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THE INTERACTION BETWEEN HUMAN AND AUTOMATIC CONTROL

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Synopsis Automatic controllers have been subjected to fairly intensive theoretical study and some attempts have been made to establish human transfer functions for certain manual control actions. The paper industry is fairly specialised, however, in that the response of the system is very slow. This paper is an attempt to study the human operators' characteristics in the control of basis weight. The paper is in two parts: the first is an ergonomic study of the process of papermaking and the second is a detailed study of basis weight control. A simulator for basis weight control is described that matches the actual operation of the papermachine and has proved extremely useful for training purposes.

Introduction

A PAPERMACHINE is a complex man machine system and presents many ergonomic problems. The problems can be divided into three groups concerned with—

1. Control of processes and materials (for example, furnish, consistency, moisture, basis weight).
2. Remote handling of materials (for example, transport of pulp to Hydrapulpers, reels to supercalender and winder).
3. Semi-repetitive maintenance (for example, grinding of press and calender rolls, wire changing).

In this paper, only the ergonomic aspects of the first group will be considered and basis weight alone has been selected for detailed study. This is because the problems of basis weight control are so well known and automatic control of basis weight is at last becoming commonplace. The study to be outlined here has been selected to illustrate the ergonomic analysis of an existing production system using direct observation and interview and owes

Under the chairmanship of N. C. Underwood a lot to the technique used by Sell,[1] although the actual results were obtained by (*a*) direct observation and (*b*) interviewing machine operators at three mills identified as A and B (newsprint mills) and C (a coating mill).

The ergonomic analysis

System goals—The ultimate goal of the papermaking operation is to convert wood into paper of dimensions and printing properties specified by orders received, using the least possible labour and materials and making the most economical use of capital equipment. Within this, the sub-goal of the papermill is to convert pulp into reels of paper and within this again the sub-goal of the papermachine is to convert thick stock into a specified sheet of paper 50–100 g/m^2, preserving at the same time a surface that will take a good print. Loss of paper due to breaks must be avoided.

The process—A, B and C are both Fourdrinier papermachines and C is equipped with a Massey coating system. In all three cases, the basis weight is adjusted by means of a stuffgate and basis weight is determined at each reel change by weighing five samples. Machine C has a single position beta-gauge.

Man's role in the system—All the physical motive power is provided mechanically and man's role is to control its application. No automatic controls were used on the machines studied, so that all the control is exercised by human beings.

There are several kinds of control function involved—

1. Primary adjustment, following a prearranged programme.
2. Secondary adjustment, needed to iron out any side effects of the primary adjustments or of other disturbances.
3. Timing control to synchronise weight changes with reel change, etc.

Each of these control functions may be carried out in either (*a*) an open loop or (*b*) a closed loop manner, depending on whether the operator has current knowledge of the results.

Detailed consideration of human tasks

Primary adjustment—basis weight

SINCE the system sub-goal is to produce paper of the basis weight required for a series of orders set out in a programme, weight changing is a primary adjustment. This is the responsibility of the machineman.

Open loop adjustment—When the schedule calls for a change in nominal basis weight, the machineman decides what change in stuffgate setting is likely to produce it, indicates his intention to the reelerman and, when the time comes, he makes the appropriate alteration to the stuffgate. He is then acting as an open loop controller.

An open loop control system must be calibrated and, in this case, the machineman carries in his head a rough table of the stuffgate changes required for different basis weights based on his past experience.

When machinemen were interviewed, it was found that they all knew the stuffgate changes needed for various changes in basis weight, but their figures and the allowances suggested differed materially between individuals.

The permitted tolerance on basis weight is about ± 5 per cent, but direct study of the effects of a basis weight change showed that several reels were out of tolerance after a major change and it seems therefore that the decision process could be improved.

Unaided human memory is used to gather the experience on which major stuffgate changes are based: but human memory for quantitative data such as this is poor. It is common practice to make a stuffgate change at the end of a reel so as to be on target for the next order. Unfortunately, the machineman does not always allow sufficient time for his change to have had full effect and often his sample (taken, say, 3 or 4 min after his adjustment) shows only half the required basis weight change and he makes a further entirely unnecessary adjustment, which he subsequently has to remove.

Machine C is equipped with a beta-gauge that monitors the base material before coating. This gives an immediate knowledge of results and should help the machineman to make corrective stuffgate changes much more rapidly. It was observed on machine C, however, that little or no use was made of the gauge. This could be because no one is particularly interested in the base weight. It is the machineman's job to keep the total weight (base plus coating) constant and the coaterman's job to keep the coating weight constant. Although this implies a constant base weight, it is not in fact a direct goal. If only one beta-gauge is to be installed on the machine, it would be far better on the finished sheet to give an indication of final substance, the machineman's goal. Ideally, of course, two are required, so that the coating weight can be obtained as well.

Since the actual weight fluctuates 2 or 3 per cent over periods of 2–3 min and the beta-gauge displays only the value integrated over 5 s, the operator must visually 'integrate' or 'average' its readings over several minutes to decide whether an apparent departure from correct basis weight is steady or merely transient. Some form of storage could well be incorporated in the display both to enable a judgment to be made without prolonged inspection and to retain information when the machineman is elsewhere.

Closed loop adjustments—The order usually calls for a run of several reels to be made to the same nominal basis weight and quality. As the order proceeds, the machineman can take corrective action to bring the basis weight into line with the nominal, using knowledge of the results of his first stuffgate settings and acting as a closed loop controller. The error-feedback information comes through a human link, since the basis weight is determined at the dry end by the use of a balance. The results are written down and reported to the machineman. Since the samples can be obtained only at reel changes, the cycle *trial-error-feedback-fresh trial* takes some time to operate and, when an inaccurate initial change has been made, several reels are made outside tolerance.

There seems to be no set instructions for making corrections. For instance, on machine B, the machineman could not immediately say how far the weight should deviate before they took corrective action. Eventually, it was said that on a making of 14 lb demy they would take action at 13·8 to increase the weight and at 14·4 to decrease the weight, but obviously these figures are not laid down and again the machineman is carrying in his head a rather diffuse table of corrections. All the machinemen on this machine stated that half a revolution of the stuffgate was about $\frac{1}{2}$ lb demy, but it was difficult to find out what magnitude of corrective changes were made. It seems that in this case the *goal* is not very well defined; although the target is said to be 14 lb demy, in fact the machineman finds it preferable to run heavy rather than light. An improvement in precision might be obtained here by giving the machineman a new goal (in this case, 14·1 lb demy) and saying that corrective action must be taken at, say, 14·4 and 13·8, although of course, if 14 lb demy is required, then the goal should remain 14 lb. The correction should also be indicated and, in this case, an instruction to change the stuffgate setting by $\frac{1}{4}$ revolution in the appropriate direction whenever these limits are reached should be given.

Some confusion exists, because in fact the machineman is never presented with an average weight, but with the weights of five samples across the machine. He averages these 'by eye', but any action he might take is governed by the highest and lowest values. Thus, if five weights 14·7, 14·4, 13·9, 14·4 and 14·8 are given, then he would not lower the value because of the 13·9 reading.

It is not so easy to find out what governs slice settings. It is certainly not basis weight, the sole criterion appears to be a good hard reel. If complaints come back from the reelerman about the reel, then the slice will be adjusted and the dry line used as a yardstick for levelness.

Making stuffgate changes

On machine C, the machineman is provided with a valve labelled 0–16 in order to control the basis weight. At the time of the interviews, the valve was set at 4 for a base sheet weight of 20 lb DC. The machineman changed the setting by tapping the handle with a short piece of steel. The first machineman questioned estimated that $\frac{1}{4}$ in movement would give a change of weight of 5 lb. The second could not say, but said that the setting was 6 for a base sheet of 30 lb. These two estimates agree moderately well.

This is a system with obvious ergonomic drawbacks. Even though this particular stuffgate may not have ideal flow characteristics, it could be provided with a simple gear reducer so that the machineman could carry out the small changes required with much greater precision. The stuffgate is placed at the backside of the machine, remote from the beta-gauge and from the machineman's normal position. On the other hand, the control of coating weight on this machine seemed to be far superior. The control wheel for regulating the weight was labelled 0–60 and the operator stated that 8 divisions was about $1\frac{1}{2}$ lb. Thus, the handwheel needed to be rotated 48° for $1\frac{1}{2}$ lb and, since the tolerance on weight is about ± 1 lb, it is obviously possible to make sufficiently fine adjustments.

On machine B, the adjustment seems fine enough, a half turn is equal to $\frac{1}{2}$ lb, which is probably remembered because of the roundness of the figures. Even if these were in error by 10 per cent, since the stuffgate is used to make corrections, then no great problem should arise. The valve suffers however from backlash and, although the machineman takes this out by feel, he does not always achieve the correct setting. In one experiment in which a machineman was asked to raise the substance by $\frac{1}{2}$ lb, he made his appropriate movements to the handwheel, but there was no change in weight and it was found that the valve stem had not in fact moved. The machineman on this occasion had not overcome the backlash.

In general, machinemen during interview did not appear to understand the behaviour of backlash and an aura of mystery seems to surround the stuffgate.

This is because it is not ergonomically sound. Either the flow of thick stock to the machine should be recorded or the position of the valve spade itself recorded. If they are recorded, a suppressed zero will be required so that the small adjustments can be seen. Again, on machine B, the stuffgate is remote from the machineman's normal position where he receives information about basis weight.

Timing control

All machinemen were aware of the time delay that occurs after a stuffgate change has been made, but none was aware of the real nature of this delay.

We have observed on machine A that very often the machineman obtains a sample at, say, time T and, even though he has in fact made the perfect adjustment, he makes a further change, because he thinks his adjustment is in error.

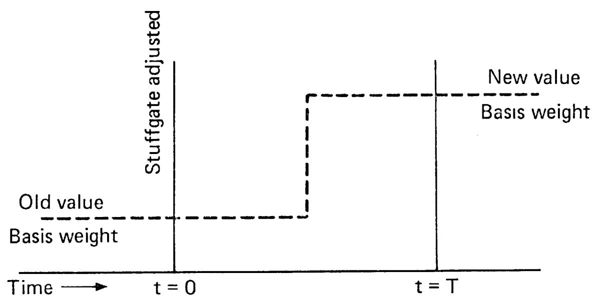

Fig. 1—What the machineman thinks happens

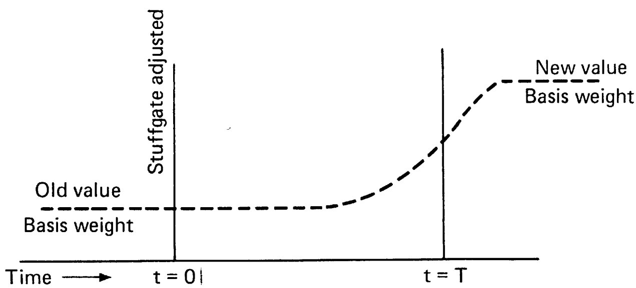

Fig. 2—What really happens

This is a tricky problem to resolve with existing equipment, although instruction might help. This time lag could be overcome with a specially built stuffgate (that is, one that overcorrected, then moved back to the desired position).

Summary of proposals

In short, then, the ergonomic analysis singles out the following points of weakness in the present system—

1. Inadequate long-term storage and processing of data relevant to stuffgate decisions.
2. Beta-gauge requires short-term storage and better display.
3. Stuffgate control needs to be centralised.
4. A display of the stuffgate setting required.
5. A preselector mechanism to carry out stuffgate changes would be valuable.

Conclusions of the ergonomic analysis

THE analysis described is only an outline. Several important aspects of mill operation have been ignored, nor have the detailed design considerations governing the proposed changes been given. Enough should have been said, however, to show how the ergonomic approach can be applied.

An ergonomic analysis involves technical and management considerations, as well as the human sciences and a particular design problem can be dealt with only in the context of the whole system of which it forms a part. Undoubtedly, the changes proposed here could have been suggested without the analysis, but there would then be insufficient grounds for expecting useful results. There are many other changes that could be made, but it is believed that the analysis pinpoints those that could contribute most to operating effectiveness.

Most studies aimed at understanding the human operator's characteristics as part of a man/machine system are concerned with the behaviour of the human operator as a controller of mechanical and electronic systems such as guns, aircraft and fast-acting machinery. Attempts have been made to establish a human transfer function, [2,3] but it is apparent from the results that performance cannot be adequately expressed in terms of any single transfer function.

Most work on manual control has employed systems having response times from small fractions of a second to a few seconds at most, so that the operator is exercising a manual skill without conscious deliberation. One of the more fruitful fields of study in the literature related to processes with slow responses is in connection with the control of atomic submarines. In physical terms, a submarine behaves in a similar way to an aeroplane, the only essential difference being the time scale, yet it is apparently true that human beings find it easier to control an aeroplane than a submarine. Chemical and metallurgical processes involving heat transfer may have time constants measured in hours and the response of basis weight to a change in setting of the stuffgate could typically have a distance velocity lag of about 3 min, followed by a time constant of about 20 min. In all these cases, an operator can exercise adequate control after a period of learning, but (as the first part of this paper indicates) there is evidence to show that manual control of these slower systems is far from perfect. To revert to the submarine problem, apparently a quite difficult task is to place the submarine on the sea bed (the effect of overshoot can be imagined) and, of the simpler aids now employed, a predictor giving a graphic display of where the submarine will be in the next 7 min is one of the most useful for the submarine. From what was said earlier, it will be appreciated that, if a predictor was available on a papermachine to show what the basis weight was likely to be over the next 7 min, the operators would be able to effect a considerable increase in their control of basis weight.

The use of automatic controls is not a complete solution, because there are many cases to which they cannot be applied and it is also clear that human operators can perform substantially better than automatic controls in certain cases.

Crossman[4] has studied the manual control of slow response systems, but seems not to have appreciated the difference between distance velocity (d.v.) lag and exponential lag of processes. He created a laboratory task having many features met in a typical process control situation, the most significant of which was that it had an exponential time constant of 2 min. He showed that manual operators very easily got the system into an unstable oscillatory condition with a time constant of about 10 min. When I published a paper[5] on the use of a beta-gauge to control basis weight, I included some studies on manual control that showed how papermachine operators managed to put the basis weight system into slow oscillation with a time constant of about 2 h. Crossman was interested in these results and, after a discussion, I decided to construct a laboratory task based on Crossman's original, but including a distance velocity lag. All the time constants were chosen to be as close as possible to the papermachine for which I had a number of results. Before describing the laboratory task, it is worthwhile to analyse the way in which papermachine A was controlled manually. This is shown in Fig. 3 and can be explained as follows.

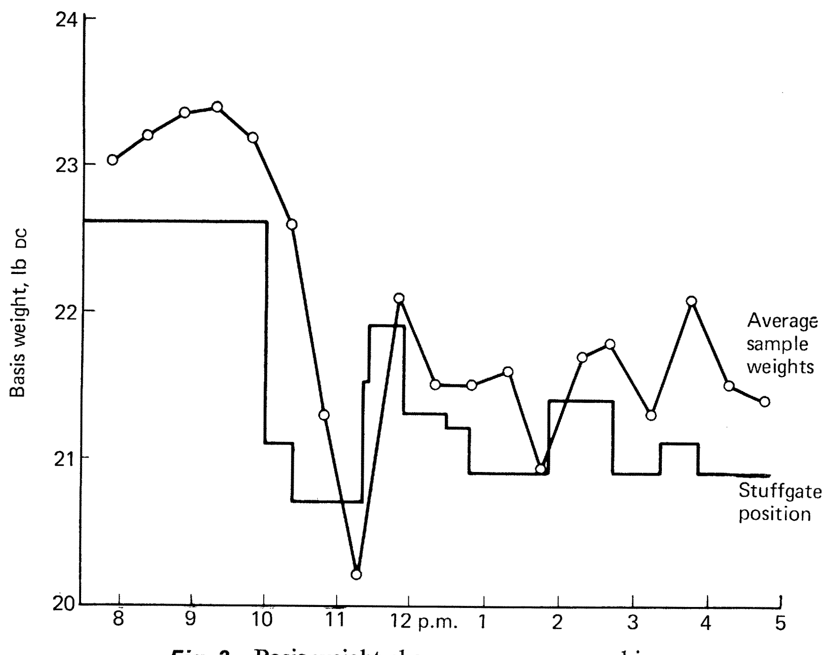

Fig. 3—Basis weight change on a papermachine (from 22·9 lb to 21·3 lb double crown)

The programme called for a change in basis weight at 22.20 h and it was to be decreased from a target of 22·9–21·3 lb DC. From 19.00 h until 22.00 h, average sample weights were being produced that apparently satisfied the machineman, although it was consistently 0·3 lb heavy. The recorder on the stuffgate showed that it was not touched during this period. At 22.00 h, there was a shift change and immediately (that is, 22.05 h) the stuffgate was closed by a considerable amount.

A reel was thrown out at 22.20 h and gave a basis weight of 22·6 lb, so the stuffgate was closed by a further amount. The next reel at 22.50 h was spot on at 21·3 lb DC and so no correction was made. The next reel, however, was light at 20·2 lb and so the stuffgate was opened in two steps. The next result was too high at 22·1 lb and the stuffgate then closed. The system was now hunting viciously and, if the graph is followed, it will be seen that each adjustment is made based only on the immediate test result. The stuffgate under the machineman's control oscillates nicely from 22.00 h until 4.00 h, giving almost a classical trace.

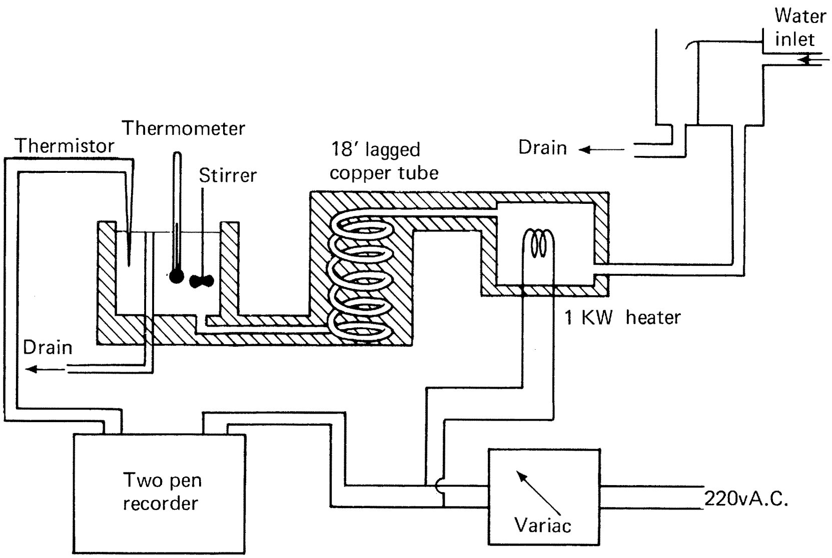

Fig. 4—Laboratory control task

Perhaps the most interesting feature is that the final position of the stuffgate is exactly where the machineman first put it. If he had left it alone, the oscillation would never have taken place and the basis weight would have been on target within $\frac{1}{2}$ h.

Undoubtedly, systems such as these are difficult to control and controllability has been defined as the product of process dead time and disturbance bandwidth. If the system has a sampled data control system, then empirically the sample period must be at least half the period of the highest frequency to which the sytem must respond. Thus, if we rely on data every half hour, then frequencies higher than 1 h cannot be affected by any control system whatever. The effect of dead time is more than twice as large as that of sampling period, but, if a process is such that the dead time cannot be altered, then the only way in which an improvement can be achieved is to raise the measuring rate—that is, by installing a continuous monitor such as a beta-gauge.

Fig. 4 shows schematically the artificial task in which a controlled supply of tap water was fed to a kettle connected to a variable transformer (0–220 V) fed from the ac main supply. The heated water then flowed down 18 ft of lagged copper tubing to provide a distance velocity lag into an agitated vessel filled with overflow and a mercury-in-glass thermometer. A thermistor was connected to the thermometer and a two-channel recorder used to record both variable transformer setting and the reading of the temperature.

Fig. 5 shows the response of this process to a step change in the setting of the variable transformer from 120 V to 175 V. The response of course shows

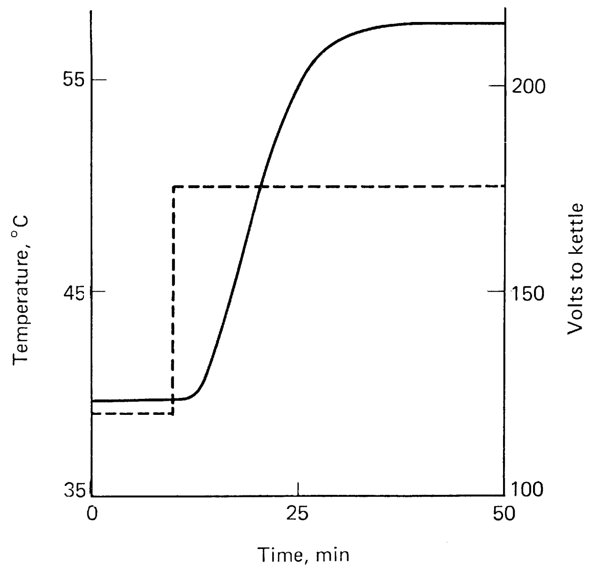

Fig. 5—Process reaction curve

the typical response of a certain delay and a slow increase to the final temperature. The d.v. lag is about $2\frac{1}{2}$ min and the exponential lag with a time constant of about 10 min.

In the first set of trials, subjects were chosen from the laboratory and asked to change the temperature of the water from a value such as 40°C to 55°C. In the first set of trials, the operator was able to see only the thermometer and to adjust only the variable transformer, the recorder being hidden at this time. Fig. 6 shows the result of the first three trials of a particular subject and three facts emerge—

1. He very easily forces the system into oscillation.
2. He learns about the process as exemplified by the fact that he improves each time.
3. There is a marked similarity between these results and Fig. 3.

To examine the charts in detail, it can be seen that the 'process' is never brought under control in the first trial and the subject indulged in wild adjustments of the control.

In the second trial, the subject achieves a better performance and is starting to appreciate the system and eventually gets the process under control after 70 min.

On the third trial, there is less overshoot, nevertheless the process is never really in control.

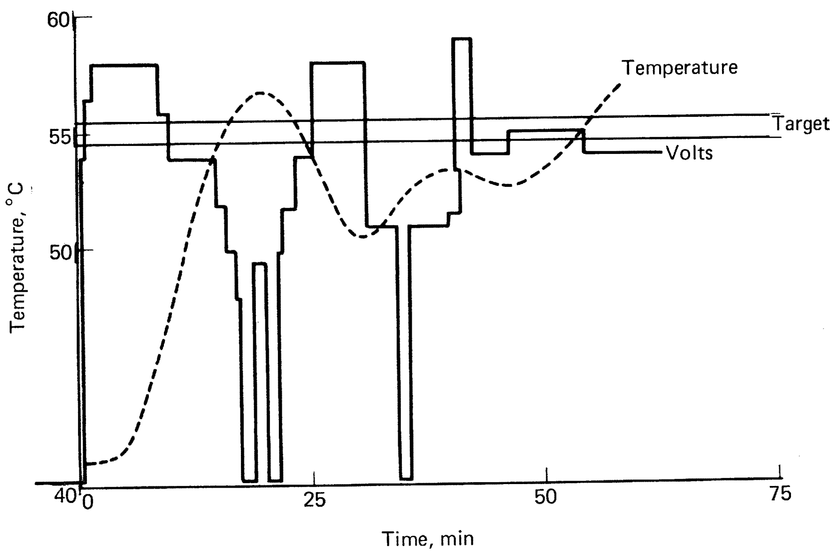

Fig. 6(a)

This set of results has been selected as being representative of a typical *good* subject. Systems engineers tended to do slightly better, many using the first trial to perturb the system and therefore gain some idea of the system.

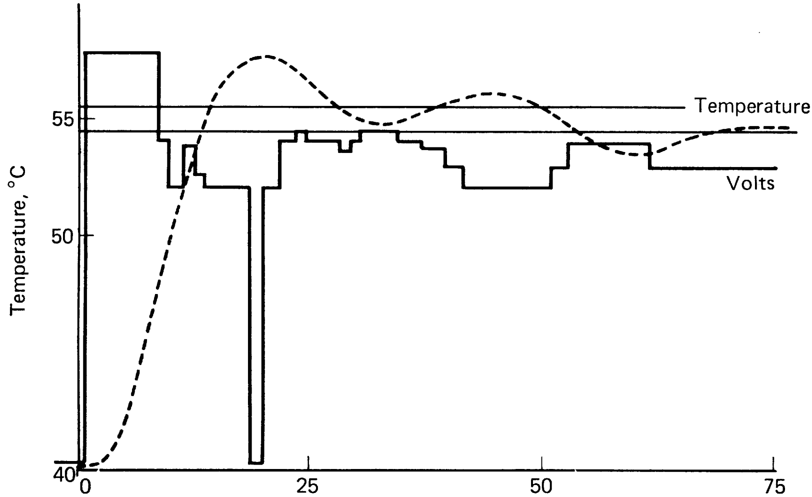

Fig. 6(b)

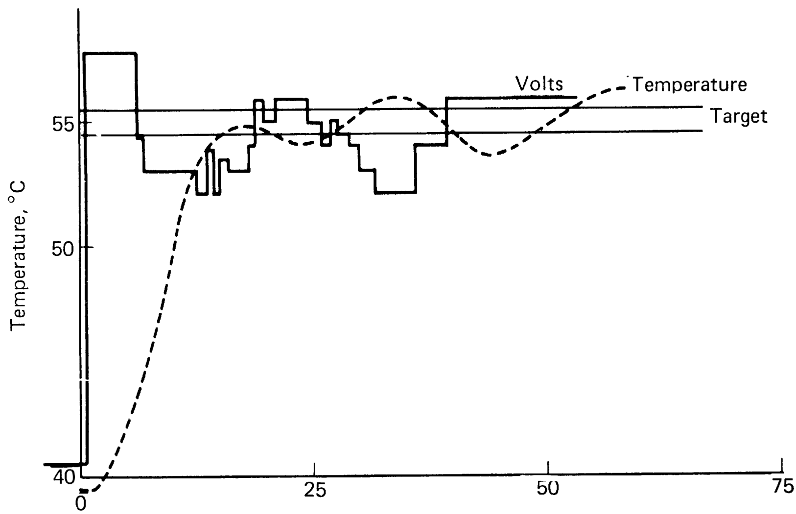

Fig. 6(c)

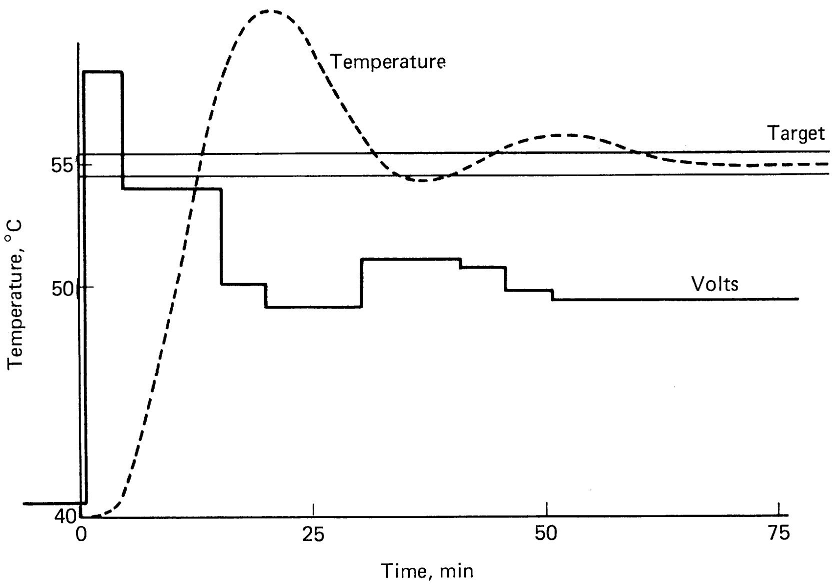
Temperature
Target
55
50
40
Volts
Temperature, °C
0
25
50
75
Time, min

Fig. 7(a)

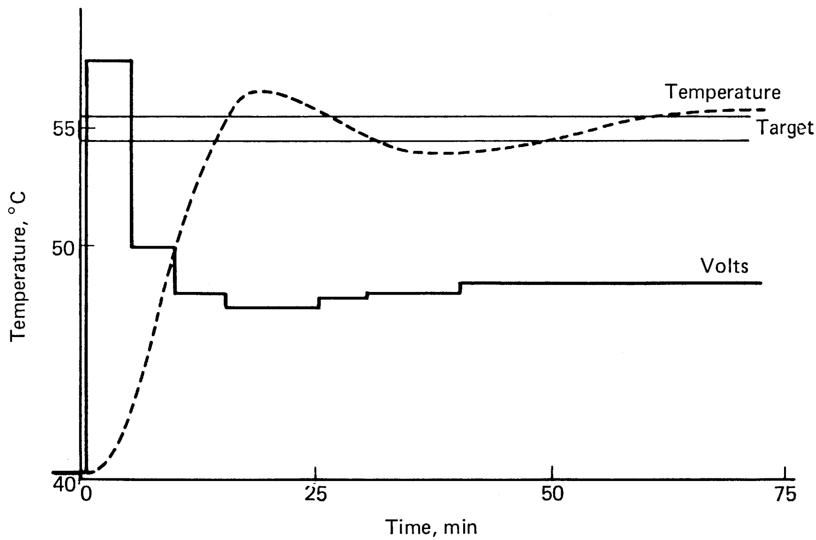
Temperature
Target
55
50
40
Volts
Temperature, °C
0
25
50
75
Time, min

Fig. 7 (b)

In studying the way in which most subjects set off to control the process, it was noted that many made far too many adjustments and of too large an amplitude and so a second set of experiments was arranged in which adjustments were permitted only at 5 min intervals. The results of an average subject are shown in Fig. 7. (These were a fresh batch of subjects who had not participated in the first set of experiments.)

In the first trial, there was the typical overshoot, but most subjects even on a first trial brought the 'process' under control. By the third trial, most subjects were curbing the overshoot and, although not meeting the specification, were considerably better than the subjects who were allowed an indefinite number of adjustments.

In the third set of experiments, the mercury-in-glass thermometer was removed and the subject allowed to use the recorder. The results are shown in Fig. 8.

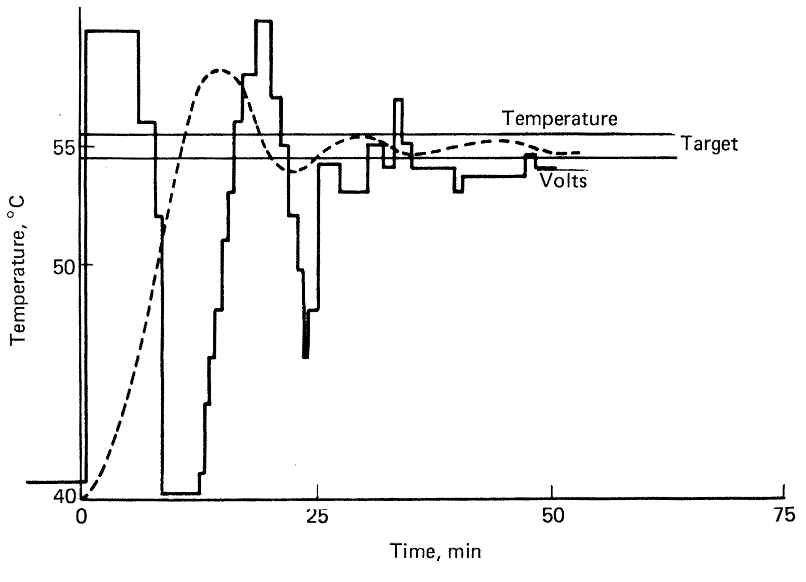

Fig. 8

The first trial using a recorder is a remarkable improvement over any of the other trials. There are no *typical* second trials, but a good proportion of subjects moved the setting of the variable transformer to the correct setting for the desired new temperature and waited. This may have been because most tests were scheduled to last the hour and, since control was often achieved in half an hour, subjects had a further 30 min to observe that the setting they had determined was the correct one.

This set of trials then demonstrates the values of trend recording and the beneficial effect to be obtained by not making too rapid changes. A final run was arranged in which the optimum control setting was worked out, then applied (in a feedforward rather than a feedback manner) and Fig. 9 is the result.

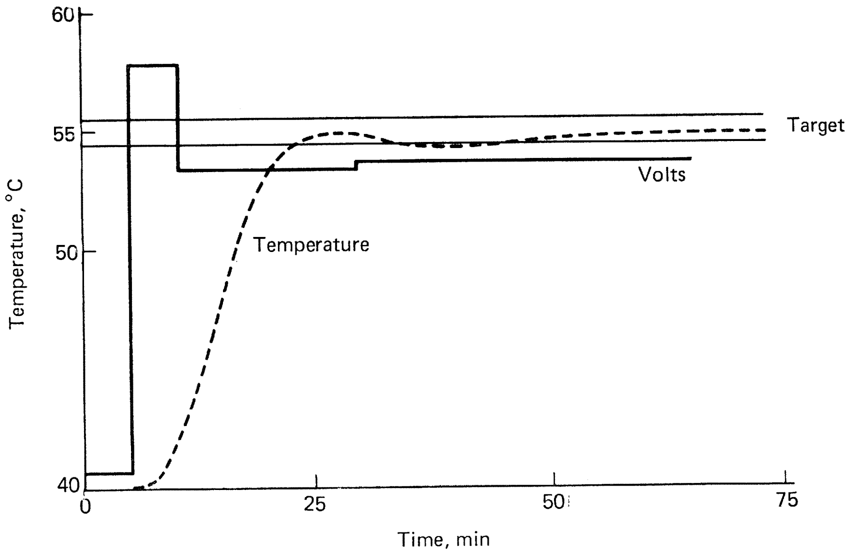

Fig. 9

The most useful aspect of all this work was to be able to discuss it with machine operators and to use the facts as a basis for training. An understanding of the system is the first requirement in controlling it and lectures based on these experiments helped to minimise occurrences such as those epitomised in Fig. 3.

With the introduction of computer control, quite different forms of presentation and control are used and it was decided to model the same process digitally, since more information was available on the laboratory task than on the papermachine to be fitted with digital control.

If $X(t)$ is the value of the temperature at time t and $X(t-1)$ is the value at time $(t-1)$ etc. and $U(t)$ is an input at time t, etc., then an equation of the form—

$$X(t) = 0{\cdot}01\ U(t-4) + 1{\cdot}95\ X(t-1) - 1{\cdot}06\ X(t-2) + 0{\cdot}1\ X(t-3)$$

best describes the process. For example, if we consider a change of U from 0 to 1 at time $t = 0$, we have the values in Table 1.

```
THE DIAL SETTING IS 0
WHAT NEW DIAL SETTING DO YOU REQUIRE? 0
THE TEMPERATURE IS 54.0882
THE DIAL SETTING IS 0
WHAT NEW DIAL SETTING DO YOU REQUIRE? 0
THE TEMPERATURE IS 55.5618
THE DIAL SETTING IS 0
WHAT NEW DIAL SETTING DO YOU REQUIRE? 0
THE TEMPERATURE IS 56.4003
THE DIAL SETTING IS 0
WHAT NEW DIAL SETTING DO YOU REQUIRE? 0
THE TEMPERATURE IS 56.6938
THE DIAL SETTING IS 0
WHAT NEW DIAL SETTING DO YOU REQUIRE? 35
THE TEMPERATURE IS 56.5249
THE DIAL SETTING IS 35
WHAT NEW DIAL SETTING DO YOU REQUIRE? 40
THE TEMPERATURE IS 55.968
THE DIAL SETTING IS 40
WHAT NEW DIAL SETTING DO YOU REQUIRE? 40


INPUT DATA NOT IN CORRECT FORMAT. RETYPE IT.
? 40
THE TEMPERATURE IS 55.0907
THE DIAL SETTING IS 40
WHAT NEW DIAL SETTING DO YOU REQUIRE? 40
THE TEMPERATURE IS 53.9532
THE DIAL SETTING IS 40
WHAT NEW DIAL SETTING DO YOU REQUIRE? 40
THE TEMPERATURE IS 52.8895
THE DIAL SETTING IS 40
WHAT NEW DIAL SETTING DO YOU REQUIRE? 40
THE TEMPERATURE IS 51.9731
THE DIAL SETTING IS 40
WHAT NEW DIAL SETTING DO YOU REQUIRE? 40
THE TEMPERATURE IS 51.2001
THE DIAL SETTING IS 40
WHAT NEW DIAL SETTING DO YOU REQUIRE? 37·5
THE TEMPERATURE IS 50.5576
THE DIAL SETTING IS 37·5
WHAT NEW DIAL SETTING DO YOU REQUIRE? 37·5
THE TEMPERATURE IS 50.0325
THE DIAL SETTING IS 37·5
WHAT NEW DIAL SETTING DO YOU REQUIRE? 37·5
THE TEMPERATURE IS 49.6123
THE DIAL SETTING IS 37·5
WHAT NEW DIAL SETTING DO YOU REQUIRE? 37·5
THE TEMPERATURE IS 49.2854
THE DIAL SETTING IS 37·5
WHAT NEW DIAL SETTING DO YOU REQUIRE? 37·5
THE TEMPERATURE IS 49.0207
THE DIAL SETTING IS 37·5
```

Fig. 10

TABLE 1

t	U(t)	0·01U(t–4)	1·95X(t–1)	1·06X(t–2)	0·1X(t–3)	X(t)
–1	0	0	0	0	0	0
0	1	0	0	0	0	0
1	1	0	0	0	0	0
2	1	0	0	0	0	0
3	1	0	0	0	0	0
4	1	0·01	0	0	0	0·01
5	1	0·01	0·0195	0	0	0·0295
6	1	0·01	0·057	0·0106	0	0·057
7	1	0·01	0·111	0·03127	0·001	0·091
8	1	0·01	0·177	0·0603	0·003	0·129

This response has been normalised to correspond to the response to step change in the laboratory task and gives almost the same shape when plotted as that shown in Fig. 5.

A computer program was then written to operate in real time, which used this equation as the process model. In this case, subjects knew that they could select any value between 0 and 100 as the setting of the valve. At half minute intervals, the computer would type out the latest temperature and say what the valve setting was and ask for a new setting. A typical print-out is shown in Fig. 10.

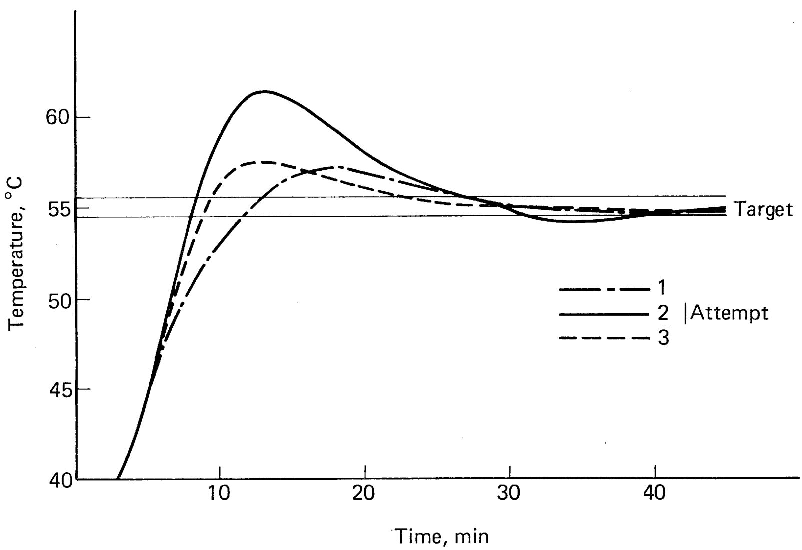

Fig. 11

Exactly the same procedure was then adopted as previously and the subjects asked to control the 'process'. In this case, however, they sat at a teletyper and had to input a number between 0 and 100. The results of the first three trials of a good average subject are shown in Fig. 11.

Typical print-outs of a whole run are too long to include in this paper, but they illustrate the type of error that can be made in inputting information via a typewriter and the wisdom of writing protective programmes to allow only numbers between 0 and 100 to be used in the calculations was well demonstrated.

With Fig. 11, the same sort of pattern emerges as was shown in the analog case. Because the 'valve' can be adjusted only each half minute, there was some restraint on the number of changes made, but it was noticed that subjects were in general more prone to make rapid changes in 'valve' setting than when they physically had to grasp a wheel and turn it.

This model could be extended indefinitely. It would have been instructive, for example, to have introduced some noise into the readings, also perhaps to have fed in a disturbance and this is work that might be done in the future.

Conclusions

CROSSMAN listed six factors that make the control of a process difficult—

1. When several display and control variables depend on one another.
2. When the process has a long 'time constant'—that is, takes a relatively long time (minutes, hours or even days) to settle down after a disturbance or alteration of control settings.
3. When important variables have to be estimated by the operator rather than measured by an instrument.
4. When the readings of instruments at widely separated points have to be collated and the operator has to remember one while going to another ('short-term memory').
5. When the operator gets imperfect knowledge of the results of his performance or when the knowledge arrives late (this is a very common condition).
6. When the basic process is either difficult to visualise—for example, chemical reactions—or contradicts 'commonsense' assumptions or is too complicated to be held in mind at one time.

Examples of nearly all these facets can be found in papermaking and this paper has sought to explore nearly all of these as they relate to basis weight control, particularly the effect of time constants.

One fact has been demonstrated that, if operatives are taught about the system and shown what plant responses are like, they can improve their performance. The value of trend logging has been demonstrated, also the value of allowing only minor changes in process variables to take place.

A great many of the proposals made in the earlier ergonomic study have now been implemented and basis weight control on machines without computers or beta-gauges is now much improved.

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Discussion

Mr H. B. Carter I would like to ask Mr Attwood if there is any implication that control is better by having an operator do it manually than by putting a non-manual (that is, automatic) controller on.

Mr D. Attwood Obviously, this depends on what it is you are seeking to control. In any case, if it is impossible to measure the property to be controlled, then I think we must continue to use manual control. If these properties are measured off-line, they must be presented to the operator graphically and he will then make more sense of them. I think it is perfectly true that an operator is capable of working in a feedforward manner and is therefore more likely to be stable than an elementary control. It is a fact that grade changes involving basis weight change is much better left to the operator than left to a simple type of controller.

Mr W. D. Hoath Could I ask whether the same operator was involved in this experiment from beginning to end?

Mr Attwood No. When one operator was involved, the graphs are listed as being first trial, second trial, third trial. Separate operators took part in the different trials, each with different operators.

Mr Hoath The thing that was interesting was that there was overshooting. This did not seem to change with the systems of the recording. Is this normal in practice on the machine?

Mr Attwood Do not forget that this is the very first time that they controlled that process. When a machineman is controlling basis weight, he has done it hundreds—if not thousands—of times before. This is the very first time that these people have sought to control this process.

Mr Hoath When you have an operator on the machine, does he normally tend to overshoot or does he err on the safe side?

Mr Attwood If you go back to my first illustration, you will see that there was considerable overshoot there.

Mr Hoath A period of 3–4 h without any adjustment at all is involved. In fact, this suggests that the man on the night shift has far more itchy fingers than the other fellow.

The Chairman You will see that Mr Attwood remarks in his paper that a skilled instrument man made a few trials at the beginning to see the effect of perturbing the system.

Mr R. Forrest Have you tried incorporating these concepts in any kind of operator training programme (including off the machine) to give them an idea of things?

Mr Attwood I think that I have indicated in the paper that this was the most valuable part of the exercise, to bring people across to the laboratory for showing them this model in operation. We undertook a considerable amount of training based on these results and found that explanations about the real nature of time lags, etc. helped the papermakers considerably.

A Speaker I disagree, for you suggest that the machineman on night shift did nothing better. This diagram indicates to me that the machineman on the evening shift had very definitely learned how unreliable his basis weight readings were. By experience, he would only make conditions worse if he tried to change them, so he left well alone.

The Chairman This is a very good interpretation, but there are others.

Dr I. B. Sanborn We have had an experience that might be of interest here. About 18 months ago, our company started up a continuous digester. There was no experience in the company in the operation of such digesters at the operator level and very little on the supervisory level as well. A year later, the digester was equipped with a computer control system. Normally, this digester changes from the cooking of hardwood to softwood approximately twice a week and, at each switch, there was a serious upset because operating conditions were violently different. Since we have put the digester on computer control, we have achieved much finer control of K number. So far, our experience has been that the improvement in the control achieved by the computer has been due to the elimination of operator overcompensation—perhaps because of his inexperience. On the other hand, we generally find that experienced papermachine crews undercompensated on basis weight and moisture control.

Dr N. K. Bridge One comment and one question. I was associated with a computer installation and noticed that the operator changed his method of manual control after experiencing the first attempt at computer control. Formerly, he made the minimum number of changes to the stuffgate to alter the basis weight, significantly fewer I think than is shown in your paper. After he had seen the computer operate the stuffgate on feedback control, however, it was noticeable that he made more and larger changes on the few occasions during which the machine was under his control. May I ask whether you have noticed similar changes in the machineman's operating procedure in your computer installation? In other words, does he behave in the way you might have predicted from your paper or do his actions go against this?

Mr Attwood I am not quite sure I understand that. Have we seen anything that goes against anything said in the paper?

Dr Bridge In your talk, you referred to the fact that, in an experiment when a person was given a computer terminal to control basis weight, he made wilder excursions in the stuffgate position. Have you found this to be the case on your computer installation on the occasions when basis weight was under manual control?

Mr Attwood We have deliberately programmed the computer installation so that he cannot do this. Not only is there a limitation that he cannot make any very serious maladjustments, but also the size of changes he can put in have been severely limited. In practice, of course, the computer is usually on computer control anyway, so no problems arise, but, if he had to switch back to stand-by, he would only be able to put in these very small changes.

Mr M. A. Keyes I am a little confused about one comment on the area of applicability of computer control or otherwise. I seem to have drawn the conclusion that you feel that control should be applied only to regulatory control rather than servo or transitional problems such as a grade change, shutdown or start-up.

Mr Attwood What I said was that grade changes are better done by an operator than by elementary feedback servo-mechanisms. I would rather see an operator change the basis weight from 60 g/m^2 to 50 g/m^2 than do it by altering the set point of a standard basis weight controller. That is not the case when one has a sophisticated weight control, but I think that basis weight control using what we call the 'kick and drift' technique is inferior to a human operator for grade changing.