REFORMULATION OF THE TANGENT METHOD FOR PID CONTROLLER TUNING

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Abstract: Process stability of a PID control loop depends upon the proportional, integral and derivative constants used. Using the conventional tangent method and the proper tuning rule, the optimum P, I and D can be estimated. With this optimum P, I and D set into the controller, an optimum response is normally achieved. A new reformulation of the tangent method is proposed in this paper where the analysis is made simpler, easier and faster. The new reformulated tangent method can be applied with ease to any recording or display devices as compared to the existing tangent method as will be shown in the experimental study section.

Keywords
Reformulated tangent method, controller tuning, optimum PID, process dynamic identification.

I. INTRODUCTION

Major manufacturing and chemical process industries have been using PID controllers in the automatic control system since the early 1940s. Since then, it has evolved from a pneumatic mechanical to a digital electronic device. Unlike on-off controllers, PID controllers are capable stabilizing processes at any set-point by utilizing a mathematical function in the form of the control algorithm.

Currently, there are several equations of the PID's control algorithm. A few of these equations are shown below.

$$MV = \frac{100}{P}\left\{e + \frac{1}{I}\int e\, dt + D\,\frac{de}{dt}\right\} \quad \ldots\ldots\ldots \quad (1)$$

$$MV = \frac{100}{P}\, e + \frac{1}{I}\int e\, dt + D\,\frac{dPV}{dt} \quad \ldots\ldots\ldots \quad (2)$$

$$MV = K_c\left\{e + \frac{1}{I}\int e\, dt - D\,\frac{dPV}{dt}\right\} \quad \ldots\ldots\ldots \quad (3)$$

Despite the variation in the equations used for the algorithm, the variables used remain the same i.e. proportional constant (P) or controller gain (K_c), integral constant (I), derivative constant (D), set-point value (SP) and measurement value (PV). In fact, the units of I and D may differ from one instrument manufacturer to another instrument manufacturer. For instance, the I constant, one manufacturer may use min per repeat (integral time) while other manufacturer may use repeat per min (integral gain) [1]. Integral time and integral gain is inversely related to each other.

The variation in these control algorithms of PID controllers only affect the shape and size, but not the characteristics, of the process response curve. These characteristics of PID controller are the tendency to produce overshoot, undershoot, off-set and oscillation in the system response.

The selection of P, I, and D values is very crucial. They determine whether the process is oscillatory, stable or unstable. To obtain a stable process, numerous combinations of P, I and D values are possible, but there is only one combination that will produce an optimum response curve.

One quick method in getting the optimum P, I and D is by using the conventional tangent method [2]. It provides two most vital information about the process dynamic i.e. the deadtime and the response rate. This information is used in the tuning rules, such as Zieglar-Nichols, to estimate the optimum P, I and D for the controller.

Chart papers or DCS's printer outputs are the common ways to record the process response curve. However, performing the conventional tangent method on the chart paper and DCS's printer output is relatively a tedious and cumbersome method.

Hence, it is the intention of this paper to present a new reformulation of the tangent method where the data extraction is made slightly simpler and quicker as compared to the existing practice. It will be shown later that this newly reformulated tangent method is applicable to any recording or display devices without laborious work.

II. TANGENT METHOD & OPTIMUM PID

The tangent method starts with an openloop test. It is done by putting the controller in manual mode and making a load change (ΔMV) of 5 to 20% to the controller's output. The resulted response curve is recorded until a new steady state level has been reached or until an ample amount of data is obtained necessary to perform the analysis.

The response curve is then analyzed for the process deadtime (Td) and the response rate (RR) by drawing a tangent line to the steepest point of the response curve. By definition, the process deadtime is estimated at the cross section between the baseline of the old steady-state level and the tangent line [2,3]. Figure 1 shows the load change made (ΔMV), the drawn tangent line and the estimated process deadtime (Td).

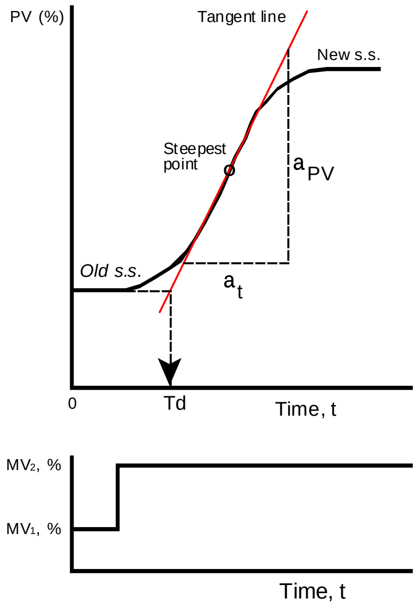

Figure 1: A step change of ΔMV (bottom) and the associated response curve (top).

The process response rate, RR, is defined [4,5] as,

$$RR = \frac{(\Delta PV / \Delta t)}{\Delta MV} \quad \text{..........} \quad (4)$$

where,

RR = response rate, 1 / time
ΔPV = change in measurement, %
Δt = change in time, time
ΔMV = change in controller's output, %

Td and RR are incorporated in the tuning rule for the optimum PID calculation. There are six openloop tuning rules, which has been compiled by Senbon and Hanabuchi [5]. One of the famous openloop tuning rule is Zieglar-Nichols as shown in Table 1 below.

Table 1: Openloop tuning rule by Zieglar-Nichols.

Mode	P, %	I, time	D, time
P	100 Td RR		
PI	111.1 Td RR	3.33 Td	
PID	83.3 Td RR	2 Td	0.25 Td

III. REFORMULATED TANGENT METHOD

The response curve in Figure 1 can be analyzed and viewed with a different perspective as shown in Figure 2 below.

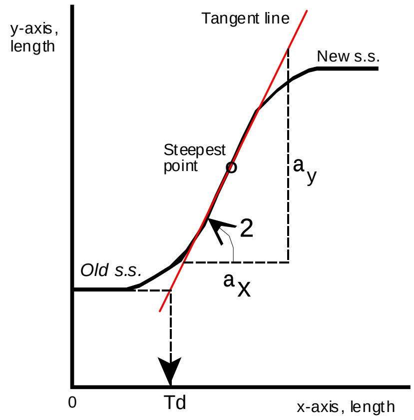

Figure 2: Transforming process rate into trigonometric form.

Here, the process rate, RR, of Eq. (4) is then reformulated by,

$$\frac{\Delta PV / \Delta t}{\Delta MV} = \frac{\Delta y / \Delta x}{\Delta MV} \quad \text{..........} \quad (5)$$

But, the right-hand side and left-hand side of the equations are not dimensionally balance. Putting the appropriate scaling factors to the right hand side of the equation, Eq. (5) transforms into,

$$\frac{\Delta PV / \Delta t}{\Delta MV} = \frac{\frac{\Delta y}{\Delta x}\frac{a}{b}}{\Delta MV} \quad \text{..........} \quad (6)$$

where,

a = scaling factor for y-axis, % / length
b = scaling factor for x-axis, time / length

Recognizing that Δy / Δx = tan θ, Eq. (6) transforms into,

$$RR = \frac{\tan q}{\Delta MV}\frac{a}{b} \quad \text{..........} \quad (7)$$

The right hand side of Eq. (7) has just provided an alternative means to analyze the process rate. The scaling factors, a and b, are measurable along the grid guides of the time and response scales, while the slope can be measured by any suitable device or by rough estimation to the nearest degree. In contrast, measurement of ΔPV and Δt are not necessarily available along the grid guides; consequently, leading to an inaccurate result when using the conventional method.

IV. APPLICATION DEVICES

Most instrumentations found in the market today are multi-function e.g. multi-loop control with LCD display. Employing the regular practice of the tangent method to the small-sized LCD display requires a lot of courage and effort. Furthermore, the measurements of ΔPV and Δt would not be accurate. However, the reformulated tangent method can be applied quicker and simpler with these devices. A few types of the multifunction instruments are listed below.

A. Field Controllers

These types of field controllers have LCD's display panel showing the controller's configurations and the process response curve. However, the display panel provides limited grid guides of the time and response scales. Thus, analysis of response curve using the tangent method would be laborious and tedious. But, in the reformulated tangent method, the grid guides are measurable i.e. converting them into appropriate conversions.

A few examples of these field controllers are Yokogawa YS150/170, Hartman&Braun Datavis B, Honeywell UMC800 and Fisher & Porter Micro-DCI 53M5000 models.

B. Paperless Recorders

The paperless recorder performs similar function as the pen recorder but with additional features such as TFT display panel, marker and data logging. Unlike multifunction field controller, the paperless recorder provides grid guides of the time and response scales. The scales are adjustable; consequently, small-sized response curve can be enlarged for better analysis when using the reformulated tangent method.

The paperless recorders are available from most scientific instrument manufacturers that include Cole-Palmer Data Logger 80805, Omega RD820, E&H Eco-Graph, Honeywell VRX100 and Yokogawa VR100.

C. Oscilloscopes and Multimeters

This new version of handheld multimeter combines the capability of oscilloscope, multimeter and paperless recorder. This device is useful in performing PID controller tuning at the place whereby the field controllers are available but not the recorders. One example of this device is the ScopeMeter by Fluke Instruments.

From experience in tuning at the DCS, the difficulty in using the conventional tangent method arise from the inadequate grid guides and improper grid scales, which makes the application of the conventional tangent method more difficult and inaccurate. This inadequacy will be alleviated when employing the reformulated tangent method.

V. EXPERIMENTAL STUDY

A multiple load change test was performed to verify that the reformulated tangent method was indeed easier, simpler and faster in extracting the process characteristics of an openloop response curve.

The control loop consists of a process to control flow of water, a Yokogawa YF100 vortex flowmeter, a Yokogawa YS170 PID controller and a pneumatic control valve with positioner. The process response data was captured using a Yokogawa VR100 paperless recorder.

The multiple load change test was made by making three simple load change consecutively after each other as shown in the Fig. 3 below.

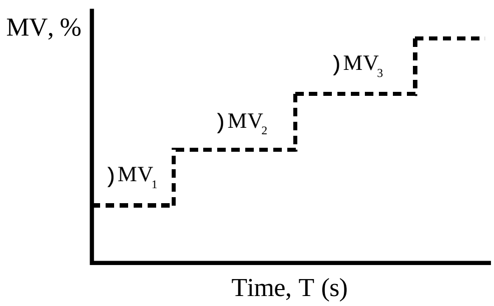

Figure 3: Multiple load change at the controller's output.

The data captured was transferred to a computer and printed on paper for analysis.

The openloop response of the multiple load change test is shown in Fig. 4.

Since, the flow loop was a fast process, then the deadtime, Td, was estimated around 1 s. Based on Fig. 4, the scaling factor for time scale is 10s / 17.5 mm and the scaling factor for response scale is 10% / 17 mm. Tangent lines were drawn and the slopes were measured.

A total of five steps (2 conversion factors + 3 slope measurements) are required to perform the analysis compared to six steps that would be required by the existing tangent method. Furthermore, analysis using the tangent method would need extra effort and time to obtain the exact

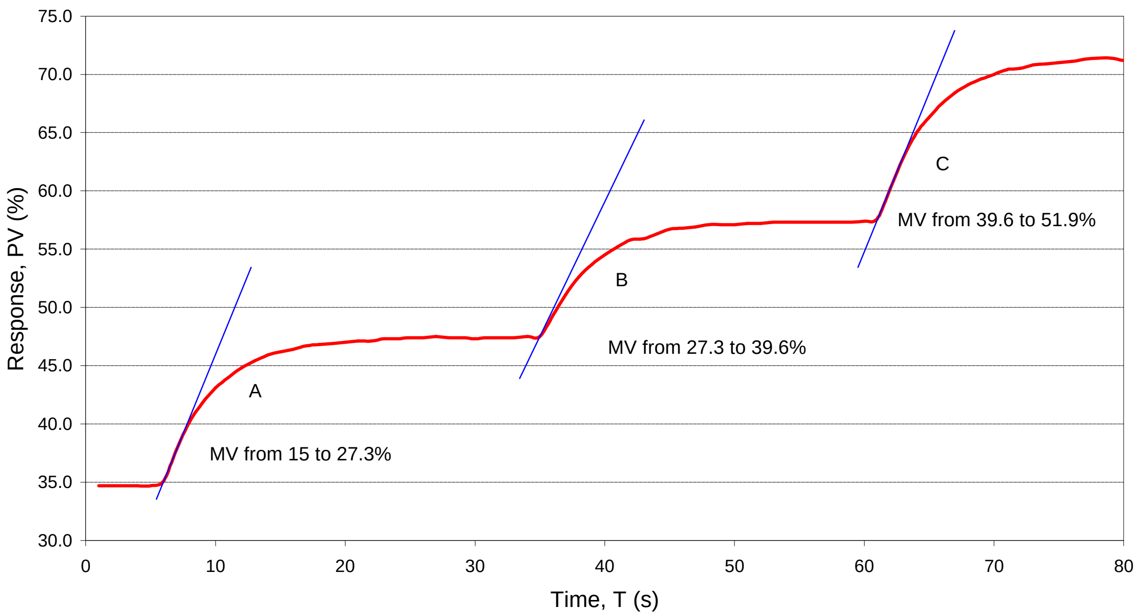

Figure 4: Multiple openloop response curve of the flow control experiment.

values of time for the given responses (PV) due to limited grid guides as in Fig. 4.

Employing Eq. (7), the process rates were calculated. Table 2 below summarized the calculated result.

Table 2: Process characteristics of the flow control experiment.

Response	) MV, %	Slope	RR, 1/s
A	12.3	69°	0.2180
B	12.3	65°	0.1795
C	12.3	68°	0.2071

Then, the optimum PI was calculated using Zieglar-Nichols tuning rule and the result is as shown in Table 3 below.

Table 3: Optimum PI based on Zieglar-Nichols.

Response	P, %	I, s
A	24.2	3.3
B	20.0	3.3
C	23.0	3.3

A conservative value of P = 24.2% and I = 4 s was chosen and set to the controller. A multiple set point change was made to check the validity of P and I values over the process range of 35% to 70%. Figure 5 shows the automatic response of the PI control. Response D and E showed identical responses; thus, one set of P and I constants obtained from the reformulated tangent method produce an optimum control over the entire range.

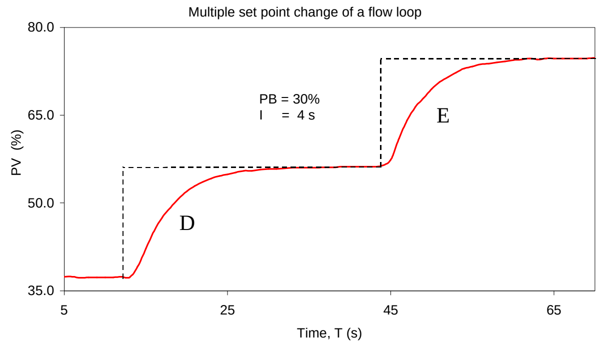

Figure 5: Response curve of the multiple set point test

Finally, when comparing the result between the conventional tangent method and the reformulated tangent method, the response rate, RR, gave close agreement with the existing tangent method and the performance for control as seen above is good enough to justify the use of this reformulated tangent method.

VII. CONCLUSION

The newly reformulated tangent method simplifies the current analysis of process characteristics of the openloop response curve. The number of steps in analyzing the response curve is not only reduced but also the ease and speed of data extraction is improved.

In this study, the use of reformulated tangent method on the paperless recorder output has been demonstrated. However, due to the simplicity in performing the analysis, the scope of applications can be extended to multifunction field controllers, oscilloscopes and multimeters.

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