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ANALOG SIMULATION STUDY OF AN AIRKNIFE COATER

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Synopsis The response of a flow balance coating weight control system to changes in control settings and transient disturbances has been investigated by means of an electronic analog. A non-linear blow-off characteristic, determined experimentally, is shown to give rise to instability in certain conditions. The effect of pipe lags and valve action times can be demonstrated by use of the model; the validity of analog approximations to pure time delays is discussed and corroborated by results obtained with a digital computer simulation technique. The extension of the model to take account of preferential pick-up of moisture by the paper web is described.

Introduction

INCREASING demands for faster and wider off-machine airknife coaters highlighted the need to have a greater understanding of the factors affecting the coating flows in the applicator section of the machine.

More expensive and sophisticated coating materials emphasised the necessity of closer coating weight control.

These two factors led to the decision in 1962 to set up an R & D project to study the behaviour of the coating applicator section. This paper deals with a part of this project work that included an analog computer simulation of the applicator section.

The study includes a single phase flow (that is, perfect mixing) and a two-phase study of water and total solids flow.

The purpose of the investigation was—

1. To determine the response of the system to transient disturbances in flow rates to enable optimum design parameters for the geometry of the applicator section to be formed.
2. To investigate the effect of pipe lags and machine speed changes.
3. To optimise controller settings consistent with stability and speed of response.

Under the chairmanship of Dr N. K. Bridge

Description of coater

THE essential features of the airknife coating system to which this analysis applies are shown in Fig. 1. The web passes over an applicator roll, which turns with the web, at an angle of wrap determined by wrap rolls. The web then passes round a backing roll, where an airknife smoothes the coat and removes excess coating mix. The pressure in the airknife is variable and the aperture and angle of the knife are preset.

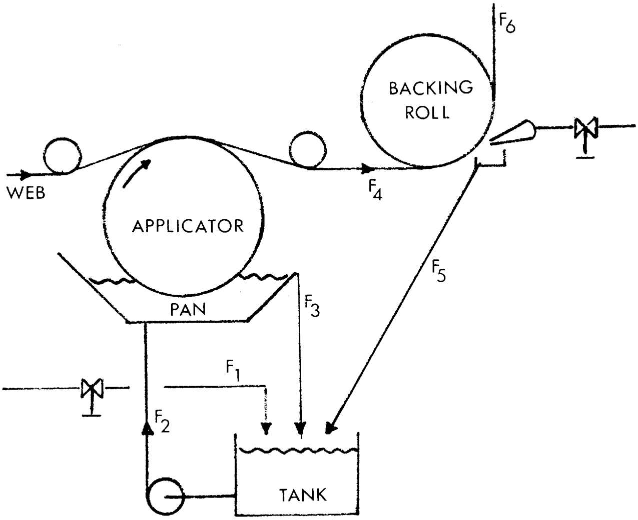

Fig. 1—Coating head

Coating mix, containing anything from 15 per cent to 45 per cent solids, is fed in a suitably controlled manner to a tank where it is mixed with recirculating flows. From the mixture in the tank, a steady flow is pumped to the applicator pan. A proportion of this flow returns at once to the tank over a weir, which is the full width of the deckle. The other part of the flow to the pan is carried forward by the web. The excess coating blown off at the airknife is collected in another pan and returned to the main tank.

There are six separate flows—

F_1 the coating mix input
F_2 the supply to the applicator pan ($F_2 > F_1$)
F_3 the return over the weir ($F_3 < F_2$)
F_4 applied to the web ($F_4 < F_2$)
F_5 excess coating removed ($F_5 < F_4$)
F_6 final coating.

By definition, $F_3+F_4 = F_2$ . . . . . . (*2.1*)

and $F_5+F_6 = F_4$ . . . . . . (*2.2*)

When all flows are steady (tank level constant)—

$$F_2 = F_1+F_3+F_5 \quad (2.3)$$

From (*2.1*) and (*2.3*)—

$$F_4 = F_1 + F_5$$

and so $F_1 = F_6$

There are various methods of coating weight control based on the principle if F_1 is maintained at the correct value, the long-term average value of F_6 will be the same. Hopefully, 'what goes in must come out'. One of the objects of the simulation is to see how quickly and accurately F_6 is likely to follow changes in F_1 in such a control system; another is to determine the conditions in which the control loop becomes unstable.

This type of coater is used in the Wiggins Teape Group at speeds between 500 and 1 500 ft/min with airknife pressures up to about 5 lb/in^2.

Factors affecting coating slurry flows

THE quantity of mix applied to the web is traditionally controlled via the airknife pressure, but it is necessary in analysing the coater to note that the applicator roll settings play an important part in fixing coating weight. For instance, the upper limit of coating weight is clearly a function of applicator roll setting. The airknife can subsequently reduce the coating applied, but it can never increase it.

Applicator roll setting is also liable to put a lower limit to coating weight. In any coater, the finite distance between applicator roll and airknife means that there is a finite dwell time of mix on the web before blow-off. During this dwell time, a proportion of the mix is absorbed by the base and no amount of subsequent blowing will remove it.

In practice, the factors that affect applicator flow (that is, viscosity), applicator roll speed, metering roll gap and angle of wrap are constant for a given run. (When viscosity is apt to vary, there is sometimes separate viscosity control.) To simplify the simulation, applicator flow was therefore included as a preset independent variable. This meant that it was unnecessary to go into, say, the rheology of film splitting; the detailed behaviour of fluid in the applicator pan and on the roll is undoubtedly very complicated, but, provided conditions are constant for a given run, they will not affect control system behaviour.

The detailed behaviour of the airknife is also a complicated combination of fluid properties such as viscosity and of mechanical settings such as airknife angle, gap setting and distance from the sheet. As in the case of the applicator roll, the effect of all the preset variables can be lumped together in a single constant for simulation purposes. One variable, the pressure in the airknife, is not preset. It is varied during a run, either manually or automatically, as a fine control of final coating weight. It is therefore necessary to know how blow-off flow changes as a function of airknife pressure. An empirical function for this characteristic was chosen to match the observed behaviour.

Approximations used in the model

THERE exist well-known techniques for electronic analog simulation of control circuits; these are discussed in, for example, a book by Rogers & Connolly.(1) The analog computer used had 36 amplifiers, ten of which could be used as integrators; there were also three multipliers and several function generators. This means it was not a particularly large analog computer and

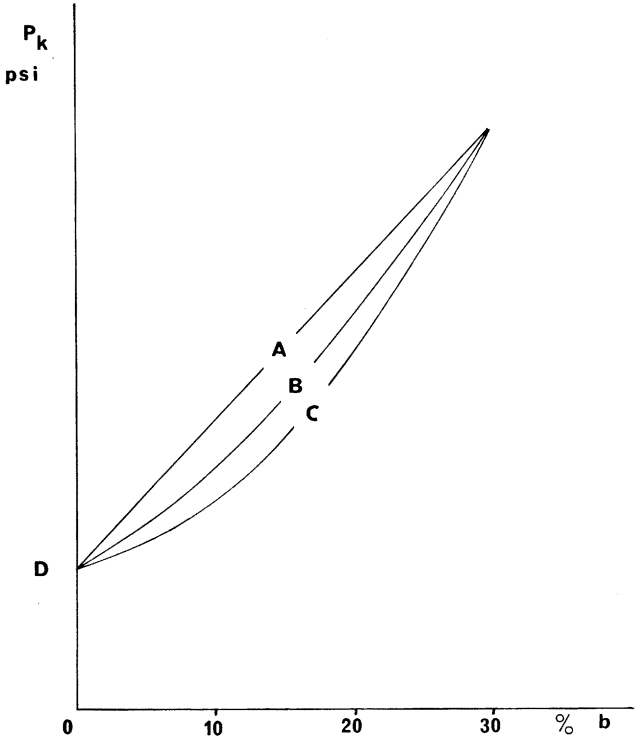

Fig. 2—Blow-off characteristics

the treatment of applicator flow as a constant, mentioned above, was necessary if only to keep the hardware requirement within the resources available. In order to build in allowances for, say, film splitting, it would be necessary to make other sweeping approximations elsewhere.

It is a well-known shortcoming of electronic analogs that there is no easy method for exact simulation of a pipe lag. This is one major reason for going to digital simulation, when long lags are involved.(2) For lags of only a few seconds, it is possible to make do with circuits (singly or in series) that give an exponential response to a step function. Use of such a circuit for the pipe lag in F_5, for instance, means that, if the airknife is suddenly applied, the return flow to the main tank appears to commence at once and rises exponentially to its steady value. For disturbances less severe than a step function, the circuit gives a response that looks more like a true lag. The time constant of the exponential is set to match the estimated duration of the lag, which itself is not known precisely.

Consider next the important function that relates blow-off flow to airknife pressure. For a given application rate, the available data suggest that the appropriate characteristic lies between curves A and C in Fig. 2. This family of curves can be generated by putting various values for constants L and S in the empirical equation—

$$\text{blow-off fraction } b = L(P_k - D) + S(P_k - D)^{\frac{1}{2}} \qquad . \quad . \quad (4.1)$$

P_k is the airknife pressure in lb/in^2 and D is the pressure in lb/in^2, different for each air knife, at which the blow-off flow falls to zero.

Note that the curved characteristic implies that at low blow-off flows a small change in airknife pressure causes a relatively large change in blow-off. When the air knife forms part of a coating weight control loop, any change in the slope of the characteristic causes a change in loop gain, which in turn affects the stability of the system.

An expression also has to be found for the weir characteristic. Fortunately, weir behaviour is not critical as long as a reasonable flow is maintained. In the simulation, it is simply assumed that weir flow is proportional to applicator pan level and that the pan level never changes enough to affect F_4.

Control system

A METHOD that could be used for automatic coating weight control on some of the coaters to which this study applies is shown in outline in Fig. 3. It comprises two separate control loops. In the first loop, which controls input mix flow F_1, simple on-line analog computation is performed to set the input flow at the correct value to give the desired final coating weight, when the system is in the steady state. The second serves simply to establish and maintain this steady state. Airknife pressure is controlled by a controller with proportional-plus-integral (PI) action, in cascade with a proportional-only pan level controller.

The appropriate proportional band (or gain) setting for the two-term air pressure controller is related to the action time of the control valve and the character of the air flow; once set to give satisfactory stability, it need never be altered.

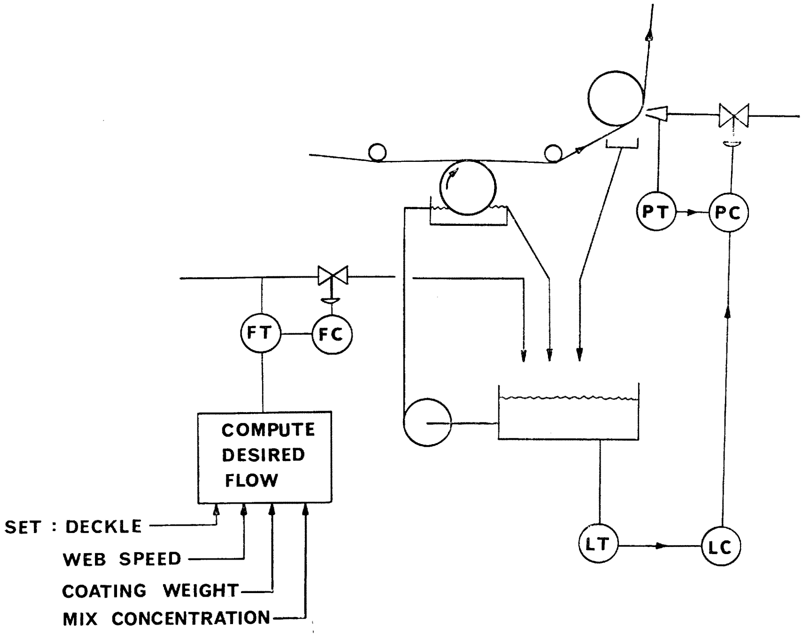

Fig. 3—Control system

The appropriate gain setting for the single-term level controller is not so easy to determine, being influenced not only by the slope of the blow-off characteristic (Fig. 2), as already mentioned, but also by tank geometry and pipe lags. If the tank cross-section is decreased, level will change more quickly, effectively increasing loop gain. If pipe lag in the feedback flow F_5 increases, the correcting signal is likely to cause overshoot unless loop gain is reduced. The electronic analog allows quantitative investigation of all these effects.

The block diagram of the coater and control system used to construct the electronic analog is shown in Fig. 4. The independent input variables for the system are given in Table 1.

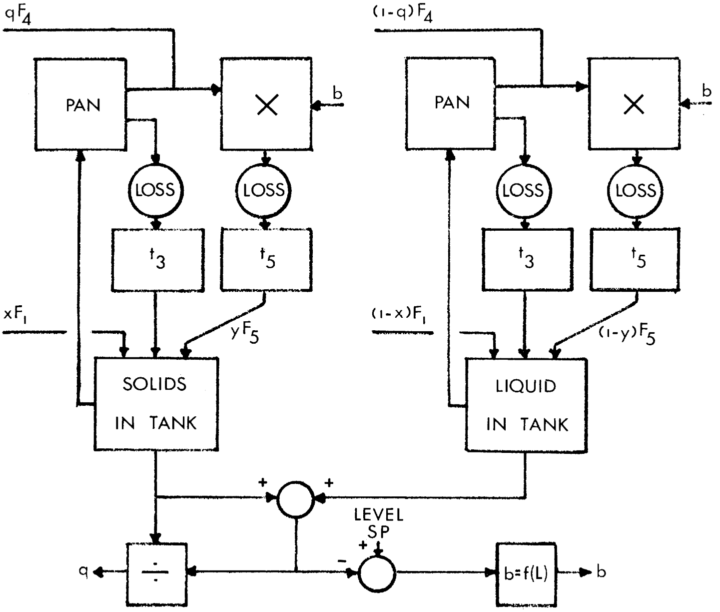

Fig. 4—Simulation flow diagram

TABLE 1

Variable	*Symbol*	*Units*
Web speed	V	ft/min
Desired coating weight	W_D	g/m^2
Deckle and solids content	—	—
Flow to applicator pan	F_2	gal/min
Flow from applicator to web	F_4	gal/min
F_1 loop gain	—	—
F_1 valve action time	t_1	s
Level controller gain	G	none
P_k loop gain	—	—
P_k valve action time	t_p	s
Weir flow pipe lag	t_3	s
Blow-off flow pipe lag	t_5	s

(*Where symbol and units are left blank, changes in the variable are not considered in the simulation*)

The outputs from the simulation are—

	Symbol	*Units*
Airknife pressure	P_k	lb/in^2
Blow-off fraction	b	none
Coating weight	w	g/m^2

The analog circuit used for the simulation is shown in Fig. 5 and the outputs during one operating sequence are shown in Fig. 6.

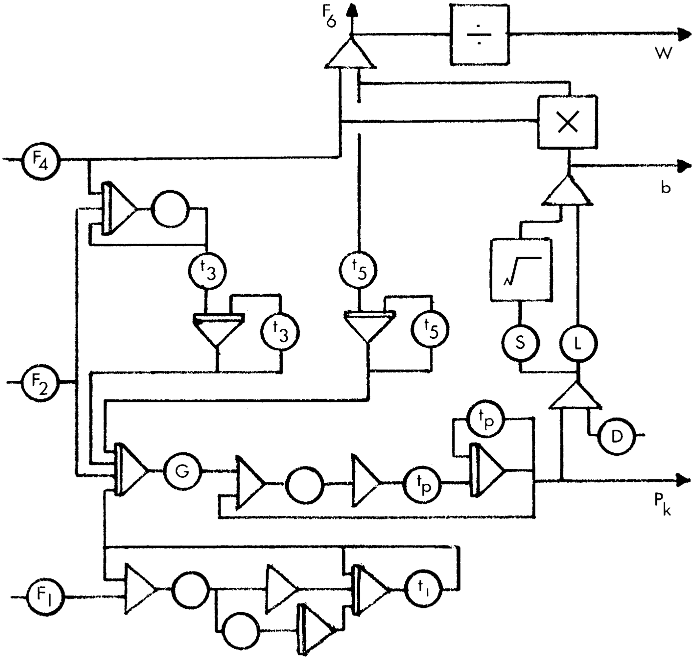

Fig. 5—Analog model

The sequence represents the effect of making sudden changes in web speed from 1 000 to 1 300 ft/min in steps of 100 ft/min, returning to 1 000 ft/min in one step. Coating weight can be seen to make brief downward excursions while the control system adjusts to the upward speed changes and a larger upward excursion at the large downward speed change.

To see how this kind of test reveals instability in the system, consider the sequence reproduced in Fig. 7. The conditions for Fig. 7 were the same as for Fig. 6, except that loop gain was increased to a point where the system became unstable at low values off blow-off. Note that in Fig. 7 the system is stable until the blow-off fraction is below 10 per cent. Instability is encountered at that point because, as stated earlier, the gain contributed by the slope of the pressure/blow-off characteristic (Fig. 2) is higher at lower values of blow-off.

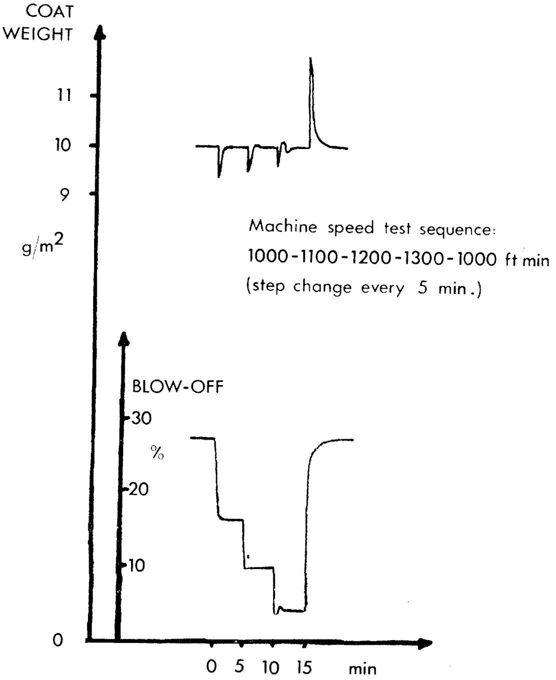

Fig. 6—Output traces

The setting of loop gain at which instability occurs was determined at various levels of blow-off for each of the three blow-off characteristics shown in Fig. 2. The results are plotted in Fig. 8. The gain values are shown relative to optimum setting, the optimum being defined as that value which produces a critically damped response to a step change in web speed. It can be seen that, for the most non-linear blow-off characteristic *C*, tolerance on the gain setting is progressively closer as blow-off is reduced.

Pipe lags and valve action times can also affect stability in that, if the time constant changes after the gain setting for critical damping has been established, the response of the system alters. For instance, the pipe lag t_5 in the return from the blow-off will certainly be a function of viscosity, probably also of the size of the flow. The effect of changes in it is illustrated in the set of sequences (each one like the sequence of Fig. 6) shown in Fig. 9. To obtain this set, the pipe lag t_5 was in turn 1, 2, 5, 10 and 20 s. The gain was previously set to give critical damping when the lag is 2 s. Overshoot is seen to increase progressively as the lag increases and, at a lag of 20 s, the overshoot is excessive; if deviation on the plant became as severe as this, interlocks would sound an alarm and switch the control system from automatic to manual.

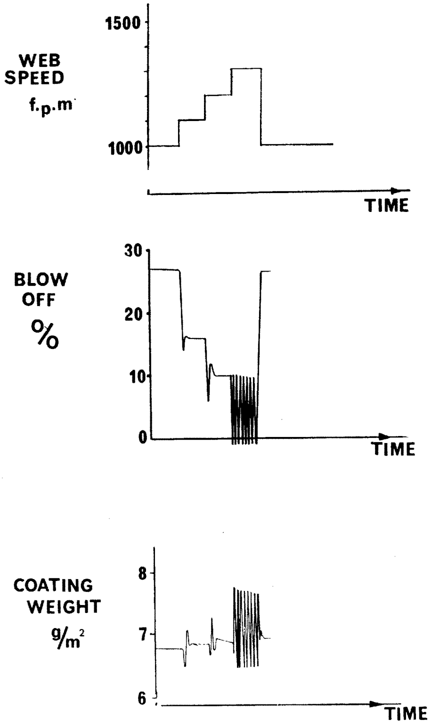

Fig. 7—Instability

The simulation showed that pipe lag in the blow-off return is much more critical than the lag t_3 in the return from the weir of the applicator pan. Increasing t_3 from 2 to 10 s produced no measurable change in response; the weir return is in any case so direct that this pipe lag is unlikely to be either large or varying.

The remaining factors affecting stability are measurement lags and valve action times. Measurements of knife pressure and pan level can be made easily and rapidly, so measurement lags can be neglected. The input flow control valve is outside the main control loop of the particular system being analysed (for some systems, this is not so), so the F_1 valve action time t_1 can also be ignored, yet the action time t_p of the knife pressure control valve has

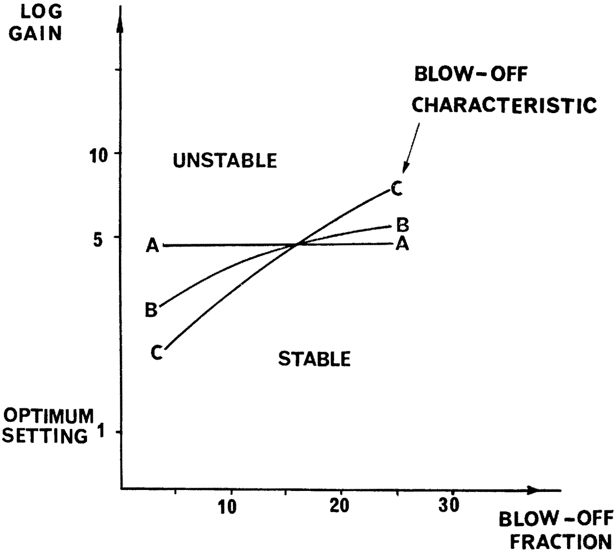

Fig. 8 –Gain margins

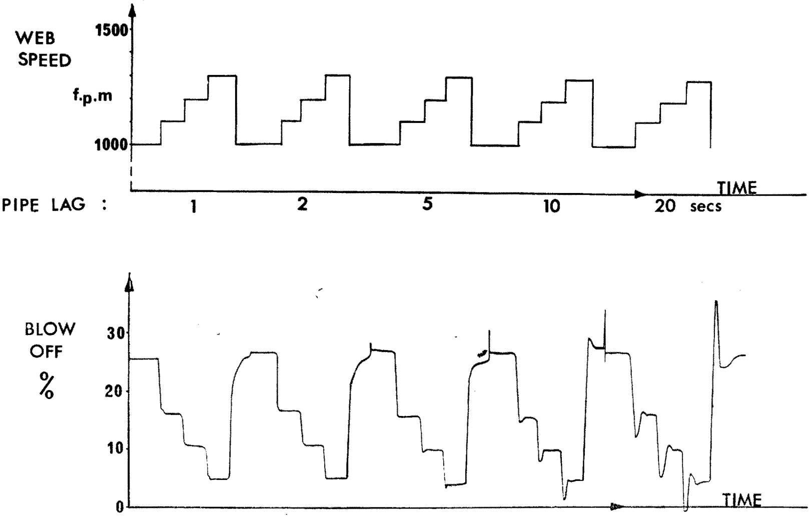

Fig. 9—Blow-off response for different lags in F_5

an important effect on stability. If it gets longer after the initial setting up, a new type of instability eventually occurs. This is illustrated in one further set of sequences (each like that of Fig. 6) shown in Fig. 10. For this set, the valve action time (normally set at 5 s) was, in turn, 1, 2, 5, 10 and 20 s.

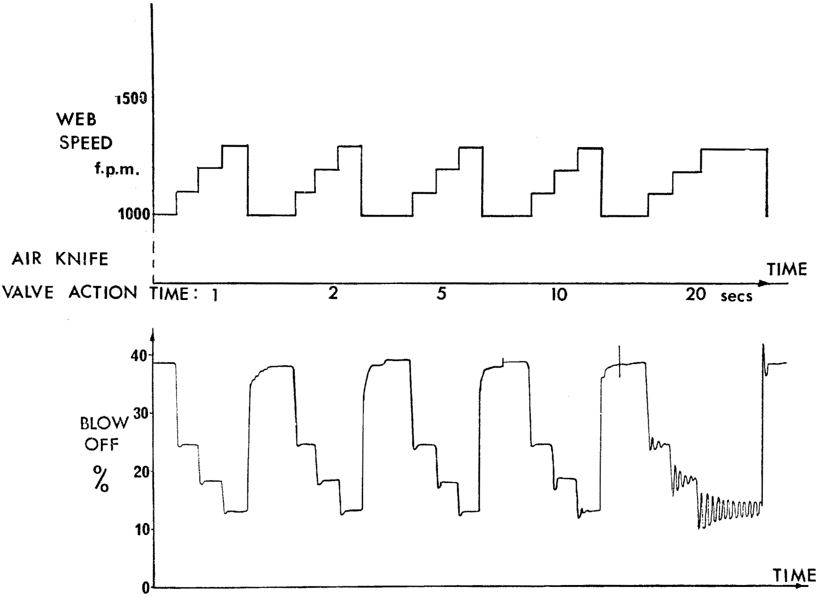

Fig. 10—Blow-off response for different P_k loop lags

In summary, the two critical time constants are the pipe lag in the blow-off return and the airknife control valve action time, neither of which ought to exceed 10 s. Loop gain setting is more critical as the blow-off characteristic becomes more non-linear. Absolute loop gain is a function of tank geometry; even so, this can be chosen entirely on other considerations, with any necessary gain compensation being provided subsequently in the controllers in the normal way.

Two-phase study

So FAR, it has been assumed that the solids and liquid in the coating emulsion remain mixed in constant proportion throughout the coater at all times. Even if the main tank concentration is kept uniform by thorough agitation, the solids content of the return flows would not be likely to equal the concentration of the incoming mix, on account of preferential pick-up of liquid at the applicator and absorption of moisture by the web in the dwell time before blow-off.(3, 4)

It is known that such effects are not negligible in the particular systems being discussed. Concentration of solids in the return flows have been observed to be 1 or 2 per cent higher than in the incoming mix. With recirculation, the effect is cumulative. It can take an hour for the concentration to reach equilibrium if the tank capacity is large and, as the mix thickens, it can become impossible to maintain an even coat.

If mix concentration in the main tank is monitored, it is possible to arrange to dilute the mix by the addition of water in a suitable manner.(3) Extra water should not affect long-term coating weight, because solids quantities entering and leaving the system are unaffected. There might be short-term effects, if the dilution is done with insufficient care.

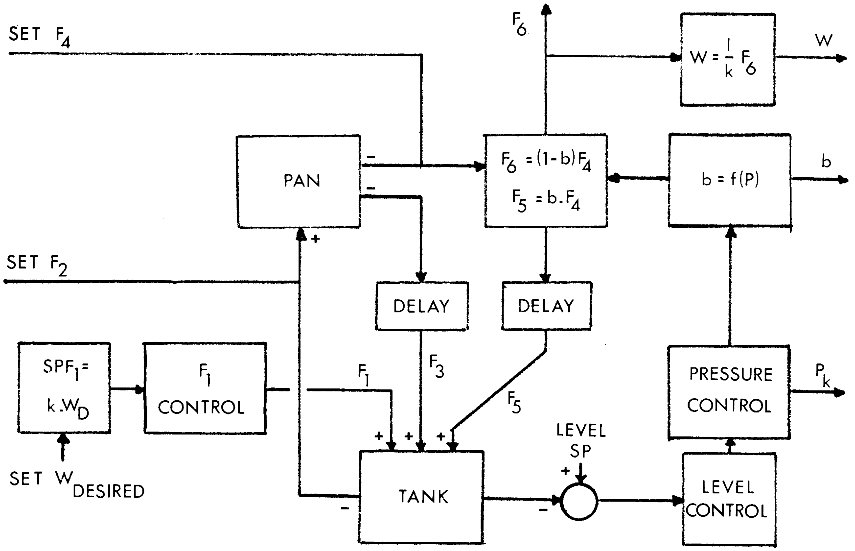

Fig. 11—Two-phase model

If the changes in concentration are well understood, they can be anticipated and compensated for in advance in the make-up of the input mix. The added complication of viscosity control can then be avoided. A straightforward extension of the simulation circuit already used provides a simple model for studying two-phase behaviour. The principle of the model, shown in block diagram form in Fig. 11, is to have two identical circuits representing solid and liquid circulations. The solid and liquid flows are integrated separately and the solids total divided by the sum of solid and liquid totals give the main tank concentration.

Let x = proportion of solids in input mix (an independent variable),
y = proportion of solids in blow-off return flow,
z = proportion of solids in weir return flow,
q = proportion of solids in main tank,
(y, z and q are dependent variables).

Then q is related to x, y and z by integration with respect to time—

$$q = \frac{\int(xF_1+yF_5+zF_3-qF_2)dt}{\int(xF_1+yF_5+zF_3-qF_2)dt+\int[(1-x)F_1+(1-y)F_5+(1-z)F_3-(1-q)F_2]dt} \quad (6.1)$$

Continuous solution of this cumbersome type of expression is exactly the sort of task best done by analog computation.

The value of q from (*6.1*), besides being displayed as an output, is then used to fix the proportion of solids at any given moment in the flow F_2 arriving at the applicator pan. The total value of F_2, set by pump capacity, remains an independent variable—

$$qF_2+(1-q)F_2 = F_2 \quad (6.2)$$

Preferential absorption and other factors causing differences between q and y and z are introduced by inserting losses at the points marked *loss* in Fig. 11. In practice, losses in the flow over the weir are negligible, so z can be regarded as equal to q at all times. For the losses in F_5, let P_s be the proportion of solids lost from the blow-off flow due to settling out and let P_L be the proportion of liquid lost from F_5 either by preferential absorption before blow-off or by evaporation after blow-off.

The method used for testing the behaviour of the two-phase model was as follows. The three time constants were assigned permanent values—

t_3, weir return lag	2 s
t_5, blow-off return lag	5 s
t_p, pressure valve action time	5 s

and a suitable value was fixed for input mix solids content x. Then the steady state values of main tank concentration q, blow-off fraction b and coating weight were recorded at different settings of loss factors P_s and P_L, as well as at various web speeds. The whole set of readings was repeated for different values of solids content in the input mix. The results are summarised in the curves of Fig. 12.

The results show that at high speeds, when the blow-off fraction is low, losses from F_5 have little effect on the solids content in the main tank for a given P_s and P_L. This is consistent with observed behaviour (remembering that P_s and P_L probably increase as F_5 decreases).

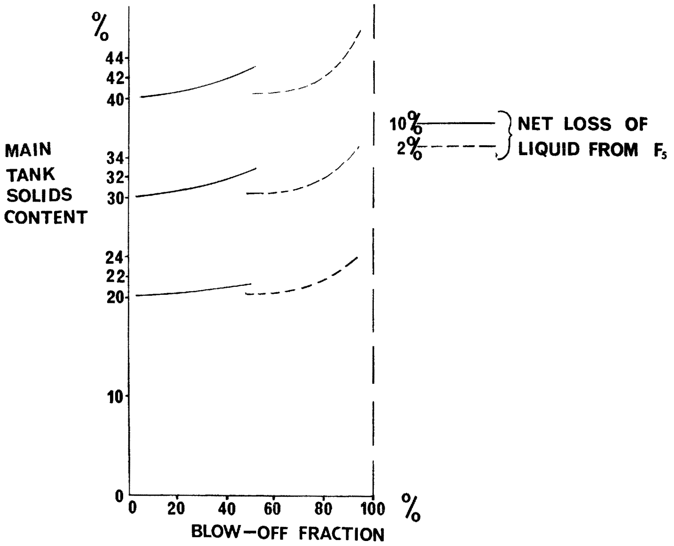

Fig. 12—Two-phase result

If it is possible to measure the solids content of the blow-off flow, it will be found that the equilibrium value of the main tank concentration is given approximately by—

$$q = x+b(y-x)$$
$$\text{or } q = (1-b)x+by \qquad (6.3)$$

where, as before—

x = input solids content,
y = blow-off solids content,
q = main tank solids content,
b = blow-off fraction.

Summary of the simulation

An ELECTRONIC analog simulation of a common type of airknife coater has been built, including simulation of a possible automatic coating weight control system.

The first model described, in which the coating mix was treated as a single-phase homogeneous fluid, was sufficiently detailed to give useful information about the stability and response of the system in a wide range of conditions. In particular, the model showed that, given valve action times and pipe lags all in the range 1–10 s, the control loop can be set to restore coating weight to a preset level within 15–30 s after a given disturbance such as a sudden change in web speed.

It was further shown that, for this particular method of control, the most critical time constants are the pipe lags in the return flow from the air knife and the valve action time in the airknife control loop. Performance of the system will deteriorate if either of these constants exceeds 10 s.

The stability of the system was shown to be strongly affected by the shape of the graph plotting blow-off against pressure characteristic of the air knife. If the characteristic is non-linear, stability is likely to be poor at low blow-off rates.

The scope of the simulation was limited partly by the size of the computer, partly by the shortage of detailed knowledge of the behaviour of these coaters. For instance, a detailed model of the applicator was omitted to economise on the computing facilities needed and, as an example of the second limitation, no account was taken of the possibility that the blow-off characteristic may vary with web speed. Such variation is highly likely, but no information was available about how it might vary, so the possibility was ignored. (Large numbers of readings of the sort of data required are of course being made all the time, but so many variables are involved that different runs are seldom comparable.)

The simulation was extended to analyse the flows of solid and liquid phases of the mix separately. From this two-phase model, some useful predictions were obtained of the way the mix is likely to thicken during recirculation. The time needed for such thickening to stabilise was found likely to be between 10 and 100 min, depending on the capacity of the particular system.

Even a two-phase model does not give an exhaustive treatment of the situation. For completeness, a multi-phase model would be needed, but an analog computer of the size needed for that probably does not exist.

Check with digital simulator

At a late stage in the work, it became possible to repeat part of the simulation on a digital computer, using the simulation language MIMIC. With this, pure time delays could be used when appropriate, instead of transfer lags. The results confirmed that the original approximation was justified. It can be shown by use of transfer functions that there are good reasons to expect the two types of simulation to give equivalent results in this particular case.

Conclusion

THE information obtained on the dynamic behaviour of the applicator section and the likely performance of control loops led to the development of a sophisticated coating weight control system.

Several control systems are currently controlling lightweight coating, in the order of 10 g/m^2 to within ± 3 per cent. The performance of the control system has been found to be in line with that recorded in the study. A coating machine study also confirmed the instability of the particular control system suggested at low blow-off flow rates.

Several further process studies have been performed on the relatively small analog computer, which, like the study described in this paper, has fully justified the original financial outlay.

References

1. Rogers, A. E. and Connolly, T. W., *Analogue Computation in Engineering Design* (McGraw-Hill, London & New York, 1960)
2. MacLaurin, M. I. and Rogers, J., *Pulp & Paper*, 1967, **41** (28), 40–43, 52
3. Gore, H. P., *Tappi*, 1966, **49** (11), 473–475
4. Booth, G. L., *Tappi*, 1967, **50** (1), 106A–109A

Discussion

Dr A. R. Farmer Could you please say what processor was used for the digital simulations and the time duration for a typical run?

Dr I. D. McFarlane We used the simulation language MIMIC and a 6 600 computer. Each run required 6–12 s of central processor time and the average cost was about £5.

The Chairman You have shown how valuable this technique is for devising the right control strategy for a particular situation. Presumably, you can also predict the controller constants required. Have you found as a result of such simulations that you can cut down the time to get the controller constant right during commissioning?

Dr McFarlane Yes, we find that we can appreciably cut down commissioning time.

Mr T. J. Boyle Did you consider other flow layouts than that described?

Dr McFarlane A number of configurations were tried. The one that we used was chosen in the light of our results.

Mr W. D. Hoath I am not quite sure what the questioner is getting at here. We certainly tried to blow off the return being mixed with a recirculation mix. This is not shown on this simulation, because the critical delay time is in fact the return from the blow-off section back into the collector tank. I should explain that the collector tank illustrated is quite a small tank under the machine. It is not remote from the machine, so it is quite a local reconstitution system as applied to this coating system.

Mr Boyle As you have introduced a number of controls, you say that you are liable to get increase in solids coming apart from the overflow. If the overflows are taken into one tank, this does not reduce the number of variables.

Dr McFarlane As Mr Hoath said, the important factor is the total capacity of the system.

Mr I. Tanner I wonder whether Mr Boyle is thinking of more traditional coating techniques in which blow-off and overflow are taken back to the colour shop to be reconstituted. In the system that Dr McFarlane has described, the reconstitution is done automatically within the coating head system, therefore the system is considerably simplified.

Mr Boyle I understand that. Surely the system could be made simpler and so reduce the number of variables.

Dr McFarlane It is possible that the blow-off return might be slightly quicker if mixed with the weir return. Apart from that, it would not make very much difference.

The Chairman I hesitate to interrupt this argument in full flow, but we really are here to discuss analog computers and their application. I suggest that the two participants discuss this point afterwards.

Dr R. A. Holm In view of the availability of programs like MIMIC and other digital simulation systems that seem to have a great deal more power and flexibility in operation, do you expect much simulation work in the future will be done on analog machines?

Dr McFarlane For a long time to come, analog simulators are going to be more readily available than the extremely powerful digital system we happen to have access to. The great advantage of analog systems is that anyone with a feel for processes can learn to use them very quickly.

Dr Holm We had an older system called PACTOLUS, which was used on an IBM 1620 computer, small and rather commonly used. It did the same job and was very useful, even with a really small system.

Mr A. J. Ward Perhaps I could relate our experiences in I.C.I. Ltd. The company has invested heavily in the provision of extensive and large computing facilities for off-line technical work. In addition, we have very few analog computers within the company. We make extensive use of simulation to study day-to-day problems, also to arrive at the fundamental nature of our processes and business. The overwhelming majority of the dynamic simulations are carried out in 360/CSMP language. It offers the opportunity for a very high level language description of the system, with the option open to the user to specify procedural blocks for which the standard facilities do not cover his case. It is being used by engineers, physicists, chemists and biologists for an extremely wide range of dynamic problems.

The Chairman Can you tell us about one or two applications of this technique.

Mr Ward At the micro-level, there have been studies of the diffusion of molecules across boundary layers. There is much work in the process control field in which the systems consist of fluid flow into tanks, with valves, pipes, etc. Reaction kinetics and distillation are fundamental aspects of business that have been extensively investigated. There has been a fascinating simulation of a large batch fermentation process, a new approach in biochemical engineering.

There are also studies in the tactical and strategic areas of the business and management of the company. These cover such a storage capacity assessment, scheduling, marketing, cash flow and stock control.

Mr J. D. Maloney On the simulation of papermachine wet end and dryer sections, an analog as well as a hybrid computer has been used. This approach has the advantage over digital simulation, because simulations can be carried out in one tenth, one hundredth, even one thousandth of real time. Thus, many cases can be run through very rapidly, which greatly shortens the total study time.

Dr McFarlane Most of this simulation work was done faster than real time. In addition to the digital packages we have been talking and hearing about and our sort of small analog computer, there is the hybrid computer that has logic and memory and so considerably widens the scope of the analog machine.

The Chairman I would like to start a discussion on the merits of small analog computing systems compared with larger digital installations and perhaps costs might be mentioned. It is likely that an ordinary mill does not have a large amount of money to spend to install any equipment, so there may be a constraint on expenditure of, say, £20 000. What are the advantages of a simple or analog system compared with more complex or digital systems? Two people have said that they would like to open the discussion: may I therefore call first on Mr Balls.

Mr B. W. Balls I am reminded of a similar occasion, the 1956 Technical Section conference, when I gave a paper on simple applications, stock blending and flow box control. The Chairman, Mr K. C. Weedy, did me the honour of saying, 'If there are many mills left uninstrumented in this country in another 10 years' time, it will not be his fault.'(1)

I can assure him that success has been less than anticipated! Here we are, more than 13 years later, discussing advanced control systems, including computers, with the same enthusiasm and, I hope, fully conscious of the fact that a lot of ground work remains to be done.

The paper industry is said to lag behind the petroleum and chemical industries in use of advanced control techniques. This is not necessarily true among the leaders. Today, of something like 2 500 worldwide process computer applications, about 4 per cent are installed in pulp and paper mills.(2) This corresponds roughly to the uptake of process instrumentation by the industry. I have been involved in the world's largest DDC project at Fawley oil refinery, which became fully operational towards the end of 1967. This was about the same time that Empire Paper Mills was operating its DDC project, also Wiggins Teape at Dartford. In supervisory control schemes, Billeruds, Harding Jones, Mead and Wolvercote were operational in 1965, which compares favourably with petrochemical schemes of similar magnitude. During 1968–69, more schemes have been announced with promise of more to come.

Down the line, however, the same cannot be said and the paper industry appears to lag. Mr Emerton mentioned the paper by J. L. Good,(3) which is really an exhortation to get moving, but to do first things first. There is a marked reluctance in many mills to get to grips with basic process control using readily available, simple analog systems, simpler even than those we have heard about today.

In my opinion, one of the greatest single factors affecting the performance of measurements such as consistency, basis weight and moisture is the way in which broke is returned. Some mills will spend considerable sums on improved control, yet fail to tackle the broke problem realistically.

At the 1965 Technical Section conference, I asked three simple questions. 'Accepting that the future lies in the direction of computer control, what have you done, what are you doing and where are the men?'(4) These same questions are relevant today. Any attempt to apply a digital computer is unlikely to be successful without adequate preparation, including reasonable familiarity with analog control and measurement techniques and their limitations. Besides, there must be a careful definition of objectives.(5)

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1 Balls, B. W., *Proc. Tech. Sect. B.P. & B.M.A.*, 1956, **37** (2), 195–210
2 Balls, B. W., 'Progress in Pulp & Paper Industry' (Poznan, June 1969)
3 Good, J. L., *Paper Trade J.*, 1969, **153** (13), 76–81
4 Balls, B. W., *Paper Tech.*, 1965, **6** (4), T106–T109
5 Stout, T. M., *Paper Trade J.*, 1969, **153** (15), 54–57

I do not see sufficiently intensive efforts being made today to support expansion of digital computer projects and I fear that much time and money may therefore be wasted.

No building can stand unless the foundations have been laid with care, unless the builders know all the skills of their trades and unless there is a capable architect. This symposium is mainly for architects and master builders, but let us not forget the rest.

Mr H. B. Carter I am very glad of this opportunity to contribute, because this has been a sore point with me for many years. Certainly for 15 years, the instrument control industry has been trying to influence papermills: they have no reliable equipment. For 15 years, we have been arguing how much back-up we need. This is 1969; in 1954, I participated in installing two analog control systems in one of the newest papermills in U.S.A. without any manual back-up whatsoever. They were two electronic amplifier sectional drives. Why was there no back-up? Because those who made it and those who bought it did not know it was going to need a small bunch of boys standing by with bicycles. How much of the control instrumentation will anybody put that much faith in? I suggest hardly any. The other side of this could be, of course, that the electrical engineers like myself appear to be ostracised by the industry. Put another way, very few other disciplines in the industry seem to want to know about anything electrical. As these systems were in use before the second world war and are now out of date, I suggest we have not got very far in instrumentation because (*a*) we are not following what the electrical people have been doing for years and (*b*) we have not done enough to put it in. If the control goes down, the machine goes down. On the dryer section, if one bearing goes, that's it.

The human problems of automation are not as complicated as they appear. You have to persuade people that automation will help them. You must persuade them to understand it and you must be convinced yourself that they can be made to understand. The earlier remark today that the speaker would not dare install an instrument on machinery in an undeveloped country is an insult to the whole human race. I am serious. If a man is a man, he's a man; if you have insufficient patience to share with him the advantages of many years of technical training and education, then you are wasting your time as an engineer or control man. The people who are living with it day and night must be reached. Our experience in this was very specific in putting basis weight control on a papermachine. We took very great pains to educate the foreman and the machine crew and there is a gentleman here today who knows how hard these people lived with this equipment. We were two years putting this equipment in reliable condition, but not once did the machine crew ask to take it off. They faithfully took profiles day and night until finally we were able to put it into operation. The result now is that, as soon as the sheet is on the reel, the basis weight control is switched on to automatic and it stays there. So long as you give time to people, you have no problem in getting instrumentation in the mill, I assure you.

The Chairman Reliability is important, but it is a question that need not concern us just at the moment. Perhaps we could have comments not from the suppliers, but from the users of the equipment on small versus large installations.

Mr A. J. Ward It is several years since the first computer schemes were initiated and a lot of water has passed under many bridges. It would be interesting to know what sort of equipment would be quoted now for an expenditure of £20 000. Has the balance changed?

Mr R. E. Jones For £20 000, a firm would probably get a small analog system. Yet I think we are all aware of the greater scope there is for process regulation and higher level control such as grade change when a digital computer is used.

Dr A. R. Farmer I agree with that.

The Chairman I do not think that really answers your question. Dr Hudson has a comment to make.

Dr F. L. Hudson Those who visited Stratford-on-Avon at the second symposium heard words appropriate to this fourth symposium from that Shakespearean rogue Richard III—

> 'Clarence still breathes; Edward still lives and reigns.
> When they are gone, then must I count my gains.'
> (*Act I, scene 1*)

When the computer makers have gone and they have been paid and the reign of the papermaker is ended, we are left with the accountant and his chopper—too similar sometimes to Richard and his axe! He will 'count our gains' and will surely find that an investment that goes three quarters of the way for £20 000 gives a better yield than one that goes all the way for £200 000. I hope we shall be better informed on this matter before the symposium is over.

Mr G. F. Beecroft May I sketch briefly the past and present thoughts at Grove Mill arising from the installation and operational effects of our computerised wet end control? Five years ago, we wondered how to simplify our operation and to reduce costs. Primarily, we wished to simplify and we considered that automation of a shortened system should not be too costly an affair. No electrical company in the computer field considered our thoughts to be viable economically, however, until English Electric made a study in depth and so evolved the present system. The economics of controlling our 84 in wide machine proved fascinating when it became apparent that we were going to be successful; nowadays, we have ceased to be amazed. In fact, we consider fully computer-controlled papermaking to be ready for discussion, bearing in mind that, whereas full control would be economical for newly built mills, older mills may be selective in the parts of the process that should be automated or perhaps only instrumented in a sophisticated manner. The day is here when the equipment can become a package deal and in such a highly capitalised industry as ours the price will hardly be noticed.

We believe that our system is one of the shortest in the world, if not the shortest and we would like to issue a friendly challenge. From starting up with an empty system and wired bales of pulp, we can be in full production of highly beaten paper in 35 min. Who can do better? Our computer produces controlled conditions at the wet end: width of the machine and its speed are inmaterial. Computer control of drying conditions, the wetting process and draw tensions can all be added if they can be shown to be economic. In our opinion, it may be unwise to control certain parts of the process by computer if there is a machineman still employed. Our present benefits are better running conditions, faster changeover times, a sales edge over our competitors because of quality and a dawning knowledge that our industry has become inefficient. We have created holes so that we may become employed filling them in. We have said, 'If it moves, measure it'; having measured, then establish a control. We are now beginning to say, 'If it moves, why?' and the answer is coming out frequently that it need not move.

Our computer has been the key that has unlocked our mind—for example, we forsee an end to effluent problems in mills such as ours. This is the most exciting part of the whole affair: this unlocking, where will it lead? So strongly do we have these thoughts that we say, if you wish to control only basis weight, then do not purchase a computer-controlled process—it would be like casting a pearl.

Naturally, we are enthusiastic and we want to see the system copied. The reason for this apparent benevolence is that we want a feedback of information. Our system is Mark 1: the sooner a Mark 10 model is developed, the greater our own development will have become. We invite visitors to pay us a visit—our only stipulation is that a return visit be permitted and we would hope that allround knowledge had improved.

Mr M. I. MacLaurin The point I wish to make is extremely elementary and obvious, but a statement of it appears to be necessary.

Dr Hudson has reminded us that, in common with many endeavours, it is probable that 75 per cent of the return on a control project may be had for 10 per cent of the cost of doing a fully comprehensive job. This is only part of the story. Consider the case of the enormous machine installed recently at Bowater's Catawba mill. The investment is very large and so presumably is the return on that investment. In such a case, the very high cost of the elaborate computer control system must be readily justified if it improves profitability by a small percentage. Such lavish provision of comprehensive standby equipment and other safety features is not justifiable even for quite substantial machines such as our Dartford No. 6. We take the view expressed by an earlier speaker, who pointed out that essential items other than the computer are not backed up by on-line spares. We have minimum standby control. A catastrophic computer failure would shut the mill for at least 24 h. The cost of a full standby system would be high relative to the cost of down-time and the improbability of down-time occurring at all. We must relate the size and cost of our control systems to the return on investment that they control.

Mr G. D. Madeley I think it is important to get into true perspective the comparative cost of analog and digital computers. The total cost of our digital installation is about £160 000, but this includes all the instrumentation as well as the computer. The cost of our computer alone ex works was about £60 000 and it is this that has to be compared with the cost of an analog computer at £20 000. The immensely greater power and flexibility of the digital computer makes it in my opinion worth the extra £40 000.

Dr D. B. Brewster I would like to add to Mr Madeley's comments. I feel that these days it is no longer a question of saying that the analog system is cheaper. For a system the size of the Grove Mill installation, you can now buy the digital hardware for about £10 000. The history of digital systems indicates that this price will be quite a bit less in a few years. This is the reason that I asked Dr Farmer for his estimate of future cost reduction on analog systems.

The Chairman Mr Beecroft's point may not have been brought home to everyone—to think about basis weight control as one of the first controls on a papermachine is a waste of time. Your return is really from other things.

Mr J. S. Harris The Chartham scheme has recovered its investment in 12 months. The real value to us has been not only improved substance control, but a new way of thinking. We are now moving in to further areas of computer control.