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CHEMICAL BOND GRAPHS

I read with delight the April 2007 issue, especially the tutorial by Peter Gawthrop and Geraint Bevan on bond-graph modeling. The tutorial is full of useful references and was timely for advancing our fledgling research in this area. My doctoral student Xi Zhang and I have extended the concept of "power" to enzyme-catalyzed systems, and we had begun applying the bond-graph concepts to fault detection and isolation for biological systems. We have found that very few researchers working in chemical and biochemical processes are acquainted with these concepts, which have remarkably broad applicability.

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MORE CLASSICAL THINKING

I retired from chemical process control still believing that the easy understanding of classical control remains central to our profession and a basis of real rigor when addressing complex commercial controls. I have promoted three related unrequited loves, namely, more exacting PID analysis, further intuitive multivariable perspectives, and the general recognition of something I called idioms and the idiomatic control language. The February 2007 *IEEE Control Systems Magazine* Classical Control Revisited special section shows there is still relevant hope for the research community.

The first of these loves, closest to classical control, is needed both for wider academic access to a basic but not well-understood tool of control, and to refine effective adaptive PID designs. The second of the loves clarifies the direct use of simpler structures in more complex applications. And the last addresses design documentation in a digital era when controls should be documented in terms of their design intents and compiler implemented with more computer techniques rather than the archaic analog/block diagram functions. It further integrates our controls with the many other forms of control evolving in a complex world.

Classical control has always had "subtleties that make us squirm" and domain gaps that undercut its academic position such as the gap between time and frequency as well as the gap between simple implications of the practice and inaccessible deep proof theory. These gaps are not just incidental, but probably inherent in the breadth of issues involved. The author fought a related "gap" between some of his eigenfunction analytic work and the understanding of colleagues who relied on simulation tools. Precomputer classical treatment covered the translation between Laplace domain poles and the time domain, but did not really recognize eigenfunctions or even give them a name.

The original EXACT PID pattern recognition adaptive system, which was the focus of the first IEEE Control Systems Technology Award, was developed from a root locus perspective, augmented by detailed experience with behavior of principal eigenfunctions and massive amounts of simulation data encapsulated as fit functions and rules. It was seen as an expert system, to its marketing advantage. But, because it was thus "magic," nobody at large felt obliged to understand it for further evolution. Likewise, we have, today, many successful but unproven tuning procedures.

Edgar Bristol
Control Concepts Originated

VIRTUES OF CONSISTENCY

I found the PID2006 special section in the February 2006 issue quite interesting. When analog computers were used for control, the subject of time scaling was often discussed. This technique, now little mentioned, is useful for examining the consistency of PID tuning rules.

The most common model in the literature for developing PID tuning rules is the first-order-plus-dead-time (FOPDT) model

$$G(s) = K_p e^{-s\tau}/(1 + sT).$$

Ideally, the PID controller has the transfer function

$$G_c(s) = K[1 + sT_d + (1/sT_i)].$$

By scaling time in the transfer function by means of $s_n = sT$, the transfer function of the loop gain with unity feedback is

$$\begin{aligned} G(s_n) &= K' e^{-s_n \rho}[1 + s_n T'_d \\ &\quad + (1/s_n T'_i]/(1 + s_n), \end{aligned}$$

where $K' = KK_p$, $\rho = \tau/T$, $T_d = T_d/T$, and $T_i' = T_i/T$. Selecting PID parameters is equivalent to selecting the parameters K', T_d', and T_i'.

The parameters K', T_d', and T_i' can be chosen to minimize a cost function, for example, the integral of the squared value of the product of the time and the error (ISTE). For any cost function, the tuning rules of the time-scaled system may be expressed as $K' = f_1(\rho)$, $T_d' = f_2(\rho)$, and $T_i' = f_3(\rho)$, where the functions f_i depend on the criterion chosen. Transforming back to the original PID parameters, the resulting PID tuning rules for the FOPDT plant should have the form

$$K = f_1(\rho)/K_p, \quad T_d = Tf_2(\rho),$$
$$T_i = Tf_3(\rho),$$

for consistency. To illustrate, the tuning rule $T_i = 4\tau^2/T$ is consistent, while $T_i = \tau + 2T$ is not.

Somewhat surprisingly, few of the suggested tuning rules in the literature satisfy this consistency test. For instance, the Ziegler-Nichols (Z-N) formula [1] is consistent only if the optimum time-scaled parameters have the form $f_2(\rho) = k_2\rho$ and $f_3(\rho) = k_3\rho$, which seems to be a very special case. Tuning rules that do not satisfy the test include the Chien-Hrones-Reswick [2], Cohen-Coon [3], and Wang-Juang-Chan [4]. Consistent tuning rules are provided in [5]. Similar consistency formulas can be obtained for other simple plants as listed in Table 1.

TABLE 1 Consistency formula for PID tuning.

Model	K	T_d	T_i
$\frac{K_p e^{-s\tau}}{1+sT}$	$\frac{f_1(\rho)}{K_p}$	$Tf_2(\rho)$	$Tf_3(\rho)$
$\frac{K_p e^{-s\tau}}{s}$	$\frac{K'}{K_p}$	$\frac{f_4(K'\tau)}{K'}$	$\frac{f_5(K'\tau)}{K'}$
$\frac{K_p e^{-s\tau}}{s(1+sT)}$	$\frac{f_6(\rho)}{K_p}$	$Tf_7(\rho)$	$Tf_8(\rho)$
$\frac{K_p e^{-s\tau}}{(1+sT)^n}$	$\frac{f_9(\rho)}{K_p}$	$Tf_{10}(\rho)$	$Tf_{11}(\rho)$

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