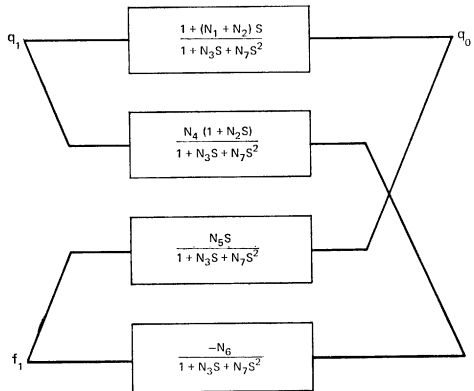# Non-Interacting Control of Pressurised Flow Boxes

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THE dynamics of a pressurised flow box can be reasonably well described by simple transfer functions, as Dr Smith has shown. Fig. 1 represents the system as multi-variable (two input/two output).

Using Smith's terminology, the values of the parameters N are given by—

$$N_1 = PAM_w/kRT$$
$$N_2 = VM_w/kRT$$
$$N_3 = 2HA/Q_o + N_1 + N_2$$
$$N_4 = 2H/L$$
$$N_5 = F_1A/kQ_o$$
$$N_6 = F_1/kL$$
$$N_7 = 2VAM_wH/kRTQ_o$$

Under the chairmanship of P. E. Wrist

(These apply to a flow box without a hornbostel hole or an internal over-flow.)

It is clear that simple feedback controls (for example, from l to f_1 and from q_0 to q_1) will be interacting. Prof. Rosenbrock* at Manchester has developed a technique for tackling the problem of interaction and an application of the technique to this particular system throws some light on to the problem of designing a non-interacting controller. Using this method, it is not necessary to diagonalise the system completely and simpler compensating networks consequently arise.

The transfer matrix in this case is given by—

$$G(s) = \frac{1}{1+N_3 s+N_7{}^2}\left(\begin{array}{c|c} 1+(N_1+N_2)s & N_5 s \\ \hline N_4(1+N_2 s) & -N_6 \end{array}\right)$$

and the inverse of this (using Rosenbrock's symbols) is—

$$\widehat{G}(s) = \left(\begin{array}{c|c} 1 & (N_5/N_6)s \\ \hline (N_4/N_6)(1+N_2 s) & -(1/N_6)(1+(N_1+N_2)s) \end{array}\right)$$

Working on the inverse, Rosenbrock shows that, if the moduli of the off-diagonal elements are made less than the moduli of the diagonal elements, then the stability of the system can be assured, provided the diagonal elements indicate stability. With luck, the transformations can be carried out by pre-multiplication by constant matrices.

Premultiplication by G(O) will eliminate zero-frequency interaction, thus—

$$\widehat{Q}(s) = \left(\begin{array}{c|c} 1 & 0 \\ \hline N_4 & -N_6 \end{array}\right)\left(\begin{array}{c|c} 1 & (N_5/N_6)s \\ \hline (N_4/N_6)(1+N_2 s) & -(1/N_6)(1+(N+N_2)s) \end{array}\right)$$

$$\widehat{Q}(s) = \left(\begin{array}{c|c} 1 & (N_5/N_6)s \\ \hline -N_2 N_4 s & 1+N_3 s \end{array}\right)$$

(N_4 and N_6 are easily found from the steady state gains in simple experiments.)

Generally, $N_2 N_4 < N_3$, hence loop (*ii*) satisfies the non-interaction criteria. To eliminate high frequency interaction in loop (*i*), subtract $(N_5/N_3 N_6)$ times the bottom from row the top—that is, premultiply by—

$$\left(\begin{array}{c|c} 1 & -(N_5/N_3 N_6) \\ \hline 0 & 1 \end{array}\right)$$

Thus $\hat{Q}(s)$ becomes—

$$\begin{pmatrix} 1+(N_7/N_3)s & -(N_5/N_3N_6) \\ -N_2N_4s & 1+N_3s \end{pmatrix}$$

There is no interaction provided that $(N_5/N_3N_6) < 1$ and the two 'external' controllers can be tuned independently.

(For complete elimination of high frequency interaction, (N_5/N_3N_6) should be known to within $\pm 100\ N_2N_4/N_3$ per cent of the true value. This should be possible through on-machine studies, together with theoretical estimates, although one value may not be adequate over the whole working range.)

Thus, the complete 'correcting matrix' is given by—

$$K = \left[\begin{pmatrix} 1 & -(N_5/N_3N_6) \\ 0 & 1 \end{pmatrix} \begin{pmatrix} 1 & 0 \\ N_4 & -N_6 \end{pmatrix} \right]$$

$$K = \frac{1}{N_6} \begin{pmatrix} N_6 & (N_5/N_3) \\ N_4 & (N_5N_4/N_3N_6)-1 \end{pmatrix}$$

The main benefits can be seen from an example using proportional control only—
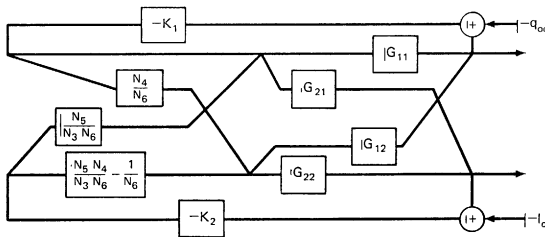
For a flow box similar to the one discussed by Smith with parameters $N_1 = 1$, $N_2 = 0\cdot04$, $N_3 = 1\cdot7$, $N_4 = 4$, $N_5 = 0\cdot1$, $N_6 = 0\cdot6$, $N_7 = 0\cdot04$, the closed loop response matrix (for $k_1 = 10$, $k_2 = 10$) is approximately—

$$R = \begin{pmatrix} 0\cdot91/(1+0\cdot002s) & 0\cdot008/(1+0\cdot156s) \\ 0\cdot013/(1+0\cdot156s) & 0\cdot91/(1+0\cdot156s) \end{pmatrix}$$

This is far better than the closed loop response matrix that would arise from an 'uncorrected' system. For example, direct proportional control between

q_0-q_1 and $1-f_1$ (with $k_1 = 10$, $k_2 = -10$) leads to a response matrix approximating—

$$R = \begin{pmatrix} \dfrac{0\cdot91(1+0\cdot15s)}{(1+0\cdot05s)(1+0\cdot11s)} & \dfrac{0\cdot013s}{(1+0\cdot05s)(1+0\cdot11s)} \\[3mm] \dfrac{0\cdot52}{(1+0\cdot11s)} & \dfrac{0\cdot86}{(1+0\cdot05s)(1+0\cdot11s)} \end{pmatrix}$$

Sensitivity of the control performance to errors in the system parameters can be determined analytically as can the frequency responses to disturbances.

Using this approach, it is also easy to determine the likelihood of instability in the two alternative 'uncorrected' control systems—that is, either q_0-q_1 and $1-f_1$, or q_0-f_1 and $1-q_1$.

Discussion

Dr L. A. Kirk   As we at Manchester University have a similar kind of papermachine, I would be very interested to know the total cost of computerising your papermachine. In view of the papers we have heard on the exact extent to which computer control has been applied in industry, do you consider it worthwhile for our machine to be computer-controlled at this stage?

Mr S. Bauduin   The total cost of the project, which extends over a three year period (until the end of 1970) is approximately £140 000, including—

Instrumentation and wiring	£30 000
Computer	£10 000
Ancillaries	£15 000
Personnel salaries, etc.	£85 000

Our machine is quite different from an industrial one, although time constants are nearly the same. We think that the approach to control problems will have to be the same. Besides, such a system is very convenient for training purposes.

Dr J. A. Robinson   In the text, it is stated that the response of the model appears to be better than the theoretical response, but the theoretical response in Fig. 7 appears to be better.

Mr Bauduin   Our paper states about Fig. 7 that 'an explanation has not yet been found for the fact that the response of the full model appears at first sight to be better than the theoretical response'. Thus, the 'theoretical' curve shows a permanent deviation, whereas the 'simulation' (full model) curve does come back to the original signal level.

We have now found the answer: it lies in an ill-adapted coefficient in the model used for the 'theoretical' curve (polynomial division program).

In spite of that, we have still shown the two graphs (Fig. 7 and 8) to illustrate the difference between the one time constant model and the three time constant model.

Dr Robinson   The only point is that it appears to be in the reverse order on the graph.

Dr D. Wahren   You said that the effects of recirculation of whitewater could be ignored. Was this because you had a very high retention on the machine?

Mr Bauduin   Yes, I think so. Most of our tests at that moment were done with kraft pulp. In fact, the model showed, at least for high frequency fluctuations, that it is still true for low retention stocks for regulation purposes.

A Speaker   In talking about head box control systems, we should remember that machines in operation today range 30–35 in to high speed newsprint machines with widths of over 400 in. A variation between 1 in and 35 in is quite different from 400 in. I think it would be helpful if any speaker who was talking of a specific machine would give the range in which he was working.

A comment on whether to install a computer on the University of Manchester papermachine. We should remember that the Fourdrinier machine is now in the state of obsolescence and, with the new formers available, before anyone can put a computer on such a machine, he should consider carefully whether it is adaptable to the high speed machines that are likely to be used in the near future.

The Chairman   We are starting up a new Fourdrinier machine in two weeks' time; I hope such machines are not as obsolete as this speaker suggests.

Mr N. C. Underwood   Will the authors and committee consider a uniform set of units for the measurement of gains, frequencies and response functions so that the results presented in the transactions may be more directly compared?

The Chairman   These are very good points that the authors should attempt to take care of in editing.

Mr A. J. Ward   Would Mr Gunnarson like to indicate the difference in cost between his rapid response electrical system and the more conventional pneumatic approach?

Mr K. G. A. Gunnarson   The total cost for an ASEA system depends on delivery time. The estimated price for a complete system, including complete dc drive (500 kW) for the fan pump, Roots blower with complete dc drive, dp cells, pneumatic reference device for the total head is about 20 000 dollars.

Discussion

Mr L. D. Edenborough   We have now seen two examples in which Mr Jones uses the CONRAD system. It seems to me that perhaps the building block approach of which he has spoken is to some extent comparable with the small mill that cannot justify a large computer system, but wants to do something a little cleverer than is possible with conventional analog control systems, a comparison of these two approaches may be worthwhile. Could Mr Jones please attempt to contrast them from the technical and economic viewpoints?

Mr R. E. Jones   Comparing and contrasting is rather a tall order, because it would take quite a long time to cover all the implications of the two techniques. What I will say is that the control strategies that we have used with a CONRAD package certainly could be implemented by analog modules. I think it would be up to the individual customer or systems engineer to decide on the relative costs of going to these two different methods of implementing control. I would point out that *behind* the CONRAD package is a central processor that can do much background work as well.

Dr N. K. Bridge   We have heard a lot about head box control this morning and speakers have quoted in passing figures for the control that they can achieve. I wonder whether it might not be of use to people when they get back to their mills if they could have a consensus of opinion from the experts on the platform on how well a flow box might perform with a good controller. What sort of variations might be expected in total head on grade, also how fast should it be possible to change the head?

Dr D. B. Brewster   I would like to comment on Dr Sanborn's paper. The head box is a good example of a process for which a mathematical model may be developed directly from physical laws. The advantage of this type of model over the black box empirical model is that there are generally fewer parameters that need to be determined experimentally by identification. Identification experiments tend to make production superintendents nervous, particularly on machines that are being pushed hard. One feature of the head box identification described by Dr Sanborn is that the pond level response is determined open loop—that is, with the analog level controller disconnected. Special care must therefore be taken to ensure that level control is not lost.

It is not necessary to perform the extensive identification described by Dr Sanborn if the valve behaviour is modelled. Dr Al-Shaikh at Westvaco did this and was able to identify the head box completely, using only one experiment with the head box pond level controller on control. A DDC algorithm was designed with the controller parameters being calculated through the

model. The validity of this approach became evident when the machine speed was changed by a factor of 2 and the automatic tuning worked perfectly.

The major problem in the Sanborn paper seemed to be the sluggish valve action that resulted in dead time. It would seem to be preferable to solve that problem mechanically.

Dr I. B. Sanborn The way we set up our system is in some respects rather cunning. We always left the analog control on when there was a mechanical failure in hardware between the computer and the head box or, if we wished to open the loop between one to the other, we always fell back on the controller. The net effect was that, as far as the head box was concerned, it was no particular problem to open loops in identification. The magnitudes of the upsets necessary in identification were in the order of 1–2 in water and this was in total head operating ranges of 50 in down to 20 in. In many instances, unless we told the operator we were making an identification, he never knew it took place.

In this particular instance, identification was not as upsetting as it might otherwise have been. This is not the case with basis weight moisture control, however, which causes a decided upset in the process. I agree that a little cleverness can avoid a lot of identification. In fact, as I pointed out during the discussion after my paper, we have developed means now by which, having identified the parameters at one particular operating point, we have calculated at all other points as well. We probably identify initially when we throw the loop, then vary very infrequently, perhaps once every six months or a year.

Mr W. D. Hoath My first question is how representative is this machine of the process efficiency found on full-scale machines? Do Ramaz *et al.* expect to modify the basic process design on those machines to improve the end product—in other words, do they intend to make major process changes linked with the computers to exploit its power and versatility?

We have heard quite a lot from Dr Smith and Dr Sanborn on the need to improve the process to achieve even better control, but have we anywhere achieved major improvement design of computer control? One suspects that possibly we have gone a little way towards this at Grove Mill, but I would like to know whether any contributions could be made to highlight whether we are able to achieve it.

Mr Bauduin I am not quite sure I understand the question, but I take it that you wonder whether our experimental machine is quite representative of

an industrial one, as far as our computer project is concerned. We have already said that it is rather different from an industrial machine, but may I remind you that our project deals mainly with studying the principles of computer control. We might undertake a similar study on an industrial machine as a future project; for the time being, we do not really care about production cost or things like that. Therefore, we are not concerned with 'major process changes linked with the computer'.

The Chairman I would like to ask a question of the audience. Is there anyone who has the experience of designing new systems or making major modifications to existing systems and who have made major departures in design as a result of their process control work? In other words, have they changed the size of chests or eliminated chests or other equipment primarily for control purposes?

Mr I. McKnight I should like to comment mainly on Dr Smith's paper with a more detailed question to Dr Sanborn. I think my remarks follow on from those of Mr Hoath and the Chairman.

I wonder, if the Fourdrinier papermachine had not been invented 150 years ago, but just a few years ago, whether the flow box would have been a rather different piece of equipment. I suspect the designer would have produced a device rather like an extruding machine under careful flow control. I suspect also that the measurement of total head would have been scarcely considered. My point is to stress the measurement of flow as the major control parameter and to ask how this conception would have modified the mathematics.

We discussed the Chartham flow box in an earlier paper and there are other machines for which flow control is the main control parameter of the flow box. If a lid was put on this box, I am certain it would continue to run for a reasonable length of time under control without even a blower or level control. If the air cushion was then pared away, you would end up with a solid flow box. Surely, accurate flow control should give the correct answer at the breast roll.

My particular question to Dr Sanborn concerns the flow loop of his flow box scheme. He has created a slightly long-term flow control, whereby the slice is used as a giant slide valve. Now, flow control is a fully established practical technology, with even controllers being manufactured with fixed terms. It is generally accepted that the equal percentage valve gives the correct characteristics. I would like to ask whether this was taken into account when programming his computer to characterise his linear slice valve.

Dr Sanborn No, we have not; we have accepted the valve as it is, but some

of the gain calculations made simply take the change in the valve constant into account.

The Chairman   I would like to draw the last questioner's attention to the fact that there has been quite a lot of experimental work of a rather substantial nature done with nozzle type head boxes without any air cushion in the system. In general, most people have found that, in order to eliminate pulsations causing high frequency disturbances to the flow arising from pumps, for example, it is necessary to have a dampening effect of the air chamber.