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COMMENTS ON THE EFFECTS OF CHAOS ON "CONTROLLABILITY"

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INTRODUCTION

Below are appended some general comments on SESSION 8, "CONTROLLABILITY", and some implications for the development of control systems, with particular reference to the phenomenon of chaos.

There are many interesting aspects and the examples of process modelling and identification in the papers of this session. The complexity of the papermaking process and hence the requirements of an effective control system are very clearly illustrated. There is a vast useful literature on control theory and applications.

The total process performance and its profitability must determine the role of the control system. The subject can be presented as a series of facets developed in an orderly manner. First there are some basic theoretical definitions such as controllability (in its specialised technical meaning), observability, sampled data systems, instability and chaos. After that, there is the process performance which needs to be considered: as a design or static system; as a dynamic operating system; and quality assurance. It is also important to encompass mill wide performance.

BASIC THEORETICAL DEFINITIONS AND COMMENTS

The conventional definitions of the above control concepts are related to random processes, together with some comments on the papers of the session.

Controllability

Definition: Pointwise: If a system is controllable pointwise, then for any desired state vector x at a given time T, there is a vector of input functions u(t) that will attain that state (Patel & Munro, 1982).

or

A controlled process is said to be completely controllable if every state variable can be affected or controlled in finite time by some unconstrained input signal (Kuo, 1967).

This is a useful theoretical concept, it can be used to confirm that it is theoretically either possible or not possible to solve a particular control problem. Simply stated if, in theory, a manipulated variable can achieve the desired output the process is controllable.

Observability

Definition: A system is observable if it possible to reconstruct the state vector from the observations of the output (Patel & Munro, 1982).

or

A process is completely observable if every state variable of the process eventually affects some of the process outputs (Kuo, 1967).

Operability

Definition: The ability of the plant to maintain satisfactory dynamic performance despite uncertainties in the process environment (Arkun, 1986).

Resilience

Definition: The ability of the plant to move fast and smoothly from one oprating condition to another (including start-up and shut down) and to deal effectively with disturbances (Morari, 1983).

Nyquist Sampling rate:

Definition: An analog signal can be perfectly reproduced from its sample points if the sampling rate is twice as fast as the highest frequency component of the signal (Strangio, 1980).

In the papers by Karlsson & Eriksson and Dumont, the problem of sheet sampling for cross profile estimation is explained very weakly and no mention of variations and couplings in the cross profile due to MD variations is given. Nothing is said about the latter effect on sampling problems either (aliasing), caused by frequencies higher than the Nyquist rate. Yet the paper by Parker clearly illustrates that these high frequencies often leave their mark on the paper. We feel that this is an extremely important problem that should not be neglected and would have a major impact on the design of paper machines.

Instabillity

Definition: A system is stable (unstable) if its output is bounded (grow unboundedly) for any bounded input (Kuo, 1967). In practice this will be associated with some form of catastrophic breakdown.

Stochastic process:

Definition: A process which is described by random variables ie their values are represented by means and variances.

Chaos:

Definition: We may say that a system is chaotic if it is deterministic, though its behaviour is more sensibly described as random (Stewart, 1982).

Although Karlsson & Eriksson give a correct definition for this dynamic problem, later they associate the idea of "chaos" with stochastic processes. This dynamic motion (chaos) is quite different from a stochastic or random process. It is related to Thom's catastrophe or bifurcation theory. The controlled behaviour will be different too, as a following example will show.

In their paper, Karlsson and Eriksson try to explain everything that is not understood or has a random characteristic as **chaos**. This is obviously not necessarily true and several different factors apart from chaos or random disturbances could be the reason for this unexplained behaviour such as a time varying nature of the process or unknown (unmodelled) dynamics.

Contrary to what is said in the paper, a chaotic behaviour can be deterministic (see statement in page 1107, lines 11 & 12), and the fact that a system with chaotic dynamics is unpredictable, does not mean that is not controllable (see page 1106). That this is false may be shown by a simple example.

Example: We choose as our example the marketing process. Assume that we have a known finite market, so that we can normalize the market size to be in the range 0 to 1. Because of advertising and customer reaction we might assume that market share can grow in proportion to its existing size, i.e.

$$X_{k+1} = K*X_k$$

where the value of K represents the technological efficiency of a company.

However, our market share cannot grow to an unlimited extent because of competition with other manufacturers and customers changing allegiance. In other words there will be a loss of market share proportional, say, to the share of the market held by others, so:

$$X_{k+1} = K*X_k*(1-X_k)$$

Now to maximize X, we operate and manufacture at the optimum that the market will bear. For this K cannot exceed 4; K=4 is the theoretical value for the operation of a perfect company. As K exceeds 3.5 the process starts behaving randomly. But this is chaotic behavior, see fig. 1 (open loop) and as shown on the same figure, conventional negative feedback control can be applied and a fixed market share is attainable. It must be noted that a genuinely random or stochastic process cannot be controlled in this way, as figure 2 shows.

COMMENTS ON KARLSSON & ERIKSSON PAPER

Based on the previous definitions we would like to make the following comments to the review paper, stressing the potential problems of chaotic behaviour.

First, the authors redefine controllability and observability on several occasions. In the numerous definitions given for controllability (pages 1105, 1107, 1112, 1116 and 1131) not only the concepts of observability and controllability are mixed, but also some of the definitions are self-contradictory (see for example definitions in page 1131 & 1112 in reference to measurements and sensors). Here, we must also point out that if a process is not observable it does not mean that is not controllable.

We think that the definitions of Operability and Resilience given above, could help in describing the dynamic characteristics referred in the paper.

In page 1107 the definition of controllability includes costs, which is unusual. The tradeoff between economic factors and dynamic performance (the so called multiobjective approach design, Arkun 1986), has for long been an area of research in process control and to date no definition nor index has been found (at least in mathematical terms) to describe such compromise.

COMMENTS ON SYSTEM IDENTIFICATION AND ADAPTIVE CONTROL IN PAPERMAKING

In an elegant paper, Dumont presents some advanced mathematical tools to control some complex processes in papermaking using adaptive control.

Generally speaking, these techniques have had little success, their implementation to real processes being very few in number.

We think that there are some important reasons why this is so that are not mentioned in the paper.

In the case of estimation of CD and MD variations, a technique that ressembles an Extended Kalman Filters is used. No mention about the robustness of this procedure is given which is known to be extremely sensitive to initial conditions of estimates and covariance matrices for example, leading in some cases to wrong estimates. This obviously casts a shadow on its applicability in papermaking.

Another general observation on adaptive control is on its convergence, robustness and stability. Ydstie (1987) gives a simple example where an adaptive configuration can lead to a chaotic motion, creating unacceptable "bursts" in the output response, although he does not say whether this problem can be of significant importance in a real "noisy" environment. This again, demonstrates a practical problem in the implementation of the advanced techniques. Nevertheless it is important that industry is aware of the development of these techniques (and their limitations) which may ultimately lead to much improved control.

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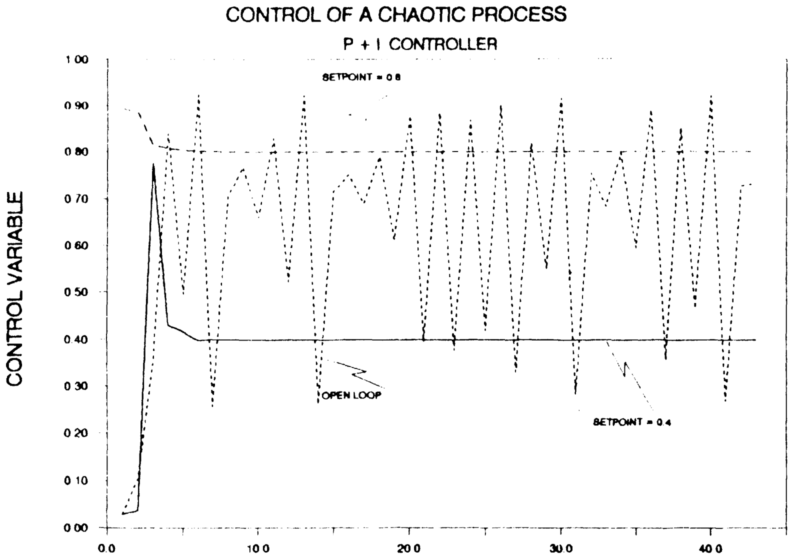

FIGURE 1

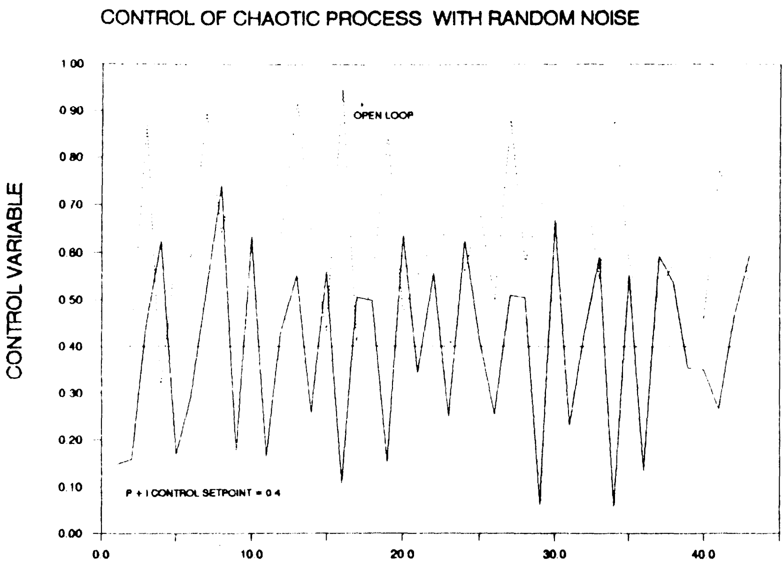

FIGURE 2