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Entonamiento de controladores PID para procesos multivariables

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Resumen

En este trabajo se presenta un método simple y robusto para determinar los parámetros de controladores PID en procesos industriales multivariales.

El procedimiento es una extensión modificada de el entonamiento automático bajo control de relay para controladores PID aplicados a sistemas SISO. La ventaja principal del método es la simplicidad de su implementación tanto para plantas reales como a sus modelos.

El modelo se probó en varios sistemas multivariables de destilación, desde sistemas 2x2 hasta 4x4. Los controladores entonados por este método dieron resultados dinámicos comparables a los obtenidos usando el método del máximo logaritmo del módulo (BLT4), el método de la matrix dinámica (DMC) y el control del modelo conservador (CMBC).

Palabras claves : Controladores PID, Sistemas multivariables, Entonamiento automático.

Tuning PID controllers for multivariable processes

Abstract

A simple and robust method to determine reasonable settings for the PID controllers in multivariable industrial processes is presented. The procedure is a straightforward extension and modification of automatic tuning under relay control for PID SISO controllers. Its main advantage is the simplicity of its implementation for real plants or their models. The method has been tested on several multivariable distillation column systems,from a 2x2 system up to a 4x4 system.The controller settings determined by this method gaye dynamic responses comparable to those obtained using the improved Biggest Log Modulus method (BLT4), Dynamic Matrix Control ant conservative model based control(CMBC).

Key Words: PID Controllers, Multivariable Systems, Automatitic Tuning.

Introduction

In recent years there has been a renewed interest in the study of design methods for multivariable control systems. Most of the control strategies developed, such as those based on the concept of Internal Model Control (IMC) (Morari et al (1986) and Dynamic Matrix Control, make use of models of the processes and desired performance trayectories. The main feature of these methods is the multiple input-multiple output nature of the controllers. Luyben (1986) points out that, despite the appeal of these techniques, very few truly multivariable controllers have been reported in use in industry. This is due in part to their complexity, excesive engineering manpower needed to implement them, and to the operators nonacceptance. At present, most of multivariable processes are still controlled by two (PI) or three (PID) modes single input-single output (SISO) controllers. Once this control strategy is selected, it is first necessary to establish the pairing of the controlled and manipulated variables, and then to select the parameters of the controllers. The first problem has been studied by several authors .Yu et al (1986), Grosdidier et al (1987), Tyreus 1979) etc, using an array, of techniques such as relative gain arrays (RGA), Direct Nyquist arrays, Load rejection indexes, resilience index, etc. The tuning of the controllers, once the pairing has been set, involves the selection of 3N parameters for a multivariable system with N loops. Most of the procedures to do this selection involve two steps. First the controllers are tuned separately using well known methods for SISO systems, and then they are detuned to reduce the interactions effects of the other loops. Luyben (1986) proposed the Biggest Log Modulus Method (BLT) to detune, by the same amount, all SISO controllers from their Ziegler-Nichols settings, to obtain a specified value of the multivarible closed loop log modulus. This parameter gives a measure of the stability of the multivariable system when the system is stable.

Monica et al (1987) improved the BLT procedure, adding derivative action to the controllers, and detuning each loop separatedly, compensating for the fact that the interactions are not symetric. Prasad et al (1990) presented the conservative model-based control (CMBC) for multivariable SISO controllers, neglecting the interaccion effects in the design. The omission of the diagonal elements of the Matrix Transfer Function is considered as modelling errors. All the methods mentioned require an approximate model for the system to be controlled, and in general are limted to open-loop stable systems.

In this paper an alternate method to tune multiloop PID controllers is presented. It uses the autotuning technique for single loops proposed by Astrom (1984), and it is based on the automatic determination of critical points in the Nyquist plot for open loops, and gain and phase margin design.

This method should be viewed in the same light as the generalizations of the Ziegler and Nichols methods for multivariable systems, and provides reasonable controller settings with little computational effort.

It is easy to use, and the only requirement needed for its application is that the multivariable plant has to be suitable for automatic tuning of PID controllers, as described in Astrom (1984) and Carreno et al(1990)

Proposed Method

The multivariable relay autotuning method (MRA) makes use of the autotuning technique for single loops . This technique, proposed by Astrom (1984), determines first the intersection of the Nyquist curve of the open loop transfer function with the negative real axis. This point, characterized by the critical gain K and critical period T_c, is determined replacing the PID controller in the closed loop, with relay having an amplitude "d". An optional hysteris of width ε may be added to the relay, to make the system less sensitive to measurement noise. See Figure 1. The determination of the critical point is based on the observation, that a process with a phase lag of at least 180° for some frequency will oscilate under relay control with the critical period T_c.

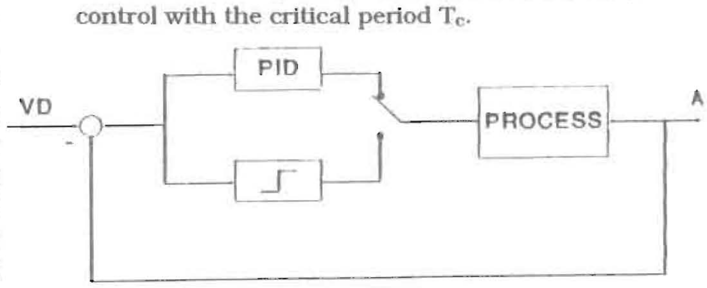

Figure 1. Block Diagram of the autotuner. Relay control in autotuning mode. PID regulator in control mode.

This phase lag requirement is met by most of the process control systems encountered in practice, and are modeled as variable lead-lags with dead-time.

Since the error signal e in Figure 1 is a periodic signal with period T_c, the output of the relay will be a periodic square signal. Approximating this signal by the first harmonic of its Fourier series expansion, whose amplitude is $4d/\pi$, the controller critical gain can be approximated by

$$K = 4d / A, \quad [1]$$

where A is the amplitude of the process output. The same equation can be obtained by considering the describing function of an ideal relay, that is

$$N(A) = 4d / \pi. \quad [2]$$

After reaching the steady state under relay control, the period and amplitude of the oscilation can easily be determined, measuring the time of zero crossing and the peak to peak values of the output. The values are averaged over several periods to obtain accurate estimates. The amplitude of the output is controlled choosing an appropiate relay amplitude.

This simple relay experiment allows the determination of a critical point on the Nyquist curve, and the application of the Ziegler and Nichols tuning rules. Astrom (1984) presented several variations of this basic design method, all based on the information on the process dynamic obtained from one or more points on the Nyquist curve determined using different relay experiments.

In the proposed method for tuning of PID controllers for multivariable systems, the critical points for each single loop are obtained first ignoring the interaction effects, that is, with the other loops open. The controllers settings are then determined using the following standard equations:

Controlller Gain, K_c = Critical Gain/2.2 [3]

Integral Time, $\tau_I = T_c / 2$ [4]

Derivative Time, $\tau_D = T_c / 8$ [5]

These settings correspond to the classical SISO Ziegler and Nichols parameters, and are used in the next step to tune the multivarible SISO controllers. This is done determining the critical point for each loop using relay control, while keeping the other loops under PID control, with their Ziegler and Nichols values obtained previously.

The interaction effects of the closed loops with their PID controllers tightly tuned will therefore influence the location of the critical point being determined. Compared to the previous values, The critical gain will decrease, the critical period will increase, and this variations will be proportional to the amount of interaction present.

Using equations [3] to [5] with these new critical points, a more conservative set of controller parameters will be obtained, that will reflect the interaction and also, implicitly, its unsymetric nature. Using this method , the tuning of the controllers can be done experimentally, with two simple relay experiments for each loop . If the relay amplitude is choosen properly there is little upsetting of the plant. This offers a clear advantage over the classical Ziegler-Nichols scheme, which is time consuming, and difficult to automatize and control the amplitude of the oscilation.

Carreno (1990) reported successful experimental applications of the method for a 2x2 system controlling flow and pressure in a highly inter active process.

Application To Distillation Columns

The performance of the controllers tuned using the MRA procedure has been tested on several simulated distillation columns, and compared with the results obtained using the BLT and BLT4 procedure. Some comparisons are also presented with the Conservative Model based Control (CMBC) (Prasad et al, 1990) for multiloop control ignoring interaction, and with the Dynamic Matrix Control. The results for the Dynamic Matrix Control were obtained from Monica et al (1987) using a prediction horizon (NP) of 15 min, a manipulation horizon (NM) of 40, and variable factors f. The tuning parameters β used by CMBC controllers are listed in the table 1.

Table 1. Controller Parameter for BLT. BLT4, ARM, DMC and CMBC

Parameters	WB	OR	A1
		BLT	
K_c	376,-0.0749	1.51,-.295,2.63	2.28,2.94,1.18,2.02
τ_1	8.29,24.46	16.4,18,6.61	72.2,7.48,7.38,27.8
		BLT4	
K_c	.191,-161	1.23,-.477,4.87	5.13,0.96,1.7,3.88
τ_1	16.3,10.86	20.04,11.03,3.6	32.1,29.5,5.1,14.4
τ_D	.074,.89	.433,.706,.296	2.5,0.04,0.17,0.83
		MRA	
K_c	0.75,-.085	1.44,-.304,4.52	2.53,5.82,2.4,6.62
τ_1	5.16,10.42	9.91,9.99,3.05	38,3.12,3.06,9.59
τ_D	0.66,1.56	1.48,1.49,0.45	5.7,0.47,0.46,1.43
		DMC Settings	
f	10	0.1	0.1
NP	40	40	40
NM	15	15	15
		CMBC Tuning Parameters	
β	.9342,.9197	-.9777,-.3079,.9159	.9771,-.5739 .9457, .9819

The open loop transfer function matrices of the systems studied may be found in Luyben (1986), and the load transfer functions in Monica et al (1987). The column configurations ranged from 2x2 to 4x4 systems, with different degrees of interaction as indicated by the interactions indexes, and are referred as WB (Wood and Berry (1973)) the 2x2 system, OR (Ogunnaiike (1979)) the 3x3 system and A1 (Alatiqi 1985)), the 4x4 system..

Simulation Results

The controller parameters for the three cases studied using the BLT, BLT4 and MRA methods are listed in Table 1.

Comparative load rejection dynamics are given in Figures 2 and 3 for the WB and OR system, and the responses to a unit step change in distillate composition for the same systems, are shown in Figures 4 and 5. The integrated absolute errors (IAE's) of the controllers for simultaneous load disturbances in all the loops, are listed in Table 2, and the integral of the square errors for simultaneous changes in all the set points, are listed in Table 3. It may be noted that the dynamic performance of the MRA, is superior to the BLT, and comparable to the the other methods that require more calculations o models for the system.

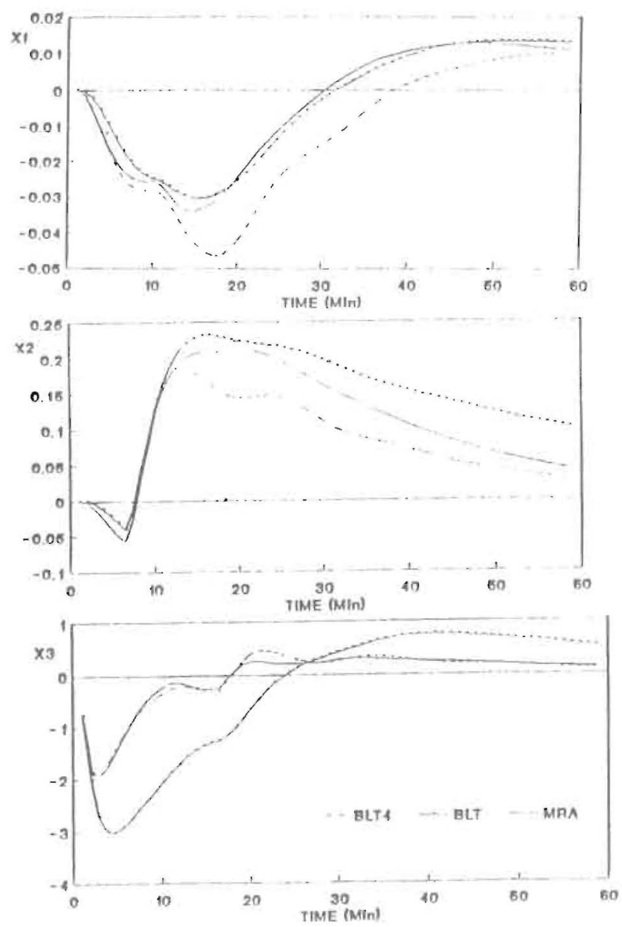

Figure 2. WB load response controlled variables

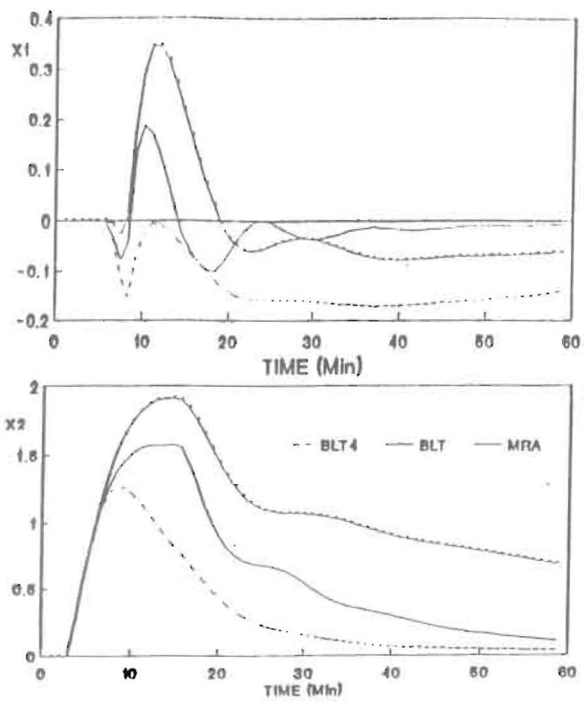

Figure 3. OR load reponse controlled variables

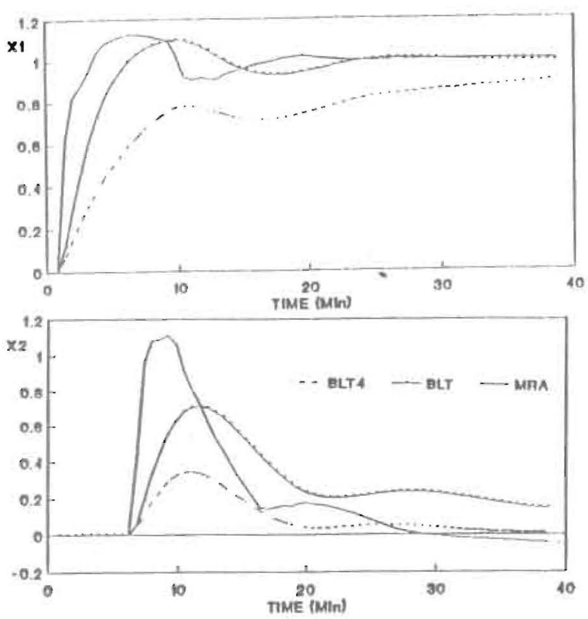

Figure 5. X1 set point responses of OR

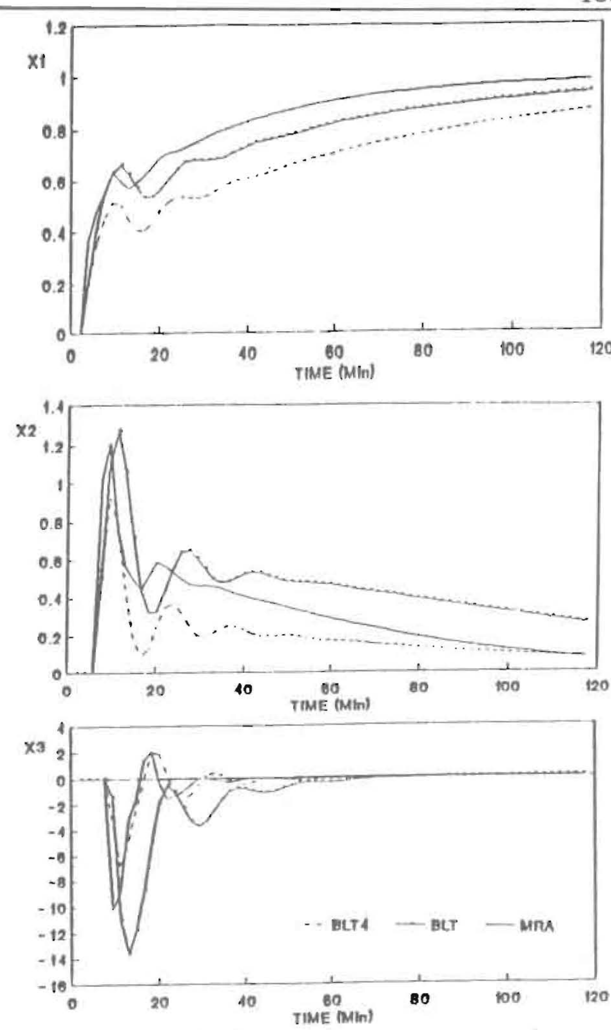

Figure 4. X1 set point responses of WB

Table 2. WB, OR and A1 IAE values for BLT, BLT4, DMC and MRA load disturbances

	IAE(X1)	IAE(X2)	IAE(X3)	IAE(X4)
	WB Load Disturbance			
BLT	4.67	61.5		
BLT4	7.22	19.0		
DMC	19.90	32.6		
ARM	31.66	1.84		
	OR Load Disturbance			
BLT	0.84	7.21	65.40	
BLT4	0.72	4.73	24.30	
DMC	1.73	3.23	28.20	
ARM	0.87	5.62	22.61	
	A1 Load Disturbance			
BLT	55.6	2.08	29.7	37.6
BLT4	13.3	17.3	15.30	11.0
DMC	15.6	11.10	4.72	5.70
ARM	15.59	0.28	10.15	6.48

Table 3. WB, OR and A1 ISE values for BLT, BLT4, CMBC and MRA set point changes

ISE total		
WB	OR	A1
7.55	1411	115.3
6.14	371	158.91
3.57	396	37.8
4.21	427	40.7

As a final comparison of the methods, the Nyquist plots of the closed loop characteristic equation

$$W= [-1 + \det (I + GB)(s)] \qquad [6]$$

over appropiate frequency ranges (i.e. near the point (-1,0j)), and the minimum singular values σ of [I+ G(jw)B(jw)], are shown in Figures 6 and 7. These parameters are reliable measures of the multivariable closed loop stability, loop errors in the presence of load or command disturbances, and closed loop sensitivity.

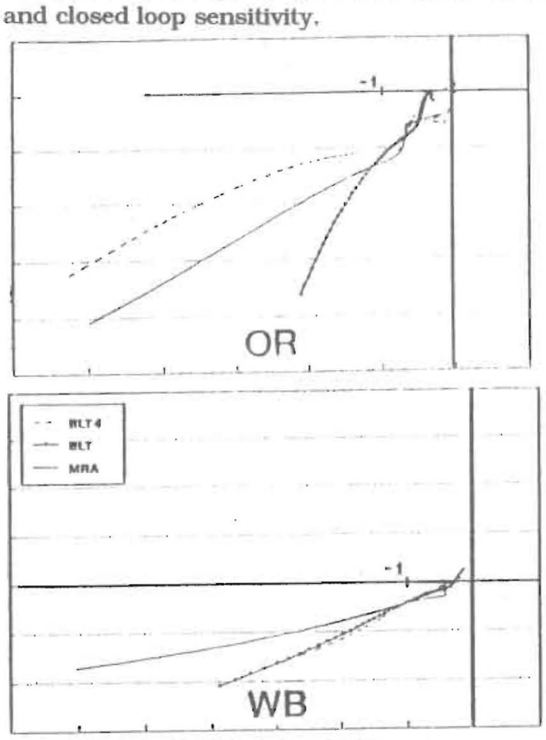

Figure 6. W plots of WB and OR

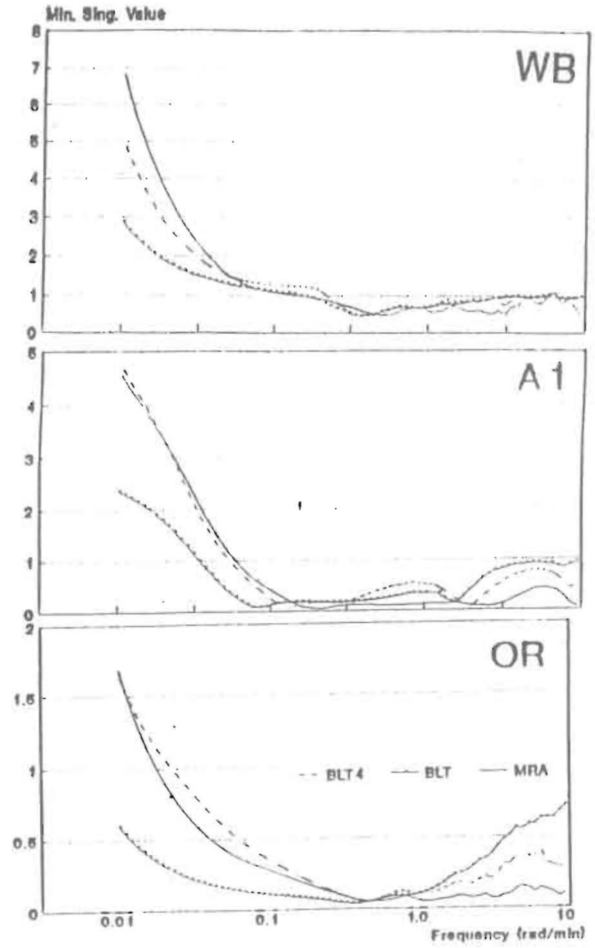

Figure 7. Minimum singular values of WB and OR

The values of maximum closed-loop log modulus defined as

$$L_{cm}^{max} = \log \left| \frac{W}{1+W} \right| \qquad [7]$$

are listed in table 4.

Table 4. Biggest Log Modulus L_{cm}^{max}

WB	OR
4	6
4.31	7.01
5.34	5.62

These frequency domain results show, that the systems with controllers tuned using the