PI CONTROLLER TUNING USING MODIFIED RELAY FEEDBACK METHOD

YOUNG HAN KIM
Department of Chemical Engineering, Dong-A University, 840 Hadan-dong, Saha-gu, Pusan, Korea

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Introduction

Though modern advanced control has been adopted extensively in numerous chemical processes, basic control mainly depends upon the conventional PID control owing to its stable and robust performance. However, tuning of the controller is difficult and time consuming. Moreover, though a number of studies have been reported on this subject, they are not useful for unmodeled processes, including most industrial applications, since they require process modelling in the form of a transfer function.

Åström and Hägglund[1)] proposed the relay feedback method that gives ultimate values directly from process response without knowledge of a process model and the ultimate values are utilized in the computation of the control parameters by the Ziegler-Nichols tuning method[2)]. Since the relay feedback method is simple and effective, it is employed in commercial applications.

For improvement of control performance and easier tuning, in this study, a modified relay feedback procedure is proposed which gives control parameters for a PI controller without the second tuning procedure, such as Ziegler-Nichols tuning. The performances of the proposed method and the original relay feedback method are compared in the set-point tracking and regulatory control of a binary distillation column.

1. Modified Relay Feedback Method

The relay feedback method manipulates input to induce continuous output oscillation and phase lag of -180° by changing square pulse input when the output crosses the initial value. In **Fig. 1a**, vapor boilup rate (input) in a reboiler of a distillation column described later is altered to a square wave having constant amplitude. Note that the changing moments are synchronized to the output, bottom product composition, crossing to the initial value.

The process' ultimate gain is found from the first harmonic of the output in Fourier series expansion[1)].

$$K_u = \frac{4d}{\pi a} \tag{1}$$

where d is the input amplitude and a is the output amplitude in steady state oscillation. The ultimate frequency is the output frequency. Real control parameters are found from these ultimate values and the Ziegler-Nichols tuning guideline.

In a similar manner, the input change can be manipulated to have a certain phase lag which is determined from the specified phase margin. As in **Fig. 1b**, vapor boilup rate is altered after output crosses the initial value and a given delay time equivalent to the phase margin. The duration between present output crossing moment and previous crossing moment, for instance indicated as the distance of points A and B in Fig. 1b, corresponds to 180° and therefore 45° of phase margin means the delay time is one quarter of the duration between A and B. A more detailed explanation is given in the following steps.

1) Specify phase margin and input oscillation amplitude. Suggested phase margin is 45° and input oscillation amplitude is 1 to 10 % of initial steady-state input value.

2) Choose small value of initial delay time say 1 minute.

3) Apply square change of input to process with either positive or negative deviation and after initial delay time give opposite deviation square input.

4) Measure interval time between output crossings to initial value and find new delay time from the interval. The interval is equivalent to 180°. In the case of a 45° phase margin, take one quarter of the interval as the new delay time.

5) Alternate input change is implemented after the output crosses the initial steady state value and after a given delay time.

6) Continue steps 4 and 5 until output variation is stabilized.

7) Take the period of continuous oscillation as the integral time and the gain computed from Eq. (1) as the proportional gain in PI controller. No detuning is necessary.

Controller design by the modified relay feedback method ensures a specified phase margin that gives better performance than a gain margin design procedure[2)], while the original relay feedback method is a gain margin ensuring procedure. Also, the modified method is simpler than the original one because no further tuning is necessary, such as Ziegler-Nichols tuning.

* Received August 16, 1994. Correspondence concerning this article should be addressed to Y. H. Kim.

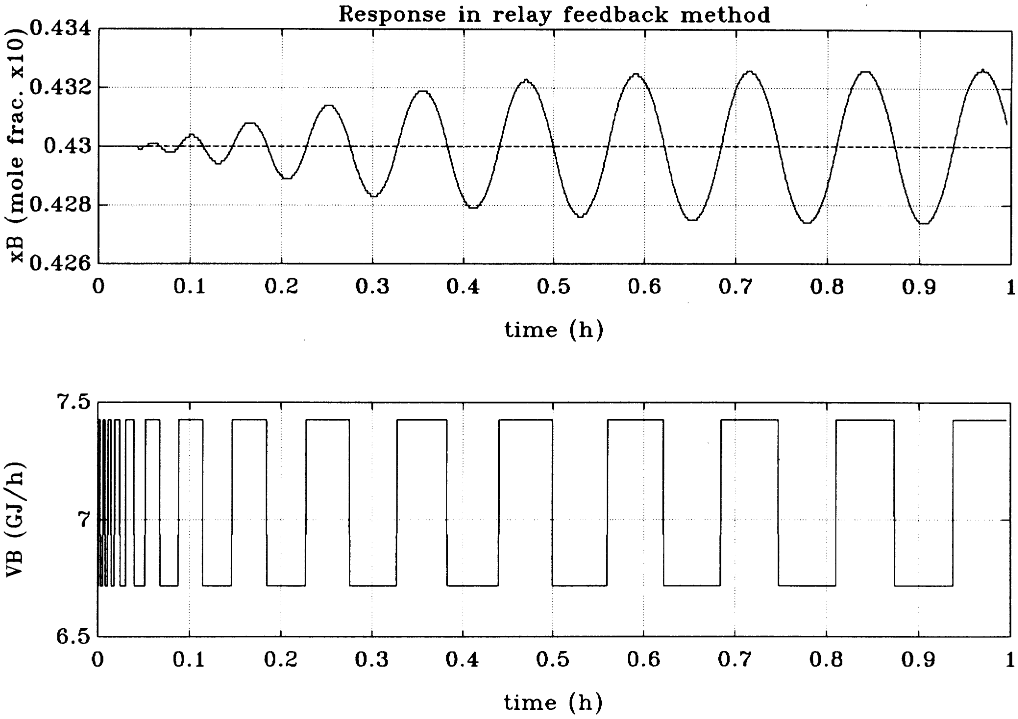

Fig. 1 - Response illustration of relay feedback method: (a) original relay feedback method;

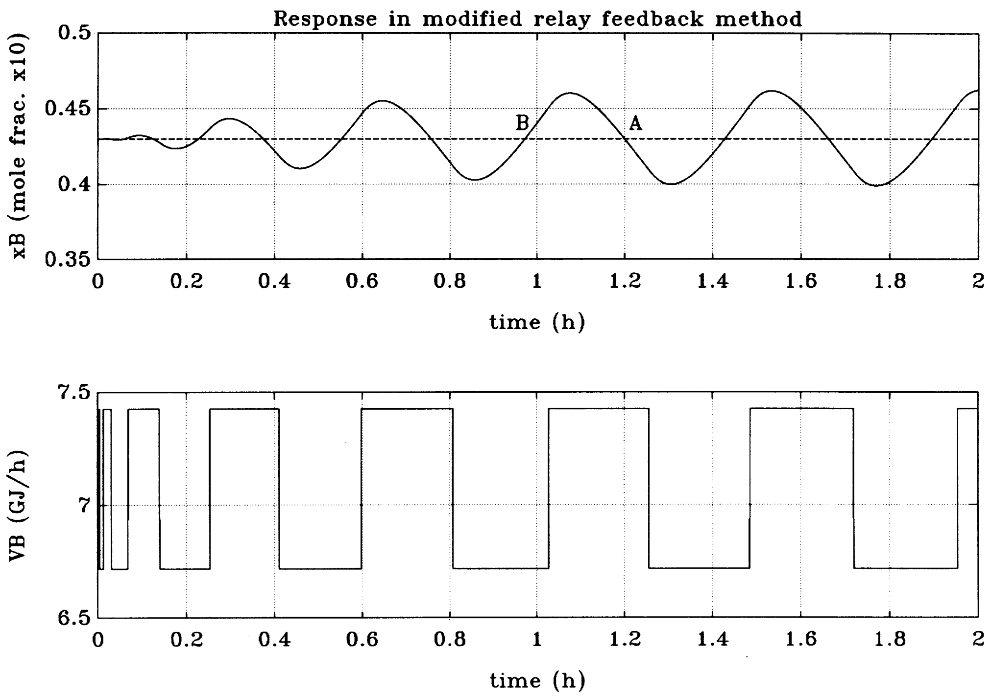

Fig. 1 - Response illustration of relay feedback method: (b) modified relay feedback method

2. Performance Comparison

Control performance with the parameters obtained by the modified relay feedback method is compared with that of the original relay feedback parameters. Tuning parameters of the original and modified relay feedback methods are summarized in **Table 1**.

A rigorous process model of a binary distillation column is employed in the implementation and evaluation of the control parameters. The model describes a real distillation column separating a methanol-water system. It consists of a six inch column with ten bubble-cap trays, a reboiler and a total condenser. Bubble point calculation in each tray is carried out by Newton-Raphson iteration with activity coefficients from the van Laar equations and vapor

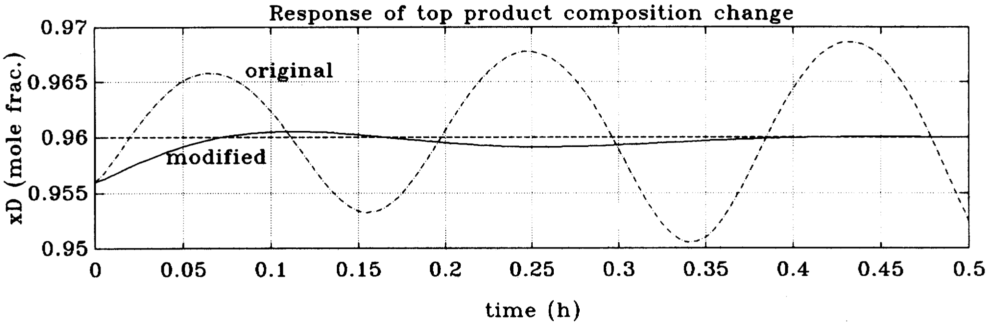

Fig. 2 - Set-point tracking response: (a) top product composition change

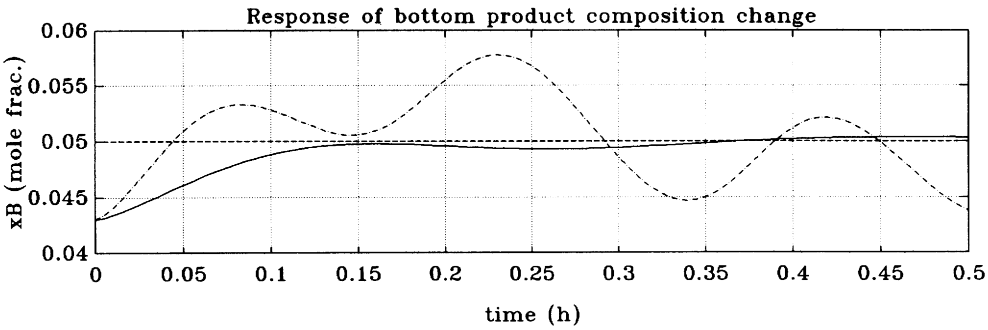

Fig. 2 - Set-point tracking response: (b) bottom product composition change

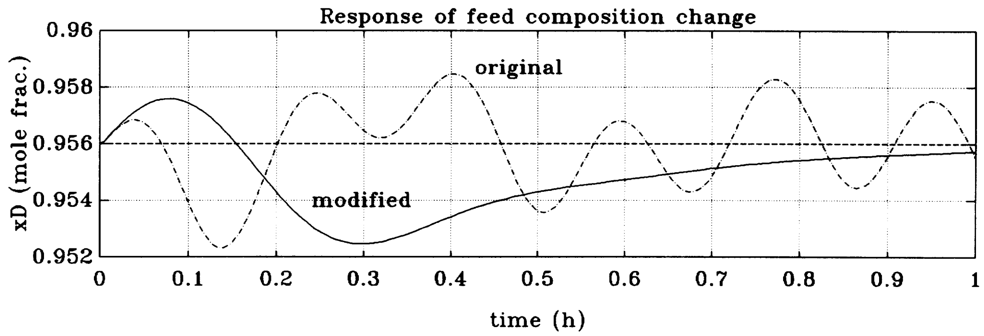

Fig. 3 - Regulatory response of feed composition change: (a) top product composition change;

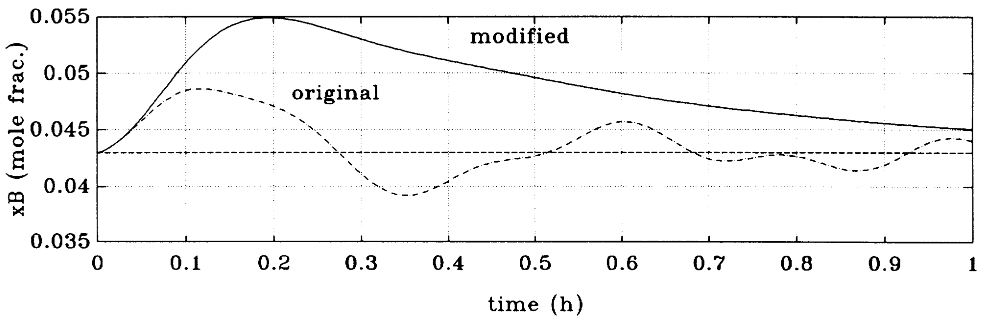

Fig. 3 - Regulatory response of feed composition change: (b) bottom product composition change

pressure from the two-constant Antoine equation. Nonlinear liquid hydraulics include the Francis weir formula and vapor holdup is neglected. Vapor flow rates are computed from energy balances. Overall tray efficiency is assumed to be 80 %. Two separate PI controllers are installed in the top and bottom product composition control loops. Reflux flow and reboiler steam flow rates are manipulated variables. In the measurement of product composition, a first

Table 1. Controller Tuning Parameters

	original	modified
Top product composition control loop		
K_u	6.050	
P_u	0.0505	
K_c	2.723	1.028
τ_I	0.0421	0.282
Bottom product composition control loop		
K_u	4.049	
P_u	0.1273	
K_c	1.822	0.754
τ_I	0.1061	0.4705

order delay with 3 minute time constant is included.

When the set point of top product composition is increased, as shown by the dashed line, variations of top product composition are illustrated in **Fig. 2a** where the original relay feedback tuning shows very unstable outcome, while the modified relay feedback leads to stable response. This indicates that the original relay feedback tuning needs further detuning. Quite similar responses are described in Fig. 2b where the set-point change of bottom product composition is imposed as shown by the dashed line. For the feed composition change from 0.36 to 0.5 mole fraction of methanol, responses of top and bottom product compositions are shown in **Fig. 3**. Again the original relay feedback tuning leads to oscillatory response, while the modified tuning yields stable outcome.

Conclusion

A relatively simple tuning technique, a modified relay feedback method, for PI controller is proposed and its performance is compared with that of the original relay feedback method.

In a simulation study using a binary distillation column model, it is found that the proposed technique gives better performance than the original relay feedback method in both set-point tracking and regulatory control and is simple and easy in application.

Acknowledgement

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Nomenclature

a	=	output amplitude	[mole frac.]
d	=	input amplitude	[GJ/h]
Kc	=	proportional control gain	
Ku	=	ultimate gain	
Pu	=	ultimate period	[h]
tI	=	integral time	[h]

Literature Cited

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2) Luyben, W. L.: "Process Modeling, Simulation and Control for Chemical Engineers", 2nd ed., McGraw-Hill Book Co., N. Y. (1990)