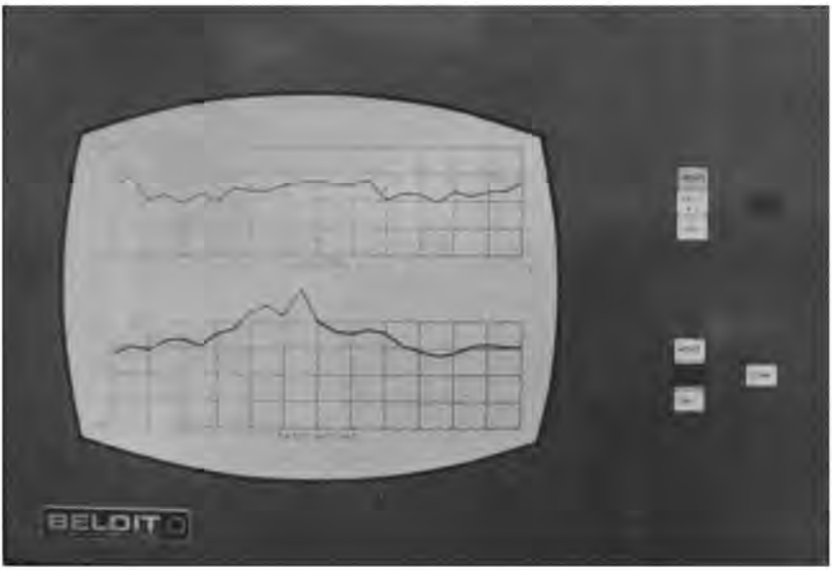

Fig. 3—Colour graphics console

graphic displays of cross-machine profiles (such as basis weight, moisture, caliper) as optional equipment. The next step is to extend the range and types of data presented graphically and to add to this colour-coded presentation to assist the operator in discriminating among the data presented (Fig. 3). Four and five colour graphic consoles will eventually be common in centralised control panels, presenting process conditions, production bar graphs, process schematics with variable data, etc. Much of this capability, with the prime exception of the colour graphics, exists today and is used in an embryonic form.(13) The power industry now makes use of computer-generated graphic displays of power grid schematics and operating conditions. Recent work in integrated circuitry and single gun multi-phosphor cathode ray tubes(14) will allow extension of single colour techniques at a price that will allow their use in industrial systems. A sketch of a console now under development incorporating a colour CRT system is shown in Fig. 4.

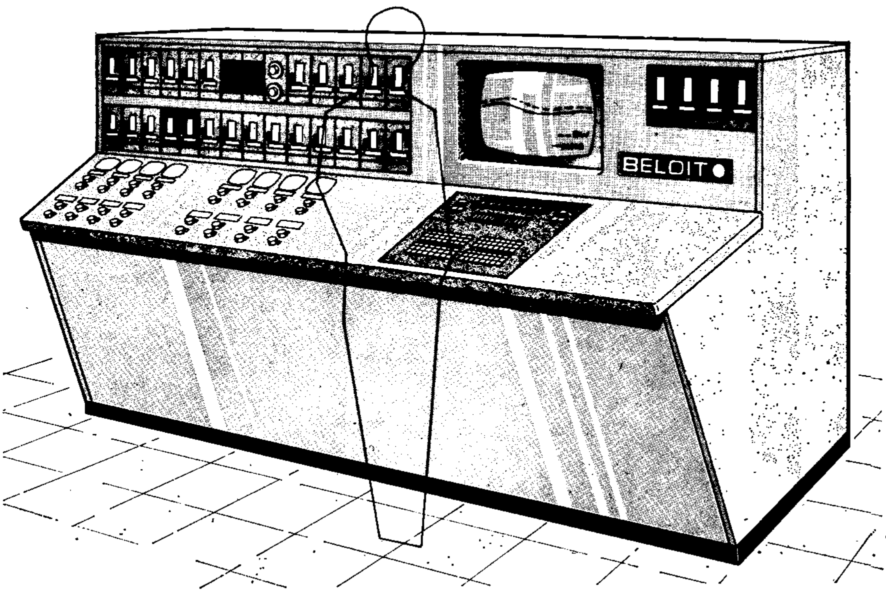

Fig. 4—Operator's control console utilising CRT-based multi-colour displays

Software and programming considerations

One of the major drawbacks in the use of current mini-computers has been the limited number of programming languages available for a given machine (typically only USASI BASIC FORTRAN IV and ASSEMBLY language). Another problem of equivalent dimensions is the amount of time and effort involved in compiling or assembling programs in the languages that are available, since most mini-computer configurations are process-oriented and have few, if any, high-speed data processing peripherals (card or high-speed paper tape input, output, line printer, etc.). This means that, on a typical installation, a programmer will experience turn-around times of 1·5–2 h for programs of moderate length; thus, his productivity is greatly reduced.

Two solutions are beginning to appear for this problem. The first will be the availability of compilers and assemblers that generate object programs for mini-computer use, but that run on some other larger computer such as a scientific or EDP machine, which has the desired high-speed peripherals. We have taken this approach in our own installation, in which we have assemblers for a DEC PDP8, Varian 620/i, and Honeywell H316 and H516 computers running on several of our larger data processing machines. The other solution is indicated by the research presently being conducted[15, 16] in the area of higher level control programming languages and standardisation efforts on user and problem-oriented languages.[17]

An integrated system

AS A summary overview of the preceding, Fig. 5 depicts a hypothetical integrated papermill with a hierarchically distributed total plant control system. The first level—or local control—incorporates eight physically small (20 in $\times$ 20 in $\times$ 60 in), freestanding (that is, not in a special computer room), dedicated computers. These first level 'area' computers perform either DDC or supervisory control (perhaps to local micro-computer controllers) as required, on the various process areas (such as bleaching plant, groundwood mill, stock preparation, chemical recovery, papermachine, power house). Graphic display capability is provided to meet each specific area's requirements. These computers are hierarchically linked to a much larger multi-programmed, time-sharing computer. This central machine co-ordinates the lesser computers and performs such functions as parameter optimisation, management and process information, reduction and presentation and on-line production scheduling.

The central computer may have additional small computers subservient to it that are used specifically as console and display drivers or for specialised input/output (I/O) tasks such as telemetry control. The optimisation of the total plant at this level may involve inventory or schedule control based on market considerations. Typical factors to be taken into account include order status, inventory position and current operating costs. The most profitable general conditions for each of the separate control areas may then be determined within observed operating constraints.

One final feature of our proposed system should be specifically noted. This is the presence of a separate monitoring and control computer allocated to the areas of water and waste treatment. This is in-line with our projection of the effects of public sensitivity, stricter legislation and responsible industry programs relative to environmental and pollution problems.

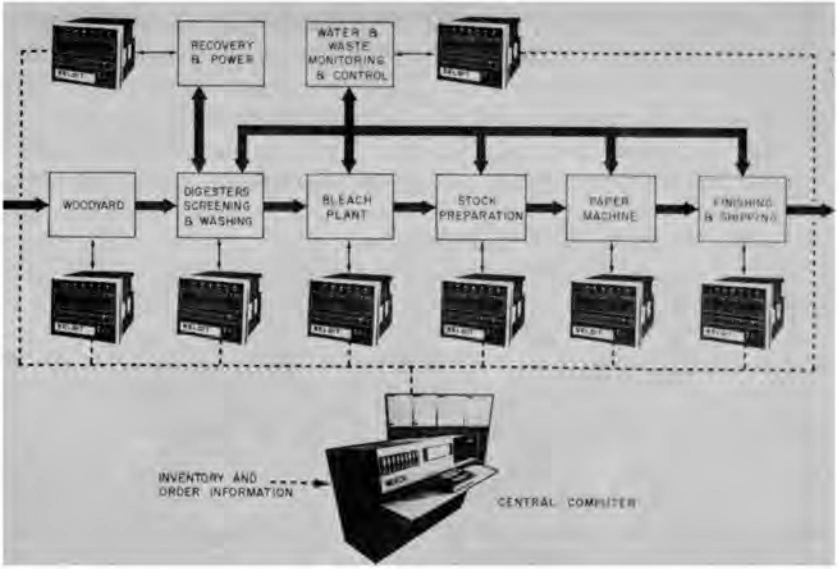

Fig. 5—Total plant hierarchically distributed control system

Application trends

THE expansion of hardware capabilities discussed in the first part of this paper will be utilised to apply techniques and strategies new to the paper industry that will improve current control system performance. Additional process parameters will also be controlled that are at present regulated manually.

We have attempted to cover the question of what will the functional appearance of control hardware be in the future, but this projection as yet has not met with the problems of application. Control and measurement problems are seldom more perplexing than those that we have in our industry. Almost every notable classified control difficulty is present to varying degrees in one pulp and paper area or another. Similarly, some of our important quality and process operating parameters still require inaccurate, slow, periodic, off-line laboratory test procedures.

With this ammunition, some critics of advanced control have yielded to the persuasive strains of 'our industry is not ready yet . . . no doubt the approach will be feasible someday'. Although this attitude undoubtedly serves to provide a reasonable amount of security in the face of new developments (whether controls or equipment), history has adequately demonstrated that it is not viable as a long-term approach. Fortunately, the pulp and paper industry as a whole is realistic enough to realise that, while perfect control does, in fact, require perfect measurements, our actual goal is *not* perfect control. Our goal is and must be an adequate return on invested capital. To achieve this, we must only provide *better* plant operation. Adequate gains can often be demonstrated with seemingly minor improvements in control easily within our present measurement capabilities.

Sensors

MEASUREMENT shortcomings nonetheless exist. Additional benefits would certainly be available if many of the lacking items were developed.

In general, two different approaches have been taken to the problem of inadequate or non-existent sensors. The first is the most straightforward—develop the necessary instrument. The saying is clearly easier than the doing. This approach has, through the combined efforts of industry, academic equipment suppliers and instrument manufacturers, provided us with an array of accurate on-line devices that we are only beginning to utilise fully. These include—

Basis weight	Gloss	Porosity
Moisture		Formation
Caliper		Pulp brightness
Colour		Pulp colour
Opacity		Spent liquor concentration

The future will bring more of these devices now undergoing development into the status of workable production tools. Research is now in progress on units for on-line measurement of modulus of elasticity (sonic) and sheet composition (X-ray analysis). Water and waste treatment control is also benefiting from new developments. Here, several continuous systems are now available for BOD via various inferential techniques, COD, turbidity, residual chlorine, dissolved oxygen, colour and zeta-potential. We are currently examining several of these units in the context of advanced waste treatment control systems. Analytical instruments of all types are being developed and will soon be standard items of instrumentation in every modern mill. In use now are systems for monitoring bleaching and pulping liquor strengths continuously. Automated wet-chemical equipment and methods abound.[18]

With these measurement systems, what is lacking? Probably the two items that come to mind easily are consistency and pjlp quality. We have been trying to obtain a precise measure of consistency for well over 100 years and it is certain that the papermaking wasp and the original Chinese practitioners of the papermaking art were also troubled by consistency control. We are only slightly closer to a final answer to this measurement problem today. Typical accuracy warrantees on consistency transmitters contain prose of the variety 'not to be calibrated in terms of absolute consistency measurements . . .'. Current work in this area includes examination of several potential new measurement principles, including nuclear magnetic resonance.

Pulp quality measurement is, if anything, harder yet in that the desired parameter has not yet been satisfactorily defined. The only universal consensus is that freeness in its various forms is not the right answer. There is even disagreement on what is to be expected of a pulp quality measurement. For example, should it predict the drainage characteristics on the machine, the runnability of the sheet or final paper strength factors? Without a statement of purpose even as broad as this, it is unlikely that any significant development in the framework of a useful operating tool will arise out of the present muddle in the near future.

The second or indirect approach to measurement problems utilises inductive measurement principles. Here a 'bad' measurement is accepted, provided the undesirable factors are largely deterministic. The measurement of consistency provides a classic example of the use of this approach. It is known that the output of all shear-based consistency transmitters is to an extent dependent upon flow, freeness, temperature, fibre blend and, hopefully, the true consistency. An illustration of this type of dependence is provided in Fig. 6.[15] The reduction of error in this type of measurement may be achieved by measuring (either continuously or in the laboratory) these additional variables and using this data to provide a corrected consistency via an empirically developed relationship of the form—

$$\hat{C} = a_0 + a_1 C + a_2 V_1 + a_3 V_2 + \ldots\ldots$$

where $\hat{C}$ = corrected consistency,
C = raw transmitter output,
V_1, V_2, etc. = additional measured factors,
a_0, a_1, etc. = empirical calibration constants.

This general technique has been further improved to limit residual measurement errors through stochastic feedback correction of the calibration equation.

It should be apparent that a digital computer is essential for the success of this approach, both in the initial equation development and in its implementation.

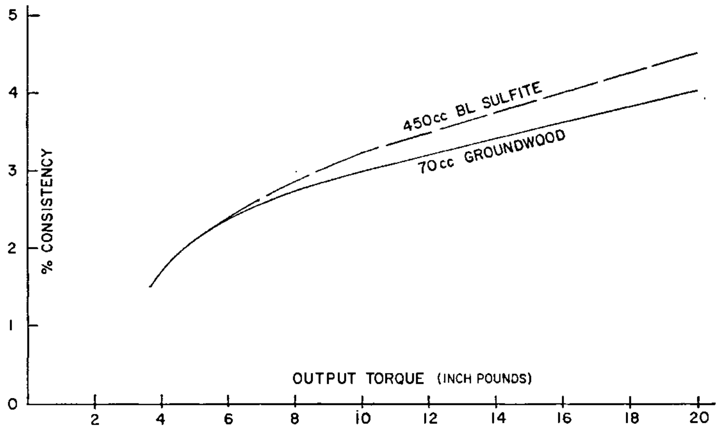

Fig. 6—Characteristic consistency transmitter response

While some specific examples of measurement problem areas admittedly tax the ingenuity of control systems engineers, it should be reasonably clear that the pulp and paper industry as a whole is no longer critically limited by lack of sensors. The majority of the burden now rests on all industry segments, both user and supplier, to utilise to the fullest extent the available measurement equipment.

Control techniques

THE mass of books, periodicals and miscellaneous publications relevant to modern control theory and control applications produced over the last few years staggers the imagination. The highly mathematical nature of the majority of this work renders it totally useless to the traditional instrument engineer as he exists today in the paper industry. The mathematics and technological level of this literature is certainly not going to get easier. TAPPI and other technical organisations have recognised the broad aspects of the re-education problem that exists because of technical advances and personnel obsolescence in all fields. Continuing education programs and various industry sponsored seminars are only part of the total solution to this problem. The ohter solution is indicated by the increasing reliance of industry on the special talents available through package or turnkey purchasing, whether the package is a power boiler or a process control system.

A review of the more noxious static and dynamic control aspects of pulp and paper processes will reveal how and where some of the current applications of advanced control principles arise. These characteristics are well-known and encompass—

1. The existence of large variable time delays.
2. Changing or unknown process dynamics.
3. Strong interaction between major control and quality parameters.
4. Non-linear static and dynamic plant characteristics.
5. A wide range of important process time constants (from approximately 0·02 s on some drive control systems to periods of days or weeks in some waste treatment systems).
6. The existence of many varied types of control problem, including continuous or conventional control, batch control (digesters and batch reactors), transitional control (grade change) and discrete control (sequencing, interlock systems).
7. The presence of significant process and signal noise.

As stated, control theory is an area of technology where theory has far outstripped applications. This is true to such an extent that a concentrated effort must be made to provide control at a level justified by the application expense and return on investment considerations. If this restraint is not exercised, 'over kill', excessive expense and late project schedules are guaranteed. A few examples of some typical approaches to the elicited problem areas will suffice.

Non-linear control

NON-LINEAR control may be applied when the process has some undesirable non-linear characteristic that non-linear control can alleviate, the actuator has some non-linear feature (such as backlash) or a non-linear response is desired. Applications of linearising cams or other elements to control systems is certainly not new. Valve manufacturers have for years supplied characterising mechanisms as an integral part of their valve positioners. The speeder-spring in a steam turbine mechanical governor is characterised in this fashion to provide more severe corrections for large deviations than for small. Modern analog and digital computer control systems simply allow easier implementation and some attractive extensions to these concepts.

Air-motors, hydraulic and electrical positioning systems on digester blow valves, refiner plate and plug position controls and horizontal or vertical slice adjustments have inherent on/off characteristics. Pulse, pulse duration or probability duty cycle control can be applied to these units, the optimum choice depending upon specific actuator characteristics in each case. The second technique has wide application in both digital computer and analog pulse duration control applications. A comprehensive computer aided design technique covering this type of control to a general dynamic process is the subject of a forthcoming technical paper by our staff.[20]

Dead time compensation

TIME lag or transport delay is present in significant amounts in water and waste treatment, digestion (continuous), consistency regulation and control of moisture and basis weight. Two approaches to the solution of this problem have been utilised. The first entails building a comprehensive feedforward model. This will allow a measure of control without the feedback stability problem. This typifies the approach initially taken with great labour and limited success to the control of bleaching plants. Unfortunately, no matter how comprehensive the model building techniques are, there will be model error.

The second method is to detune the feedback control system to the point where it is stable and operates acceptably under steady-state conditions, although generally not under set point changes. [21, 22] Prof. O. J. M. Smith of the University of California in 1958 proposed an analog feedback scheme for dead time compensation that allowed use of higher system gains, thus smaller errors. This scheme requires a simplified dynamic process model to provide synthetic feedback to the controller, but a simple model whose static and dynamic characteristics only crudely approximate to the actual plant is satisfactory for this purpose. Application of this technique to the control of basis weight pulp bleaching and a variety of other pulp and paper processes has been shown to be feasible by our Control Engineering Staff.[23]

Adaptive control

ADAPTIVE control is so vaguely defined that it led Eli Mishkin[24] to define an adaptive system as '. . . any physical system that has been designed with an adaptive viewpoint'. This definition is notably lacking in utility. For our purposes, adaptive control systems are those that embody the capability of making on-line modifications to their own control parameters to meet changing conditions. Fig. 7 and 8 indicate the improvements in control performance that may be obtained through the use of these techniques. Adaptive control complexity varies from an elementary application of the prior knowledge of how plant parameters vary with operating point to more complex schemes when spectral decomposition of the error signal or on-line plant identification is used.

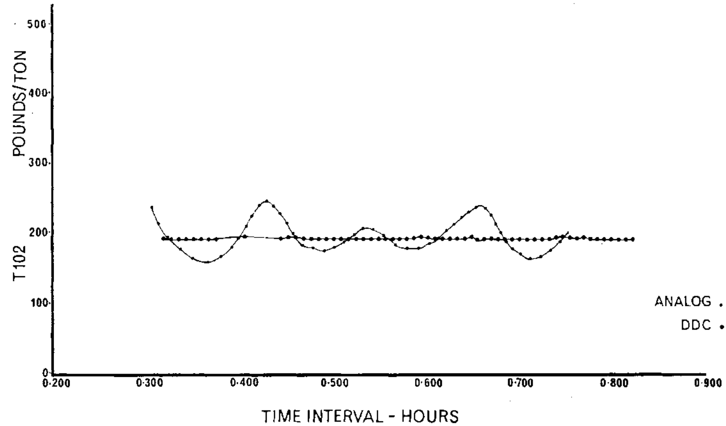

Fig. 7—Control comparison analog against adaptive DDC
Standard deviation analog 15.19, adaptive DDC 1.91

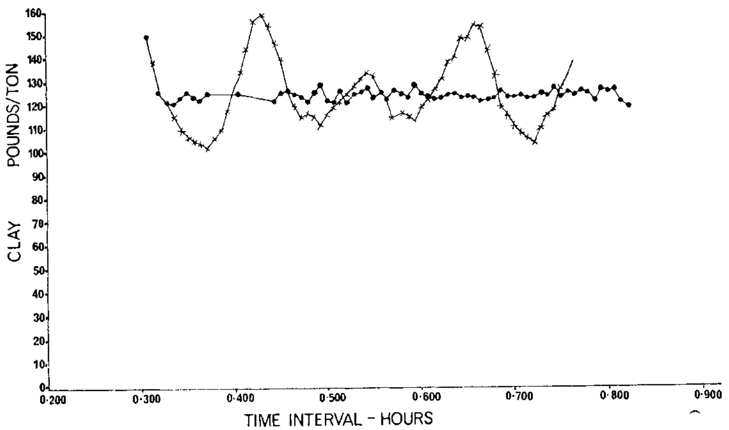

Fig. 8—Control comparison analog against adaptive DDC
Standard analog 23–69, adaptive DDC 1.13

Non-interacting control

FACTORS that interact both statically and dynamically include pulp viscosity and brightness in a bleaching plant; total head, level and head box consistency in the head box of a papermachine; and the classical papermachine variables of basis weight and moisture.

Decoupling techniques have been widely publicised by Gibson[25] for continuous systems. A technique utilised with success involves expressing the multi-variate plant and control characteristics as the product of two matrices of transfer functions. A decoupling controller is then derived via simple matrix algebra to provide independence of the various control parameters and the desired response characteristics. This method has been applied to basis weight and moisture control.[26] Its application is elementary with a digital process control computer system.

Range of dominant process dynamics

THE problems associated with the wide variety of dynamic characteristics encountered in pulp and paper practice are those of efficient utilisation of computational resources. There are at present a number of regulatory problems for which an analog system will still provide far superior dynamic response, although lower accuracy than is feasible with large-scale digital computers whose use is shared on a number of other tasks. These applications include drive system regulation where the bandwidth may typically be 40 radians/s or greater. To match analog performance on these systems, a digital unit would have to sample at a rate in excess of 30 times per second. A current answer to this problem is supervisory control of the analog subsystem.

Many drive suppliers today utilise special purpose digital techniques, for which both high accuracy and fast response are essential.[27] These applications include variable speed fan-pump drives where accuracies as high as ±0·00001 per cent are claimed.[28] Within five years, however, the advent of general purpose LSI micro-computers will make the economics of such special purpose devices questionable This latter approach, as previously indicated, will simplify the integration of these systems into the complete hierarchical control structure.

Simulation

ALTHOUGH specific control techniques abound, very little in the way of simple pencil and paper methods for analysis or synthesis of complex control systems such as those that have been described is available. A technique widely utilised by control engineers for both complex process analysis and advanced control system design is that of simulation. The use of these methods originally was limited to those who both understood the electronics of the simulator (an analog computer) and the mathematical description of the process and control element static and dynamic properties. Development of digital and hybrid simulation languages that are user and use oriented has extended the use of simulation to a wider group of people and a wider class of problems.[29] A modern facility for the testing of advanced control algorithms, new process designs and complete real time software systems is illustrated in Fig. 9.

Fig. 9—A process control and simulation laboratory

Summary

AN EXAMINATION of available control technology indicates that no radical new developments are needed to solve our industry's control problems. The most complex of these systems is totally feasible with the process control systems of today. The majority of effort over the next five years will entail applications of existing technology and not, generally, from radical new development in the field.

Hierarchically distributed control concepts will achieve full acceptance during the next five years due to maturing application technology and massive reductions in hardware costs. With the realisation of these projects, the close integration of process control systems into plant and corporate management information and control systems will come to pass. The inescapable consequence of matching papermaking needs against modern digital technology will be the transition of the process control computer to its rightful status as an effective operating tool.

Fig. 10—Typical aerospace computer

References

1. Anon., 'Information processing': *Forbes Magazine*, January 1969, 181
2. *Control Data 449–1*, Micro-Electronic Computer System (Control Data Corporation product announcement)
3. Anon., 'New process makes smaller circuits': *Chem. Eng. News*, September 1969, 45
4. Anon., 'A trend report of electronic process controllers': *Control Eng.*, August 1969, 71–86
5. 'Mini-computers—What all the noise is about': *Control Eng.*, September 1968, 73–80
6. 'Digital proliferation—Mini-computers revisited': *Control Eng.*, November 1968, 72–74
7. 'Mini-computers—A look at the breadth of control applications': *Control Eng.*, January 1939, 128–132
8. *Data Sheet* 3751, 12 bit A/D converter (Fairchild Semi-conductor, Mountain View, California)
9. *Digital Equipment Corporation PDP–14 programmable controller* (product announcement)
10. *Ruggedised DDP–516 GP Computer* (Honeywell Computer Control Division product announcement)

11. *Dataspec—Ruggedised Varian 620/i* (Varian Data Machines product announcement)
12. Pratt, W., *Laser Communication Systems* (J. Wiley & Sons, New York, 1969)
13. Kazan, B. and Knoll, M., *Electronic Image Storage* (Academic Press, New York, 1968)
14. *Sylvania multi-colour display tube* (Sylvania SC–4876P226/P22R product announcement)
15. Temple, R. H. and Schoeffler, J. D., 'RTL—A real time language for computer control software': *Proc. IEEE,* January 1970
16. Temple, R. H., *RTL—A real time language for computer control software* (Ph.D. thesis, Case Western Reserve University)
17. Anon., Minutes of the *Workshop on standardisation of industrial computer languages* (Purdue University, 17th–21st February 1969)
18. Anon., *Automation in Analytical Chemistry* (Technicon Symposia 1965–68, Mediad Incorporated, New York)
19. DeZurik Corporation, Santell, Minnesota
20. Persik, S. R., *Pulse duration control of industrial processes* (Beloit Corporation, publication pending)
21. Persik, S. R., Process analysis report No. 19: *Design of a scan average feedback regulatory integral controller for direct digital control of machine-direction basis weight* (Beloit Corporation, internal report)
22. Persik, S. R., Process analysis report No. 20, *Feedforward basis weight control loop analysis* (Beloit Corporation, internal report)
23. Persik, S. R., Process analysis report No. 22, *Dead time compensation with the Smith linear predictor* (Beloit Corporation, internal report)
24. Mishkin, E. and Braun, L., *Adaptive Control Systems* (McGraw-Hill, New York, 1961), 4
25. Gibson, J. E., *Non-linear Automatic Control* (McGraw-Hill, London, 1963), 23–33
26. Dahlin, E. B., 'Integrated control of Fourdrinier machines': *Second International Symposium on Water Removal at the Press and Dryers* (Mont Gabriel, P.Q., Canada)
27. Keyes, M. A., Process analysis report No. 27, *Differential drive control analysis* (Beloit Corporation, internal report)
28. Strand, S. M., 'Frequency-based regulators lock dc machine speeds': *Control Eng.*, March 1967
29. Terhar, R. J., 'Simulation in the pulp and paper industry': *Pulp & Paper Mag. Can.*, 1967, **68** (6), T295–T300

Discussion

Mr S. Hem We had heard exclusively about the hardware side of your systems. As potential users of the computers, we are also interested in the control aspect of the problem. In what areas of the papermaking process can you see advanced control theory being used?

Mr M. A. Keyes All areas.

Dr H. Sandblom It has been very interesting to listen to this paper, for it is always of great interest to look into the future to see where computer technique is heading.

My company is of course very interested in the small, but powerful Data 449 computer control and has been studying it very carefully. In this connection, was the input/output equipment included in the basis weight figures (that is, its connections with the process)? If not, only very small computer systems were considered.

May I add a further comment. One of your diagrams shows the relationship between software and hardware costs. Even if systems are becoming increasingly involved and complex, with the use of better software packages like process input acquisition and better programming systems like AUTRAN, the software costs should not rise as steeply as you have shown.

Mr Keyes There are several vendors and systems houses such as ourselves who are introducing packaged software systems. The advantage of this approach is that these people are in a position to spread the development over a number of systems rather than on one specific application, thus reducing the user costs.

Dr S. W. Kingsnorth As you are head of the control division of a major machine manufacturer, could you comment on the likely future of papermachines in their ability to respond quickly and accurately to the information

Under the chairmanship of P. E. Wrist

that the control systems are feeding back to them on flow boxes, steam systems, calenders and everything else that is in the major hardware of papermaking?

Mr Keyes Well, of course there will be changes in the process and one of the things that is taken into account in a system design is the response capabilities, the controllability of process and machine equipment. There is a certain amount of literature on this co-ordinated design approach. I presented a paper at a TAPPI meeting in Boston some years ago, for example, on the integrated design of hardware systems for controllability.

The Chairman We will now proceed to the general discussion of the papers in this session and I would like first to say a few words in the context of control to review very briefly what these gentlemen seem to say and what people seem to hear them say.

Mr Jolliff raised questions about process interactions that are fundamental to solving the entire papermaking control problem. Mr Mardon and his colleagues raised questions about the control system learning curve and the return of investment curve. In particular, it was notable that the discussion centred around the psychological problems of training, man-machine communication and intergroup behaviour and communication. Messrs Cyprus & Attwood dealt with a computer control project, in particular with the economic aspects, organisational and interpersonal aspects, technical considerations, redundancy of control equipment and man-machine interface.

The two written contributions dealt again with man-machine problems. Mr Unthank talked about the conflict between production and development demands placed on a single computer and Mr Keyes brought out the question of good project management and continued with a review of some of the remarkable advances that continue to take place in digital computer equipment. He referred to software costs, hierarchical control, multi-connected computer control relative to single computer implementation of hierarchical control and again about man-machine communications.

In my opinion, a number of the pieces of the jigsaw of entire papermachine control have been discussed as has some of the glue (so to speak) that might stick these pieces together. I have a feeling that we really have not come to grips with the problem of entire papermachine control and that it is going to require some highly skilled artistry to complete this picture. I hope that we can deal with this in the discussion.

Dr H. K. Corte I am somewhat disturbed by the emancipation from papermaking of the development of electronic hardware in papermachine control, which seems to run far ahead of our papermaking knowledge. It is still the chief aim in the life of a papermaker to produce paper that performs to the satisfaction of the customer. The first word on Mr Keyes' first slide, giving reasons for computer control, was *quality*, but I have not heard one paper concerned with the control of quality. Basis weight and moisture control improve the quality of a reel or consignment, but, if the paper is found not to be dimensionally stable enough or if the *small-scale* basis weight distribution is unsatisfactory, what do you do then? Too much emphasis perhaps is given to those quantities that we happen to be able to control (such as flow rates of steam, water, etc.) and too little to those that we ought to control in order to make better paper, not only more money.

Mr Keyes It is readily admitted by most people who put in control systems that they do not pretend to have a final answer. Their justification of advanced control is measured rather in terms of improvement over standard operation than in achievement of ultimate performance.

Your second statement on pulp and paper quality interests me, for the industry as a whole has for a number of years been pursuing the elusive goal of a device that measures pulp quality. I have yet to see a satisfactory definition of just what pulp quality is, whether it is measured automatically or whether it is measured by manual means.

Mr J. Mardon I think we can draw an analogy from the rules of sport. If one referees a game, one is commonly expected to have a thorough knowledge of that game. You cannot referee a hockey match using football rules and such is the situation in which, in the application of advanced control systems, the companies are placing themselves. I absolutely agree with what you say, but much of this information is available. The point is that those implementing control systems are often not cognisant of it and do not attempt to use it. It is certainly true in any company thinking of applying an advanced control scheme that known papermaking technology should first be put to use; before applying an advanced control system, thoroughly investigate the process. If the available technology is inadequate—and, in certain areas of the manufacturing processes such as for pulp, the technology is clearly not adequate—one must find it out. This is one reason for our systems engineering group to be moving slowly. They are taking cognisance of the points you have raised and are making sure that they understand the rule book before they start to referee the game.

Mr G. F. Underhay Following on what Dr Corte said, I notice that, in stating the degree of accuracy in controlling basis weight, not one writer has said what size of paper he is concerned with when measuring basis weight. Square centimetre samples will exhibit far greater basis weight variations than square metre samples and, of course, the wider the paper, the worse will be the indicated weight variation, especially if small samples are used.

Mr M. I. MacLaurin Mr Jolliff remarked that the Georgetown project was directed from his New York office with no consultation at the mill. I expect this approach to raise problems.

Mr C. C. Jolliff The original computer installation was put in purely as a research project, without any planning or knowledge on the part of the individuals who were brought together to start the project. That was the last computer installed in that way, the others have been planned for and have been justified on the basis of expected improvements in product quality or productivity.

Mr R. G. Nagro Perhaps, to tie together the pieces of the jigsaw, we should look at the non-control aspects of the computers and see if we can get an analogy. Originally, when computers first came out, people installed them where they worked with well-defined, but limited objectives. We are still doing this with control computers today and I think we have reached the stage of some rather well-defined applications. We may not know exactly how well they pay off yet, but I assume in the next year or two that you will be able to assess them fairly well. Nevertheless, we are reaching the point of being on the verge of a major revolution in the management of papermaking companies, as we are in the management of *all* companies. What management is going to be faced with over the next two or three years is a major change in the techniques of doing business, not necessarily through the computer, but through a well-defined, very precise sort of system—all the elements of process from the receipt of the order to the shipping. That is the opportunity that the paper industry will have to grasp. Although some managements consider themselves being dragged into this, I am afraid that in one way or another we must all be involved. Maybe, we ought to look at the hardware and software we have been talking about and the definition of control in the context of how we really want to run our paper companies.

Mr G. D. Madeley My first point is that people have been very defeatist in their ideas—that, because we do not understand papermaking fully, we cannot attempt to control it. The way you learn to play football is just by playing it, then you start learning the rules. This is how we feel about it. Our computer installation highlighted our areas of ignorance: we rapidly learned to overcome them. We learned about papermaking—indeed, a great deal about it.

We are now getting a more consistent, uniform product. Perhaps we do not understand how to control the wet expansion of our paper, but at least it is uniform now. If we make a change, we obtain a uniform change.

My second point is on extending control throughout the whole of the management system. This is something we are very keenly interested in. At present, we have a computer on the papermachine by which we are hoping to control the actual papermaking. At the same time, we are introducing into the mill a planning system conceived in logic rather than just growing up like Topsy. This planning system, although essentially manual, is designed in such a way that automatic accounting machines—perhaps even computers—can be put into it with the minimum of problems. I am sure that this is the way papermill control will go.

Mr O. Alsholm Being in the initiation stage of the game, it is only natural that quite a bit of money has been spent on back-up instrumentation for computer control loops. Thus, it was interesting to hear from Mr Cyprus about the cheap 'degraded' controllers used at the Sittingbourne Mill.

Mr Keyes, you have been involved in two of the world's largest DDC installations, which have both almost 100 per cent back-up instrumentation. What of the future installations? For example, some people claim that one gains more than the cost of back-up installation by including several recorders during start-up. I cannot imagine that this will still be true in the future.

Mr Keyes Neither of these installations incorporates full back-up. Our experience has shown that the use of full back-up is detrimental both to reliability and to the human engineering aspects of the job. When a papermaker is confronted with a choice between a system that performs better, but is new and a system that performs not as well, but with which he is traditionally familiar, he will tend to use the familiar equipment with loss of performance. Secondly, in some of our installations, we found that one of the weakest links in the entire system has been the reliability of the back-up equipment.

Mr H. D. Cyprus The system at Sittingbourne has six bumpless controllers, which are quite expensive. To a large extent, this reflects what little lack of confidence we had when first putting this system together. Our plans for No. 17 machine include nothing like this extent of standby back-up; we would almost totally eliminate the need for the bumpless controller and standby system would therefore rely largely on the simple standby controllers (about £30 apiece). They share output lines with the normal computer outputs, so cabling, etc. is no additional cost. They have a very limited proportional band and fixed integral time, but both these are easily changeable from the nominal values that are set when the equipment is purchased. In any event, I believe a new improved range of equipment is at present available.

Mr B. W. Balls On this question of tying the machine together, I think a lot can be learned from a large number of installations that have been made in the chemical industry, where surprisingly enough the problems are similar. They talk about it in different terms, but the pattern that emerges is the importance of control enforcement, by which is meant making the system perform as it was designed to do with minimum operator interference. DDC provides a standard of control enforcement never before experienced in any control system. There is ample reference to this in the literature and, if you are able to talk to people who operate DDC systems, this will be said. Today, any machine of reasonable capacity can be tied together very easily and simply with a DDC system; I think it could be guaranteed that an upgrading of the whole performance of the machine would then be noted. One advantage of DDC that was not learned with some of the earlier supervisory computer systems is the need for total involvement of everybody in the project, from the management downwards. In this respect, I support what Mr Mardon says in his paper on the involvement of people. If the people are not involved, the computer project will fail.