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PID Controller with Enhanced Disturbance Rejection

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Introduction

The Proportional – Integral – Derivative (PID) controllers are the most popular controllers used for process control in industry. This is caused by effectiveness and simplicity of these controllers. One of the main goals of the control system used in industry is the disturbance rejection. The most common disturbances in process control are load disturbances. These low frequency signals are added to the control signal at the process input and drive the system away from its desired operating point. Good rejection of such signals is the first design goal. The situations when the set point response is followed by the positive load disturbances frequently appear in practice of control systems. It is desirable that the overshoot and settling time of the set point response of the control system should be low and at the same time the system should be characterized by the good positive load disturbance rejection. The PID controller provides a relatively good transient performance of the control system. To achieve possibly high load disturbance rejection the integral constant of the PID controller must be maximized [1]. However, often this causes the increase of the overshoot and settling time of the set point response of the control system. Some compromise between the transient performance of the set point response and the load disturbance response can be achieved using appropriate tuning methods of the controller [2, 3] but in the general case the conventional PID controller does not allow us to achieve low overshoot and settling time of the set point response and the best disturbance rejection at the same time. The modification of the PID controller called two degrees of freedom PID [1, 4, 5] allows a good combination of load disturbance rejection and set point response of the control system at the same time. In fact it provides a response to load disturbances that is independent of the dynamics of the set point response. However, the adjustment of this controller to the plant dynamics is more complicated as in case of the conventional PID controller [1]. On the other hand, the practicing engineers in industry prefer the controllers that can be tuned to the plant using commonly known methods developed for conventional PID controllers.

In this work we present the modification of the PID controller with the switched parameters. In comparison with the conventional PID method, the employment of the proposed control algorithm allows us to increase the degree of freedom during tuning of the controller to a plant. This fact enables the positive load disturbance rejection of the control system to be improved not sacrificing the set point response dynamics. The procedure of the controller tuning is the same as that used for the conventional PID controller.

Control system description and problem formulation

We consider the classical closed-loop control system with the unity feedback affected by the load disturbances. The following designations are used: Y_d is the desired (reference) value of the plant parameter, $Y_a(t)$ is the actual value of the plant parameter, $e(t)=Y_d - Y_a(t)$ is the error (controller input), $U(t)$ is the controller output, $D(t)$ is the load disturbance added to the plant input and t is time.

The control system is analyzed with the plants that have the following transfer functions, which present typical dynamics found in industry [1, 6–8]:

$$G_1(s) = \frac{e^{-0.5s}}{(s+1)^2}, \quad (1)$$

$$G_2(s) = \frac{1}{(s+1)^5}, \quad (2)$$

The set point unit step ($Y_d = 1$) response followed by the positive unit load disturbance ($D(t)=1$) of the control system with plants $G_1(s)$ and $G_2(s)$ based on the PID controller with different values of proportional (K_p), integral (K_i) and derivative (K_d) constants is presented in Fig. 1. The dependences were computed using the dynamic system simulation program Simulink. The curves presented by solid lines correspond to the PID controller adjusted to achieve the set point response with low overshoot and settling time. The dependences presented by dashed lines correspond to the controller tuned to the good load disturbance rejection. It is seen that improvement of the set point response worsens the load disturbance rejection and vice versa. This clearly demonstrates the limitation of the conventional PID controller, which is caused by the fact that the same parameters of the controller are responsible for dynamics of the control system during the set point response and positive load disturbance response. In other words, it has low degree of freedom during tuning.

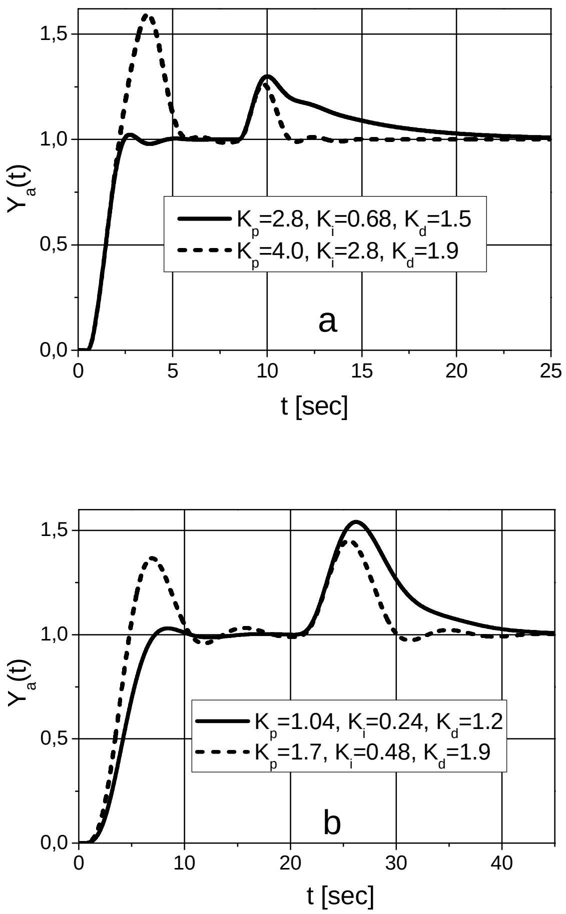

Fig. 1. Unit set point step response followed by positive unit load disturbance of the control system with plants $G_1(s)$ (a) and $G_2(s)$ (b) based on the PID controller with different values of parameters

PID controller with the enhanced load disturbance rejection

Analysis of the $e(t)$ variation during the set point response followed by the positive load disturbance of the control system shows that during the set point response $e(t)$ is predominantly positive and during the positive load disturbance – negative. Consequently, the sign of $e(t)$ can be used as some indicator for approximate estimation of the control system state. Knowing that the values of K_p, K_i and K_d that provide the low overshoot and settling time of the set point response and the good positive load disturbance rejection are different (Fig. 1), it is logical to commute these values when $e(t)$ changes the sign, i.e. to use a PID controller with the switched parameters. The control algorithm of the PID controller with the enhanced load disturbance rejection, which has switched parameters, can be presented as follows:

$$\begin{cases} U(t) = K_{\mathrm{p}}(t)\, e(t) + \int_{t_0}^{t} K_{\mathrm{i}}(\tau)\, e(\tau)\, d\tau + K_{\mathrm{d}}(t) \dfrac{de(t)}{dt}, \\ K_{\mathrm{p}}(t) = K_{\mathrm{pp}},\ K_{\mathrm{i}}(\tau) = K_{\mathrm{ip}},\ K_{\mathrm{d}}(t) = K_{\mathrm{dp}} \mid e(t) \ge 0, \\ K_{\mathrm{p}}(t) = K_{\mathrm{pn}},\ K_{\mathrm{i}}(\tau) = K_{\mathrm{in}},\ K_{\mathrm{d}}(t) = K_{\mathrm{dn}} \mid e(t) < 0, \end{cases} \quad (3)$$

where K_{pp}, K_{ip}, K_{dp} and K_{pn}, K_{in}, K_{dn} are proportional, integral and derivative constants that act at positive and at negative $e(t)$, respectively, t_0 is point in time at which the algorithm starts to operate.

During the set point step response, K_{pp}, K_{ip} and K_{dp}, that act at positive $e(t)$, have a decisive influence on dynamics of the control system in the algorithm presented by (3). On the other hand, during the positive load disturbance ($D(t)$ >0) response the K_{pn}, K_{in} and K_{dn}, that are involved at negative $e(t)$, become crucial. This means that K_{pp}, K_{ip} and K_{dp} predominantly influence the transient of the set point response and K_{pn}, K_{in} and K_{dn} – the positive load disturbance rejection. Consequently, the employment of the PID controller with the switched parameters in comparison with the conventional PID allows us to increase the degree of freedom during tuning of the controller to the plant. The values of K_{pp}, K_{ip}, K_{dp} should be chosen according to the requirements for dynamics of the set point response and K_{pn}, K_{in}, K_{dn} – to provide good rejection of the positive load disturbance.

Investigation of the controller

The set point unit step response followed by the positive unit load disturbance of the control system with plants $G_1(s)$ and $G_2(s)$ based on PID controller with the switched parameters and conventional PID controller was simulated. It is seen (Fig. 2) that employment of the PID controller with the switched parameters allows us to improve the positive load disturbance rejection of the analyzed control system as compared with the case when the system is based on the conventional PID controller adjusted to low overshoot and settling time of the set point response. On the other hand, it is evident that the transient of the set point response of the control system based on PID controller with the switched parameters and conventional PID controller is practically the same (Fig.2). Consequently, during the set point response the PID controller with the switched parameters behaves in a similar way as PID adjusted to low overshoot and settling time of the set point response and during the positive load disturbance – as the PID tuned to good rejection of the positive load disturbance (compare curves presented in Figs. 1 and 2). The parameters of conventional PID controller and PID controller with the switched parameters used for simulation are presented in Fig. 2.

The PID controller with the switched parameters has six parameters and therefore, it seems that tuning of the controller to a concrete plant can be complicated. However, the parameters K_{pp}, K_{ip} and K_{dp} predominantly influence the set point response and K_{pn}, K_{in} and K_{dn} – the positive load disturbance response, consequently, the problem of tuning splits into two separate tuning problems. The values of K_{pp}, K_{ip} and K_{dp} should be chosen according to the requirements for dynamics of the set point response and K_{pn}, K_{in} and K_{dn} – to provide good rejection of the positive load disturbance.

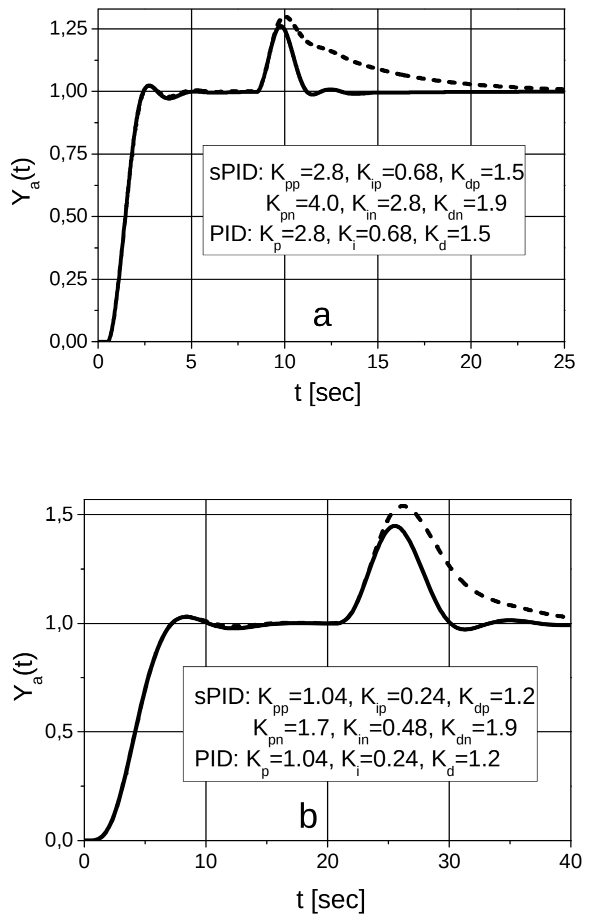

Fig. 2. Unit set point step response followed by the positive unit load disturbance of the control system with plants $G_1(s)$ (a) and $G_2(s)$ (b) based on PID controller with the switched parameters (sPID) (solid line) and conventional PID controller (dashed line)

The parameters of every group are tuned to the plant using methods developed for the conventional PID controllers.

Since the plant can be affected not only by the positive load disturbance but by the negative one as well, the negative load disturbance ($D(t)$ < 0) response of the control system based on the PID controller with the switched parameters was analyzed. For this purpose the unit step response followed by the negative unit load disturbance ($D(t)$ = –1) of the control system with plants $G_1(s)$ and $G_2(s)$ based on PID controller with the switched parameters and conventional PID was computed. Simulation was provided for controllers with parameters given in Fig. 2.

The investigation shows that in case of the set point response followed by the negative load disturbance the transient of the control system based on the PID controller with the switched parameters coincides with the transient of the corresponding control system based on the PID controller adjusted to low overshoot and settling time of the set point response (Fig. 3), i.e. in case of the negative load disturbance the PID controller with the switched parameters does not have advantage over the conventional PID controller.

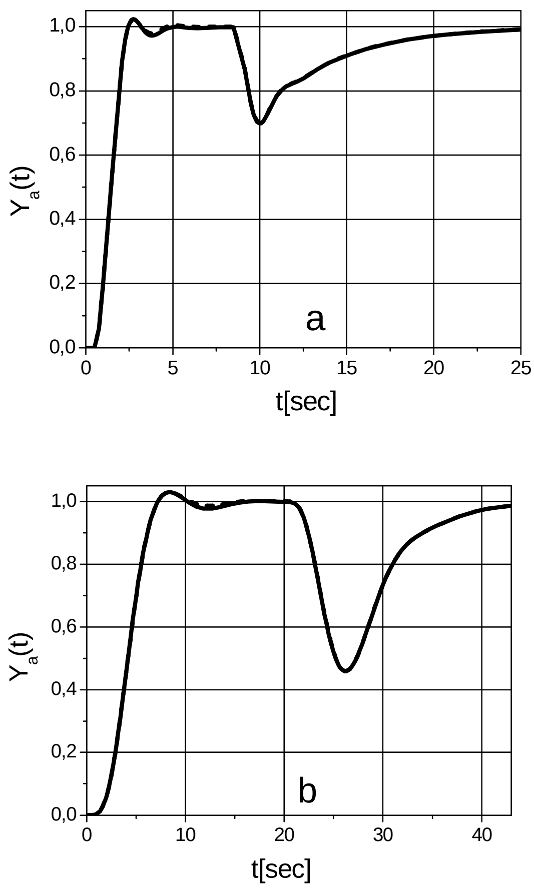

Fig. 3. Unit set point step response followed by the negative unit load disturbance of the control system with plants $G_1(s)$ (a) and $G_2(s)$ (b) based on PID controller with the switched parameters (solid line) and conventional PID controller (dashed line)

Conclusions

The conventional PID controller has low degree of freedom during tuning. This is caused by the fact that the same parameters of the controller are responsible for dynamics of the control system during the set point response and the load disturbance response. Therefore, the conventional PID controller cannot guarantee low overshoot and settling time of the set point response of the control system and the good load disturbance rejection at the same time.

In comparison with the conventional PID controller, employment of the proposed PID controller with the enhanced load disturbance rejection allows us to increase the degree of freedom during tuning of the controller to the plant. This enables the positive load disturbance rejection of the analyzed control system to be improved not sacrificing the set point response dynamics.

In case of the negative load disturbance the PID controller with the enhanced load disturbance rejection does not have advantage over the conventional PID controller.

Acknowledgements

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V. Zlosnikas, A. Baškys. PID Controller with Enhanced Disturbance Rejection // Electronics and Electrical Engineering. – Kaunas: Technologija, 2008. – No. 5(85). – P. 65–68.

The Proportional – Integral – Derivative (PID) controller with the enhanced load disturbance rejection has been suggested. The algorithm of control in this controller employs different values of controller parameters during the set point change response and load disturbance response of the control system. The controller parameters are switched when the sign of the error changes. This feature allows us to increase the degree of freedom during tuning of the controller to the plant. The tuning technique of the controller is the same as that used for the conventional PID controller. The results of the investigation of the concrete control system based on the developed controller show that proposed PID controller in contrast to the conventional one allows us to improve the positive load disturbance rejection of the control system not sacrificing the set point response dynamics. In case of the negative load disturbance the proposed modification of the PID controller does not have advantage over the conventional PID. Ill. 3, bibl. 8 (in English; summaries in English, Russian and Lithuanian).

В. Злосникас, А. Башкис. ПИД регулятор с повышенной компенсацией возмущения объекта управления // Электроника и электротехника. – Каунас: Технология, 2008. – № 5(85). – С. 65–68.

Предложен пропорционально–интегральный–дифференциальный (ПИД) регулятор с повышенной компенсацией возмущения объекта управления. Алгоритм управления, применяемый в регуляторе, использует разные значения параметров регулятора при реакции системы управления на изменение входного сигнала и при реакции на возмущение объекта управления. Значения параметров регулятора изменяются при изменении знака ошибки управления. Эта особенность регулятора позволяет увеличить степень свободы при его настройке к объекту управления. Методика настройки разработанного регулятора такая же как и классического ПИД регулятора. Результаты исследования конкретной системы управления показывают, что предлагаемый регулятор, в противоположности классическому ПИД регулятору, позволяет улучшить компенсацию положительного возмущения объекта управления, не ухудшая динамики реакции системы на входной сигнал. В случае отрицательного возмущения объекта управления, предлагаемый регулятор не имеет преимущества перед классическим ПИД регулятором. Ил. 3, библ. 8 (на английском языке; рефераты на английском, русском и литовском яз.).

V. Zlosnikas, A. Baškys. Valdomojo objekto trikdžius geriau kompensuojantis PID reguliatorius // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2008. – Nr. 5(85). – P. 65–68.

Pasiūlytas valdomojo objekto trikdžius kompensuojantis proporcinis–integrinis–diferencinis (PID) reguliatorius. Reguliatoriuje, pritaikytame valdymo algoritme, naudojamos skirtingos valdymo sistemos atsako į nuostato pokytį ir atsako į valdomojo objekto trikdžius parametrų vertės. Reguliatoriaus parametrų vertės yra pakeičiamos keičiantis valdomojo dydžio nuokrypio ženklui. Ši reguliatoriaus savybė leidžia pasiekti aukštesnį laisvės laipsnį derinant reguliatorių prie valdomojo objekto. Pasiūlyto reguliatoriaus parametrų derinimo metodika yra tokia pat kaip ir klasikinio PID reguliatoriaus. Konkrečios valdymo sistemos tyrimų rezultatai rodo, kad siūlomas reguliatorius, priešingai nei klasikinis PID reguliatorius, pagerina valdomojo objekto teigiamųjų trikdžių kompensavimą, nepablogindamas valdymo sistemos atsako į nuostato pokytį dinamikos. Kompensuojant neigiamuosius valdomojo objekto trikdžius, pasiūlytasis reguliatorius nėra pranašesnis už klasikinį PID reguliatorių. Il. 3, bibl. 8 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).