INPUT WEIGHTING FOR SISO SYSTEM WITH FEEDBACK PID CONTROLLER

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Abstract

This paper describes experimental studies of a regulating and tracking control strategy in which the attempt to improve the system performance is externally issued to the control loop. The control method can be viewed as the input compensating technique. The results illustrate strengths and weaknesses of the method. The method is quite attractive to industrial applications since it introduces minimum disruption to an existing control system.

Key words : PID control, input weighting, tracking, regulating.

The use of PID controllers in industries has been known since 1939 (Bennett, 1994). Conventionally, the controller appears in the feedback loop of the control system. To obtain suitable controller's parameters, one can proceed with available design methods or tuning rules. Mostly the design methods, such as stated in some references (Kuo, 1991; Golten and Verwer, 1991; Dorf, 1992), assume known plant models. The tuning rules, such as stated in references (Ziegler and Nichols, 1942, 1943; Cohen and Coon, 1953), assume known process responses. The controller's parameters obtained from both methods are based on the assumption of time-invariant parameters of certain kinds. In practice, these parameters and the response dynamics may change. The controller's parameters are thus optimum at the beginning of the design or tuning process. If the controller's parameters are not adjusted correspondingly to the plant dynamics, the final response of the control system will be satisfactory only for a certain period of time. There have been several attempts to adjust the controller's parameters on-line according to plant dynamics to keep the process's response at optimum. The methods require an identification of the process's parameters as well as an adjustment of the controller's parameters on-line and real-time. These reflect the need for a dedicated control system. If one has a PID control of a classic type, the methods may not lend themselves to the situation except that the existing control system is redesigned and rewired. Apart from the adaptively automatic adjustment of the controller's parameters as mentioned above, one method usually employed in industries is the manual adjustment of such parameters. In this, an operator monitors the process output and adjusts the controller's parameters accordingly in order to maintain satisfactory time response at all time. It requires an experienced operator and manually adjusted knobs available on the control panel. A difficulty always

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arises when the control system in use is of the fixed parameter type providing an experienced operator is available. One may overcome this difficulty by applying the method introduced by Eitelberg (Eitelberg, 1987). This method suggests fractionalizing of the reference input as illustrated in Figure 1. It also suggests manual adjusting of the input portion from the outside of the control loop. This is practically attractive due to less interruption to the original control system. In Eitelberg's work, there is no detailed discussion on the test against PID controller. Suggestion is made via the illustration on the control system configuration as shown in Figure 1 only. The work presented herein is an extension to cover the case of having a SISO system with a feedback PID controller.

Using the block-diagram algebra, one can easily obtain an equivalent system as shown in Figure 2. Equation (1) expresses the transfer function of this equivalent system.

$$\frac{C(s)}{R(s)} = \frac{G_{mc}(s)G_p(s)}{1+G_c(s)G_p(s)} \qquad (1)$$

where

$G_p(s)$ = plant,
$G_c(s)$ = PID-controller (see equation (4)), and
$G_{mc}(s)$ = modified PID-controller (see equation (5)).

It can be seen that the method is equivalent to using a feedforward PID compensator in conjunction with the original feedback one. However, the original controller is repositioned to be in the feedback path receiving and processing the sensed process output instead of the error signal. The adoption of two controllers ensures the regulating and tracking objectives (Kuo, 1991; Astrom and Wittenmark, 1984). The feedback-path controller plays a vital role in disturbance rejection while the feedforward-path controller is particularly for tracking purposes. This description would give a clear view for the Eitelberg's method. Moreover, the technique can be considered as "zero-placement" method. The equation (1) illustrates that the technique is equivalent to adding zeros to the system transfer function providing the repositioned controller $G_c(s)$. Even though the effects of zeros on a system's response have been recognized for years (Truxal, 1955; MacFarlane and Karcanias 1976; Hang, 1989; Kuo, 1991; Golten and Verwer, 1991; Dorf, 1992), the zero-placement method has not been strongly studied and introduced to industrial uses. However, some control theorists have proposed coupled "pole-zero placement" methods (Hostetter and Santina, 1988; Chen et. al., 1990; 1994) which are different and interesting issues.

The current paper describes the experimental results of applying the Eitelberg's method to control an electronic plant. The counterpart simulation results are presented in the co-paper (Puangdownreong, Sujitjorn and Prempraneerat, 1994). The results presented herein show that the method has promising industrial applications. Implementation can be devised by using various techniques. Finally, the paper points out relevant areas of further research.

Materials and Methods

Experiments were conducted against electronic plants. These plants are first-, second-, and third-order networks built from commercially available op-amps. Figures 3(a) and 3(b) depict the circuit diagrams of the first- and the second-order plants, respectively. For the first-order plant, various resistor combinations provide responses with different time- constants. The description of the plant is

$$\frac{V_{out}(s)}{V_{in}(s)} = \frac{1}{1+\tau s} \qquad (2)$$

where τ = time-constant = RC

R = combination of 4kΩ R(s) and C of 0.01 μF

For the second-order one, similar combinations provide responses with different overshoot, rise time, and settling time. Equation (3) describes this plant.

$$\frac{V_{out}(s)}{V_{in}(s)} = \frac{K\omega^2_n}{s^2 + 2\zeta\omega_n s + \omega} \qquad (3)$$

where

K = $1 + R_f / Rn$,

$\omega_n = \sqrt{1/(R_1R_2C_1C_2)}$, and

$$2\zeta = \sqrt{\frac{R_2C_2}{R_1C1}} + \sqrt{\frac{R_1C_2}{R_2C_1}} + (1\text{-}K)\sqrt{\frac{R_1C_1}{R_2C_2}}$$

(for proof of this transfer function, see appendix). Both can be series connected to provide a third-order plant with various response profiles. One can adjust the resistance knobs made available on the panel to obtain different response profiles from the third-order plant.

The PID controller shown in Figure 1 possesses the transfer function :

$$G_C(s) = K_p + K_i / s + sK_d \quad (4),$$

where

K_p = proportional constant,
K_i = integration constant, and
K_d = derivation constant.

The physical controller of parallel configuration can be realized by using conventional op-amps. The controller's schematic diagram can be found in any standard textbook on control electronics such as that of Jacob (1988). All constants of the controlling elements are adjustable to provide an appropriate controlling signal and, hence, a satisfactorily visualized plant's response. Moreover, this adjusting function can represent the time-varying controller parameters.

The weighting elements F_p, F_i, and F_d shown in the Figure 1 are realized by using conventional op-amps. Each element is implemented in the form of a simple proportional circuit issuing weight in the range of 0 to 100%, the configuration of which is available from a standard textbook (e.g. Jacob, 1988). However, a weighting of greater than 100% may be used. When the control system is equipped with these elements, the modified PID controller as mentioned earlier can be described by

$$G_{mc}(s) = F_pK_p + \frac{F_iK_i}{s} + sF_dK_d \quad (5)$$

The conducted experiments are to investigate the step response of the system since the step input has been commonly accepted as a standard test input both in industrial use and in control theoretic. The square wave input is of 120Hz. This enables a conventional oscilloscope to trace the response signal appropriately. Experimenters turned the knobs on the control panel to obtain responses of any desirable shapes. These knobs are provided for adjusting the plant's dynamic characteristics, the controlling elements (K_s) of the PID - controller and the input weighting elements (F_s). The former two sets represent changes in dynamic parameters of the system due to environmental changes and aging, for instance. The latter represents control efforts to regain a satisfactory response.

Results and Discussion

The experiments were conducted to investigate the effects of adjusting F_p, F_i and F_d on the signals obtained from the P+I+D elements and on the time responses of the system. Firstly, the P+I+D signal is discussed. The curve in figure 4 illustrates the P+I+D signal. Results demonstrate that adjusting F_p to decrease the level of the input signal introduces the following effects: the curve a-b-c-d is shifted downward, the line a-b becomes longer, and the point -c- becomes lower. F_i and F_d are set to 100% while F_p is being adjusted. Adjusting F_i while F_p and F_d remain at 100% results in a change of the slope of line c-d. Decreasing input level via adjusting F_i yields a decrease in the slope of line c-d with point -b- fixed. Adjusting F_d while F_p and F_i remain at 100% affects the slope of a-b. Decreasing the input level via adjusting F_d results in point -a- being shifted downward and hence the slope of a-b being decreased. Changing the portion of the input via F_p, F_i and F_d as mentioned above obviously affects the controlling signal obtained. from the P+I+D controller. This certainly introduces some changes in the system performance which are discussed below.

Observations for the changes in the system performance were conducted under the circumstances of adjusting F_p, F_i and F_d individually. This means that when one of the fractionalizing elements was adjusted to obtain the corresponding output ranging from 0 to 100% the other two elements were maintained at 100% output.

Adjusting F_p solely decreases the magnitude of oscillation in the final system's response. Steady-state error appears noticeably when the signal obtained through F_p is about 40% of its input. At-

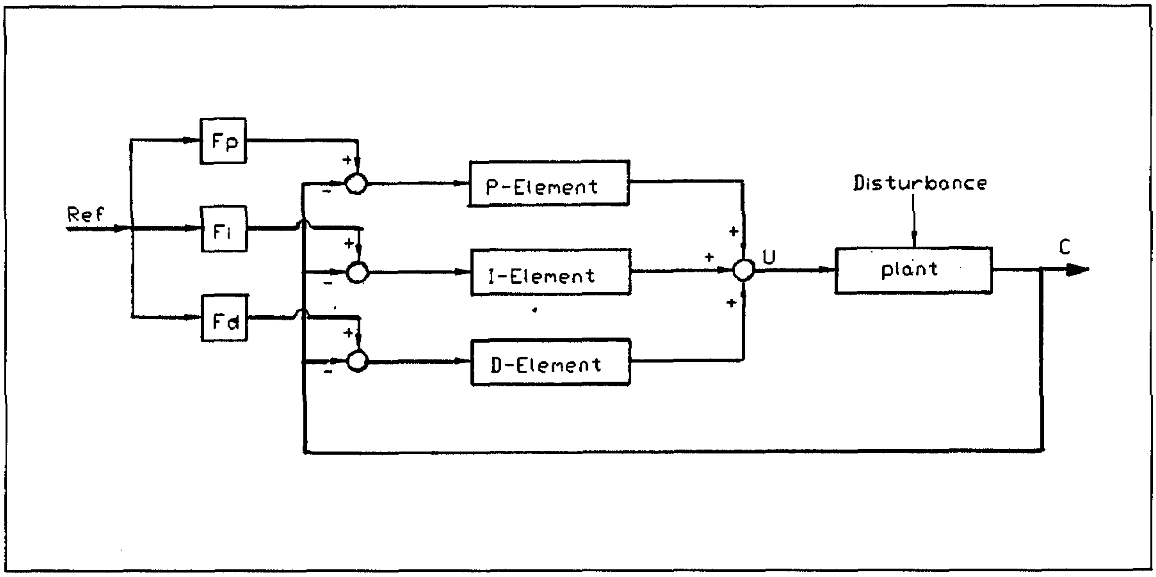

Figure 1. Fractionalizing of the reference input as proposed by Eitelberg in 1987.

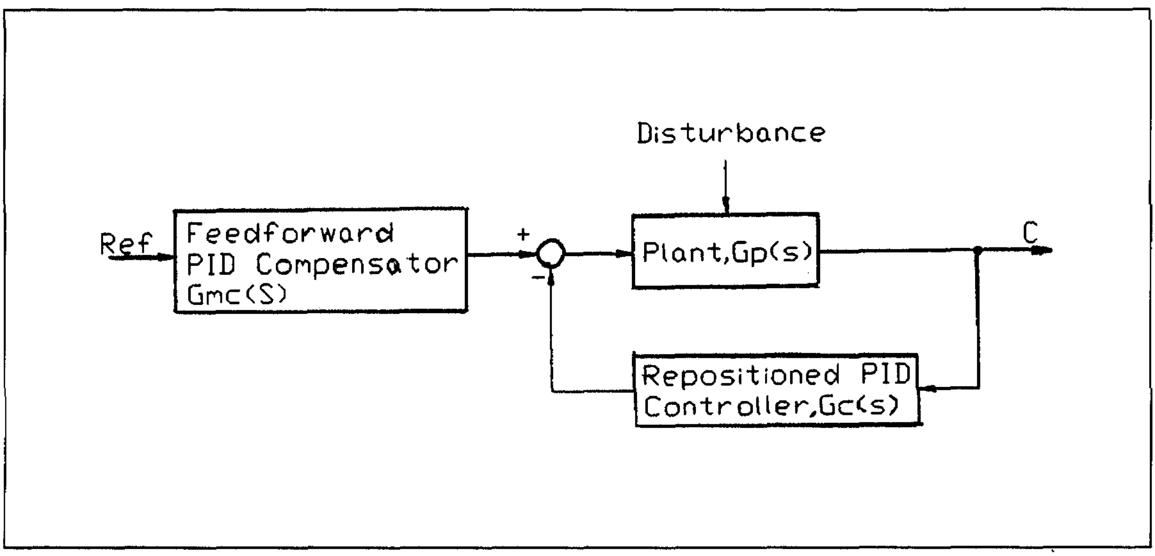

Figure 2. Block diagram illustrating the Eitelberg's method in a clearer view.

tempt to reduce the magnitude of the output signal from F_p beyond this level introduces more steady-state error and longer rise-time to the response. Moreover, the time response exhibits oscillation during the transient period. It is recognized that adjusting F_p yields a downward movement of the positive (+) envelope (see Figure 5) providing no visualized steady-state error.

Adjusting F_p further results in an upward movement of the negative (-) envelope (see Figure 5), a further downward movement of the positive envelope, and a growth in steady-state error. An interpretation of the results is that a lower level of input signal gives an initial kick to the system at its state closer to equilibrium.

Adjusting F_i reduces the swinging-down magnitude of oscillation, i.e. the negative envelope is shifted upward. A drawback is a decrease in the level of steady-state response. It is noticed that F_i should be adjusted to a level of greater than 100% to recover the steady-state response from being decreased by the adjustment of F_p to reduce the magnitude of oscillation. Surprisingly, oscillation grows when F_i is further adjusted to a certain level (F_i's output is about 40% of its input) to reduce the input to the system. The system may become unstable or have sustained oscillation if F_i is further adjusted.

Adjusting F_d does not introduce any significant changes in the system response. This is mainly due to the nature of step input. Therefore, the effects of Fd for various shapes of input waveforms should be further investigated.

Some of the results illustrating effectiveness of the method are shown in Figures 6 and 7. Figures 6(a) and 7(a) show step responses with moderate and high oscillation, respectively. The oscillation in the responses could be reduced by adjusting the fractionalizing parameters properly. The obtained responses are depicted in Figures 6(b) and 7(b), correspondingly.

The results obtained from the experimental and the counterpart simulation studies would lead to several future researches. The authors wish to point out areas of further research as follows :

- The manipulation of input weighting function studied thus far can be automated. One possibility is to model the operator behaviour in fractionalizing the input. In this domain, a fuzzy system is a useful approach to model the human operator. However, an identification of the system is also necessary and can be accomplished in the fuzzy system domain. Thus, the automated input weighting can be viewed as a fuzzy adaptive learning system. (This project is currently supported by the National Electronics and Computer Technology Center under the research contract #048/2537.)

- The automated input weighting function can be implemented alternatively by using the conventional adaptive control system. This needs that would yield dominant the identification of the system transfer function and/or oscillatory poles. The fractions of the input can be adjusted to obtain appropriate zeros' locations to compensate for the oscillatory poles. However, the polezero cancellation method is to be avoided in practice (Clark, 1988; Kuo, 1991).

- The effects of zeros on the system's response should be theoretically studied in further detail. This would lead to practical recommendations for control system design to utilize more on zero-selection for the system transfer function.

- The obtained results show that fractionalizing the input portion fed to the derivative part is ineffective. This would lead to the modified Eitelberg's method in which F_d would be a derivative function in stead of being a common proportioning function. This should be further studied. In addition, the effects of the simple proportioning F_d for various types of inputs, such as ramp, parabolic and step-ramp, should be further investigated.

- Implementation of the method for a real-world problem is also an interesting matter.

This issue is currently being conducted by the authors' team at the King Mongkut's Institute of Technology, Ladgrabang for serving control of a DC motor, at least.

Conclusion

Experimental studies of the regulating and tracking technique introduced by Eitelberg are discussed in this paper. The technique is attractive to industrial use since it requires less disruption to existing processes. For a manual control process,

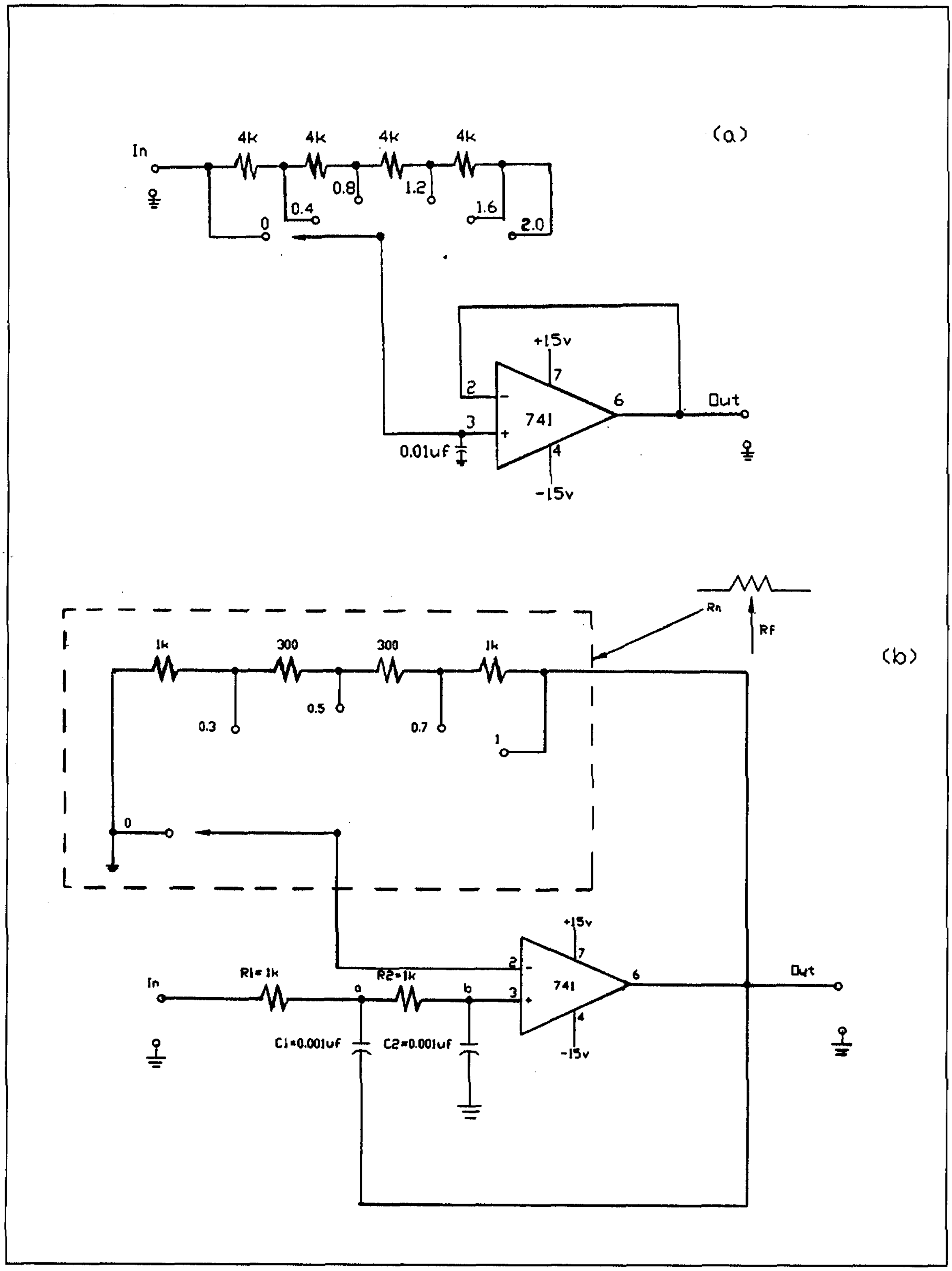

Figure 3. Electronic plants (a) first-order (b) second order.

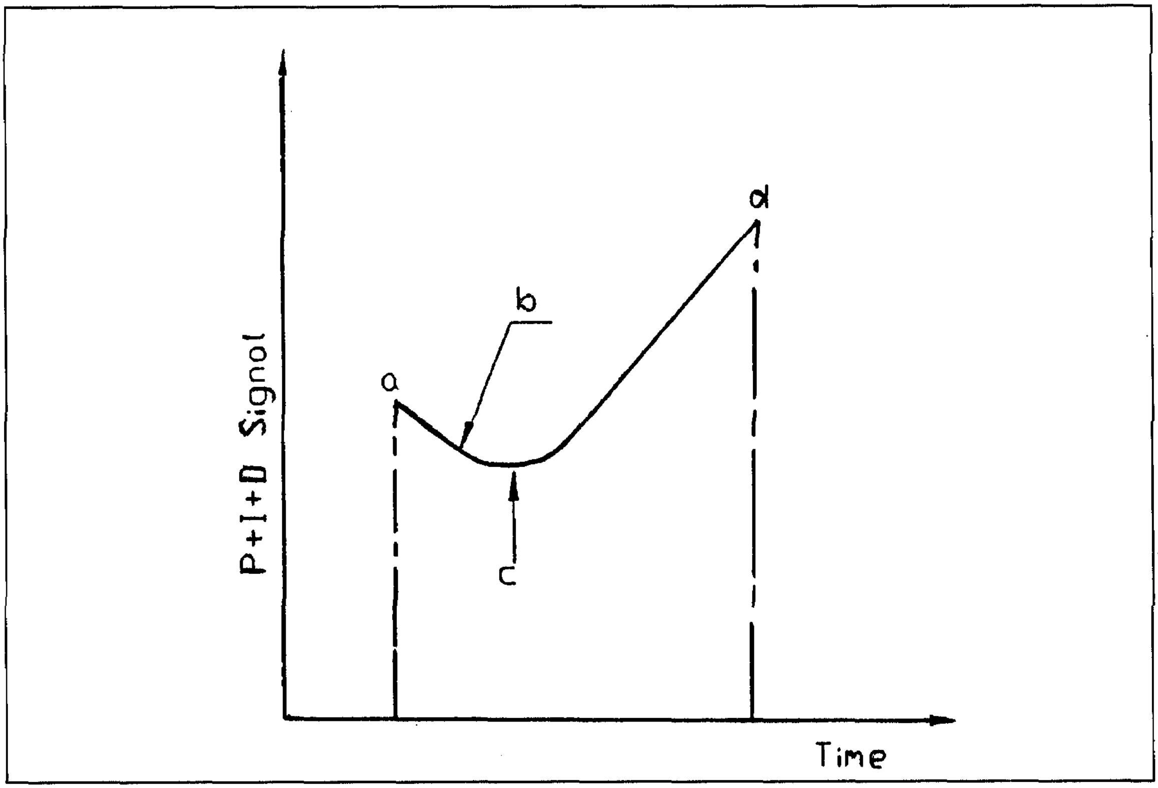

Figure 4. Signal obtained from P+I+D controller.

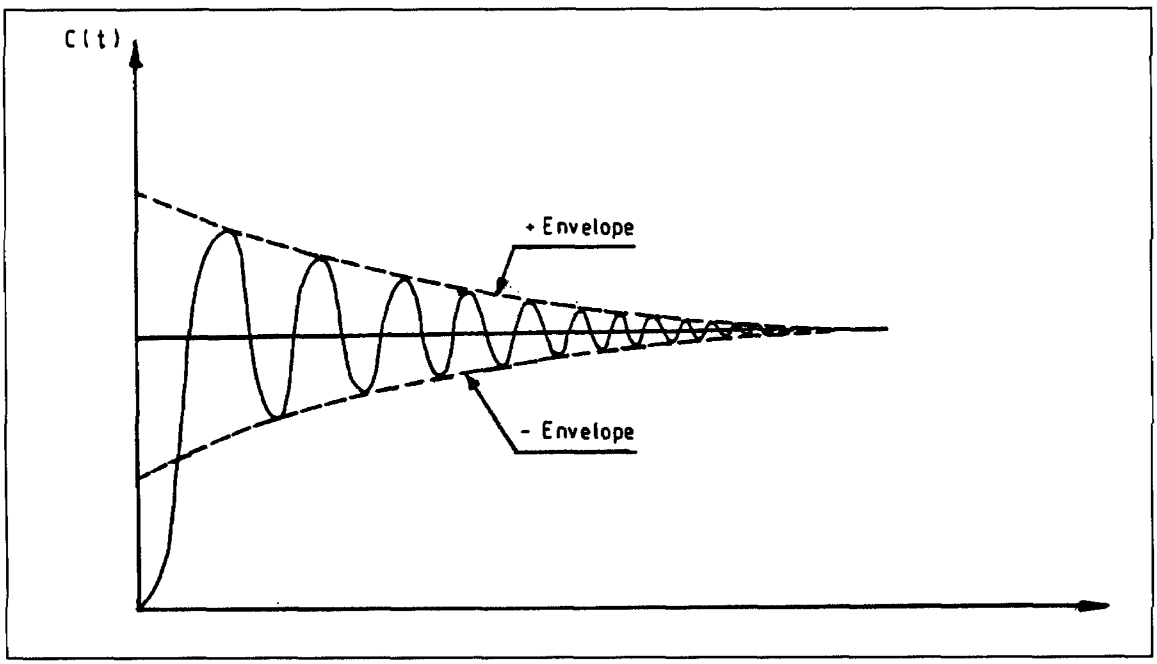

Figure 5. Time-domain response.

Figure 6 (a). Step response before adjusting input level.

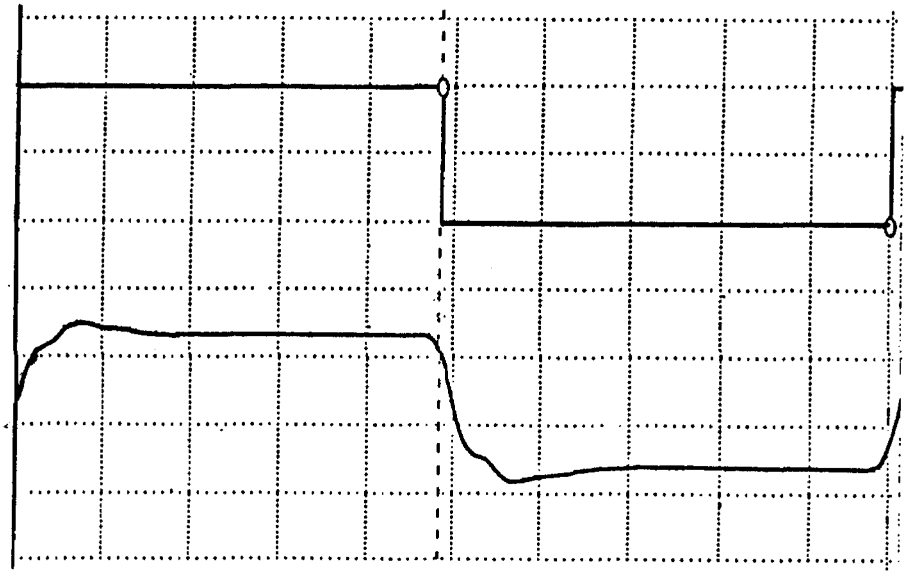

Figure 6 (b). Step response after fractionalizing input signal.

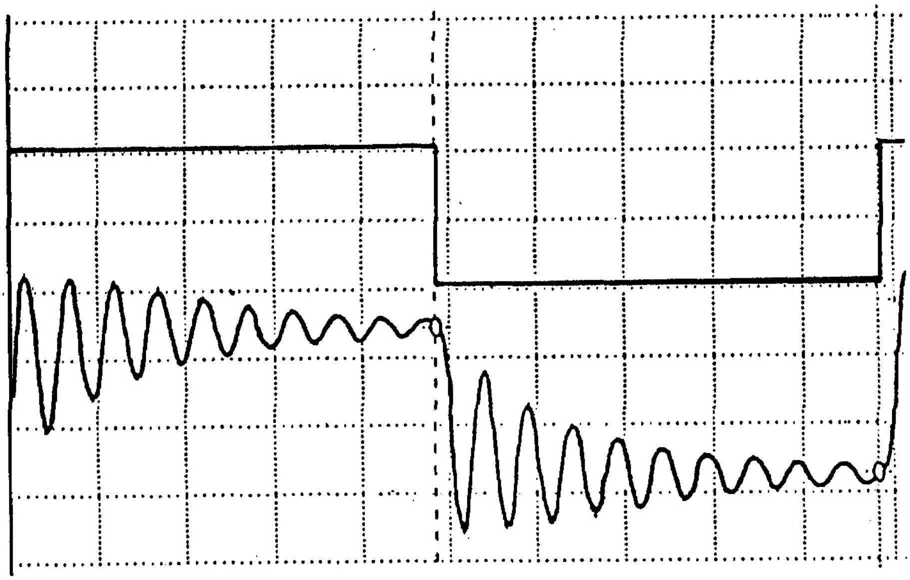

Figure 7 (a). Step response before adjusting input level.

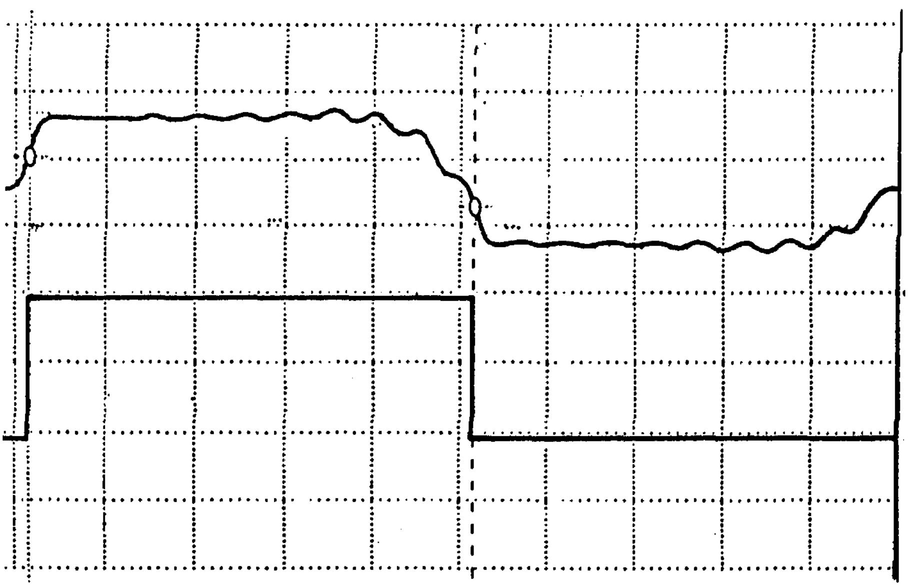

Figure 7 (b). Step response after fractionalizing input signal.

to implement the technique requires appropriate transducers and proportional circuits to provide the input-weighting function that can be operated manually. For an automatic one, it requires a computer with specific software to provide the system identification and the input-weighting functions instead of using analog circuits. In this study, the method demonstrates its capability of successful improvement in system's response. Limitation of the method exists in that it is ineffective to the oscillating frequency of the response. Another attractive feature is that a would-be implemented controller can be coupled externally to an existing system. The disruption introduced to the existing system is minimum.

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Appendix

Referring to Figure 3 :

at node a : $(V_m - V_a) / R_1 + (V_o - V_a)\, C_1 s + (V_b - V_a) / R_2 = 0$ (a.1)

at node b : $(V_b - V_a) / R_2 + V_b C_2 s = 0$ (a.2)

from (a.2), we can obtain $V_a = V_b(R_2C_2 s + 1)$

from the circuit diagram, it is obtained that $V_b = V_o R_n / (R_n + R_f)$

substitute V_a and V_b into (a.1), thus obtain :

$$\frac{V_{in}(s)}{V_o(s)} = \frac{R_n}{R_n + R_f}\left[R_1R_2C_1C_2 s^2 + (R_1C_1 + R_1C_2 + R_2C_2)\, s - \left(\frac{R_n + R_f}{R_n}\right) R_1C_1 s + 1 \quad \text{or}\right]$$

$$\frac{V_o(s)}{V_{in}(s)} = \frac{K}{R_1R_2C_1C_2 s^2 + [(R_2C_2 + R_1C_2) + (1 - K)\, R_1C_1]\, s + 1} \qquad \text{(a.3)}$$

where $K = 1 + R_f/R_n = (R_n + R_f)/R_n$

(a.3) can be rewritten as

$$\frac{V_o(s)}{V_{in}(s)} = \frac{K/R_1R_2C_1C_2}{s^2 + \left[\dfrac{R_2C_2 + R_1C_2 + (1 - K)\, R_1C_1}{R_1R_2C_1C_2}\right] s + \dfrac{1}{R_1R_2C_1C_2}} \qquad \text{(a.4)}$$

from the standard 2nd - order transfer function $\dfrac{\omega_n^2}{s^2 + 2\zeta\omega_n s + \omega_n^2}$, one can deduce from (a.4) that

$$\omega_n = \sqrt{1/(R_1R_2C_1C_2)}, \text{ and}$$

$$2\zeta = \sqrt{\frac{R_2C_2}{R_1C_1}} + \sqrt{\frac{R_1C_2}{R_2C_1}} + (1-K)\sqrt{\frac{R_1C_1}{R_2C_2}}$$