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Prepared discussion contribution

Incomplete Control Systems

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ENTIRE papermachine control implies at least the regulation of all the product quality variables such as basis weight, moisture content, strength, opacity and porosity. Implementation of such a control scheme is generally done in a piecemeal fashion. The usual starting point is automatic control of basis weight by manipulation of stock flow. The remaining variables are on manual control.

This partial automatic control system in general causes a change in the response behaviour of the remaining product variables to adjustments in the manipulated input variables, which are not being used for automatic control.

This sudden change in the effective process response can be quite disconcerting to the operator and has contributed to the failure of automatic control systems in a number of cases. A proper understanding of the phenomenon, imparted through operator training, can usually overcome the problem.

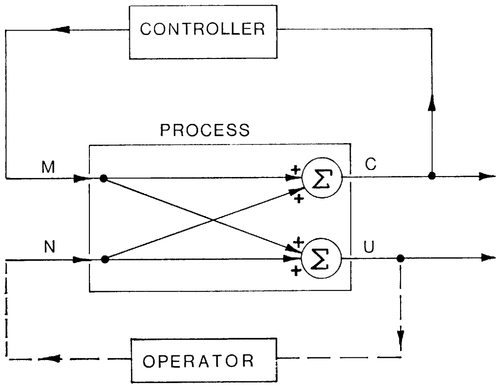

Fig. 1

Under the chairmanship of P. E. Wrist

Fig. 1 shows a general diagram of the situation with a set of quality variables C being automatically regulated by manipulation of a set of variables M. The remaining quality variables U are adjusted by manipulating the set of variables N.

As an example of the phenomenon, consider a two input/two output system for automatic control of basis weight (C) and manual control of moisture content (U), using stock flow (M) and steam pressure (N) as the manipulated variables.

If the moisture content (U) is running high, the operator will make an increase in the steam pressure (N), which, before automatic basis weight control, would have put the moisture content on target. This change will result in a drop in basis weight (C) arising from the interaction (*nc*). The drop in basis weight will cause the automatic controller to increase the stock flow (M). This stock flow increase will prevent the moisture content from dropping to the target because of the interaction (*mu*). This phenomenon in effect reduces the steady state response or 'gain' between steam pressure and moisture content. As mentioned earlier, unless the operator is warned of this occurrence, he is likely to be less than pleased with the automatic basis weight control system.

The extent of this problem can be analysed as follows. The stead state gain between N and U is defined as $[K(nu)]$ in matrix notation. The other three gains are similarly defined. The open loop steady state response is then simply—

$$[C] = [K(mc)][M]+[K(nc)][N] \quad . \quad . \quad . \quad (1)$$

$$[U] = [K(mu)][M]+[K(nu)][N] \quad . \quad . \quad . \quad (2)$$

where $[C]$ and $[U]$ are deviations from target and $[N]$ and $[M]$ are deviations from steady state.

With effective automatic control, variations in the controlled variable are minimised so that effectively $[C] \approx 0$.

Equation (*1*) then becomes—

$$[M] = -[K(mc)]^{-1}[K(nc)][N]$$

Substitution in equation (*2*) gives—

$$[U] = \{[K(nu)]-[K(mu)][K(mc)]^{-1}[K(nc)]\}[N] \quad . \quad . \quad (3)$$

It can be seen that the second term inside the curly brackets is the modification of the original open loop gain $[K(nu)]$. It is also clear that this modified term is zero if either of the interactions is zero. The problem then ceases to exist. Inspection of equation (*3*) shows that the problem is minimised whenever—

$$[K(nu)]^{-1}[K(mu)][K(mc)]^{-1}[K(nc)] \ll 1$$

For a two input/two output system, this can be simplified to—

$$K(mu).K(nc) \ll K(nu).K(mc)$$

which says that the product of the 'straight-through' gains should be much greater than the product of the interactions to eliminate the problem.

For pulp and papermaking processes, these interactions are usually quite strong so that the problem is normally present.

Discussion

Mr A. J. Ward Could you please indicate whether you tried this automatic grade change on the actual mill. If so, did you find that the constant values of the parameter in the equations remained valid over the whole range tried?

Mr S. Hem No. Unfortunately, I have been unable to implement these control strategies in full, but the grade change at constant production rate and efflux ratio have been implemented practically by synchronously changing the thin stock flow and wire speed. There is no doubt that, by manipulating the thick stock flow as well, an even better response could be achieved.

Mr H. B. Carter Can you give some figures on the improvement made in basis weight variation with the implementation of this control?

Mr Hem This is an experimental project, not long enough in operation to have reliable figures, but the sort of *variance* that we hope for on basis weight is 0·3 per cent.

Mr W. T. Whight A certain amount of investigation on the results has been done by Mr Burrows of our research and development department. We have at the moment another controller of our own that gives the basis weight in the machine-direction to within ±1·25 per cent. The information on Mr Hem's controller (in the experimental stage) is that it is as good as this and there is evidence to believe that it is suitable for our purposes. If more tuning effort were put into it, it would perform better.

Mr R. E. Johnston Would you like to guess at the major contributing effect to the difference between your controller and any other controllers that might be used? Is it the fact that a more complicated state space model than a linear estimator was used or is it that the amount of stock valve movement was included in the cost function?

Mr Hem There is a considerable difference between this controller and the one used by Åström, for instance. With this controller, we have the possibility of weighting the inputs in order to tune the controller. We can then prevent wear on valves, especially when, in this case, we were taking corrective action on the thick stock valve every 10 s. I think that the controller used here contains a larger memory than the Åström controller; in addition, it is a multi-variable approach applicable in a general sense.

Mr O. Alsholm I would add a few words that may be of interest. What I have encountered during this session is very much the same as Mr Johnston said earlier. It seems to me that everybody is trying to do the same thing, but using more and more complicated mathematics. I do not intend to discuss the differences between the Åström controller and other controllers presented here today or explain how much more efficient you could work with our DDC package than in CONRAD, but I would like to ask the authors to translate their nice mathematics into somewhat simpler terms. I enjoy listening to these excellent mathematicians and I really believe we need them for the future, but the majority of the problems that we implement today could be presented in a much simpler manner. If, instead of using the term Åström controller, for instance, one explains that there is a digital controller corresponding to PI plus dead time correction, people would not be so confused that they do not dare implement the strategy in practice. On the other hand, we should give credit to the mathematicians, because, if they do not continue with their advanced work, we will be left stranded.

Mr Hem May I say that, although the mathematics may sound awfully complicated, the actual process, once it has been done, can be performed on a fast computer in about 30 s and the implementation takes no longer than to implement the Åström controller.

Mr J. A. S. Newman Is it possible to use such mathematical models not only to predict how they can be controlled by the application of, say, DDC, but also how they can be made more inherently stable or controllable by modifications to their structural parameters such as pipework and tank sizes.

Mr Hem Yes, the structure of the plant is easily recognised in the formulation of the model. The parameters are very quickly changed if you want to investigate their effect on the plant behaviour.

Mr T. J. Boyle In 1959, dynamic programming was in vogue. I was in graduate school and applied this method on a chemical reactor problem similar to a grade change. I was successful in finding an optimum change on a simulated basis, but was very disappointed to find that some very simple strategies did quite as well as the optimum strategy. In this paper and that by Johnston & Kirk, we seem to have a similar situation with one being an optimum change, the other selecting the best version of a heuristically developed strategy. Has either author applied his technique to the other's model and thus developed a comparison?

Mr Hem Well, the grade change strategy at constant production rate and influx ratio was obtained purely and simply by solving the equations. There are no special optimisation procedures involved at all. This is mainly because the wire speed can be changed only at a certain rate. When one computes all the other manipulated variables, we find their trajectories never violate their constraints. It is therefore very easily obtained.