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Integral Controller for the Plants with the Asymmetric Dynamics

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Introduction

The plants with the asymmetric dynamics are often met in mechatronic systems. The characteristic feature of these plants is that the dynamics of the rise and decay of the plant output parameter $Y_a(t)$ is different. However, typically the theory of automatic control deals with the plants that are characterized by the symmetric dynamics [1] and there are very few contributions devoted to this specific topic. Some material dedicated to control of plants with the asymmetric dynamics can be found in [2-5].

The parameters of transfer function of the plant with the asymmetric dynamics change when the sign of the $Y_a(t)$ time derivative $dY_a(t)/dt$ changes. Therefore, the classical controllers with the constant parameters do not allow us to achieve good transient performance of the control of the mechatronic system in such a case. The employment of the controllers with the switched parameters improves the transient performance of the control system. For example, the Proportional - Integral - Derivative (PID) controller with the switched parameters presented in [4] allows us to achieve good transient performance of the control system with the plants that are characterized by the asymmetric dynamics. However, in practice there are situations when on the one hand, the duration of the response transient is nonessential and on the other hand, the simple easily adjustable to the plant dynamics and electromagnetic disturbance (EMD) compatible controller is needed. In such a case, the Integral (I) controller can be used. It provides the zero steady-state error, it can be robust [6] and is not sensitive to the influence of the EMD [7].

In this work we present the modification of the I controller developed for plants with the asymmetric dynamics. The developed controller enables achieving reasonable transient performance of the control system with the analyzed plant and it is characterized by good EMD compatibility and has only two parameters for adjusting the controller to the dynamics of the plant.

Problem Formulation

Let us assume that the plant in the analyzed control system is characterized by the asymmetric dynamics and can be presented by the following first-order transfer function with dead time:

$$G_1(s) = \frac{e^{-2s}}{b\,s+1}, \quad b = \begin{cases} 7, & dY_a(t)/dt \geq 0, \\ 2, & dY_a(t)/dt < 0, \end{cases} \qquad (1)$$

where *s* is the Laplace variable.

It is seen from (1) that the value of the plant transfer function parameter *b* changes when the sign of the derivative $dY_a(t)/dt$ changes, i.e. the plant has different dynamics during the rise and decay of $Y_a(t)$.

It is necessary to stress that the simulation of the plant with the asymmetric dynamics using a standard transfer function blocks of the generally accepted program Simulink is complicated. The problem is that it is impossible to switch the value of the parameter *b* in (1) during the process of simulation. It may appear that such a plant could be realized by employment of the network that contains two transfer function blocks with different *b* values and a switch, which depending on the $dY_a(t)/dt$ sign commutes the outputs of blocks. However, this way of problem solution is not correct. The reason is that in the general case the values of outputs of transfer function blocks are not the same at the switching moment and this causes the jump of $Y_a(t)$ [4], which in fact does not exist. Because of this, the generally used electronic circuit simulation program Spice was applied to the investigation. This program has all the elements that are necessary for simulation of the control system dynamics.

Using RC networks with the variable R value in the program Spice allows us to develop the models of plants with the asymmetric dynamics that guarantee the smooth transient of the plant response, which corresponds to the actual transient of plants [4].

By applying the program Spice, the closed control system (Fig.1) with the plant $G_1(s)$ and a classical I controller was investigated. The Y_d value in Fig.1 is a desired (reference) value of the plant parameter, $e(t)=Y_d - Y_a(t)$ is the error (controller input), $U(t)$ is the controller output, $U_P(t)$ is the plant input, $N(t)$ is noise produced by EMD and $D(t)$ is the load disturbance. It is of interest to analyze the positive and negative set point step response. For this purpose the unit set point step response (Y_d =1) followed by the Y_d drop (Y_d =0.5) of the control system was simulated in the case when *D(t), N(t)* =0. The obtained results for different values of the controller parameter (integral constant (K_i)) are presented in Fig.2. The dependences are calculated for the cases when K_i is adjusted to dynamics of the plant transfer function associated with b = 2 and b = 7. It is seen (Fig.2) that the I controller provides a good positive and negative set point step response if the controller parameter K_i is in agreement with the plant dynamics. For example, the I controller adjusted to dynamics of the plant transfer function associated with b = 2 gives short settling time (t_S) and low overshoot (M_S) of the negative set point step response of the control system (Fig. 2, dashed line). However, unacceptably high M_S in such a case characterizes the positive set point step response. On the other hand, the I controller adjusted to dynamics of the plant transfer function associated with b = 7 guarantees low M_S of the positive set point step response but gives unacceptably long t_S of the negative set point step response (Fig. 2, solid line).

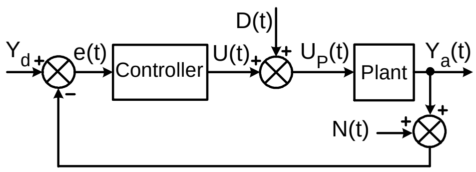

Fig. 1. Block diagram of the control system

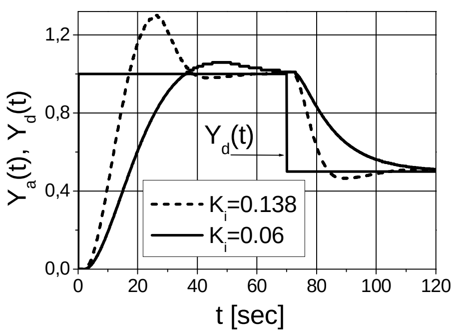

Fig. 2. The unit set point step response followed by the Y_d drop of the control system with the plant $G_1(s)$ based on the I controller adjusted to dynamics of the plant associated with b = 2 (dashed line) and b = 7 (solid line)

The investigation results presented above show that in case of control of the plant with the asymmetric dynamics $G_1(s)$, the classical I controller cannot provide short t_S and low M_S of the positive and negative set point step response at the same time.

Asymmetric integral controller

Knowing that the value of the controller parameter K_i that provides short t_S and low M_S of the positive and negative set point step response is different (Fig.2), it is logical to commute it. The problem is how to estimate the moments when K_i should be switched. The sign of $dY_a(t)/dt$ could be one of possible criteria. However, in case of plants with the dead time the response of $Y_a(t)$ and consequently the response of $dY_a(t)/dt$ are delayed. Because of this, the value of K_i would also be switched with the delay, and the behavior of the control system during the delay period would be determined by the previous value of K_i, which is determined by the previous situation. This can cause increased uncertainty of the control system operation.

The variation of Y_d changes the value of *e(t)* without delay. During the positive set point step response, *e(t)* is predominantly positive and during the negative set point step response – negative. Consequently, the sign of *e(t)* could be considered as an indicator for estimation of the control system state and K_i should be switched at instants when the sign of *e(t)* changes. By employing this idea, the I control algorithm, which uses different values of K_i at positive and negative *e(t)*, can be presented as follows:

$$U(t)=\int_{t_0}^{t} K_i(\tau)\, e(\tau)\, d\tau, \quad \left| \begin{array}{l} K_i(\tau)=K_{ip},\ \ e(t)\geq 0\ , \\ K_i(\tau)=K_{in},\ \ e(t)<0\ , \end{array} \right. \qquad (2)$$

where K_{ip}, and K_{in} are the values of K_i that act at positive and negative *e(t)*, respectively, t_0 is the point in time at which the algorithm starts to operate. The K_i changes its discrete value at instants in time when *e(t)* changes the sign. Therefore, it is time-dependent in algorithm (2), i.e. in fact, it is not constant.

The impact of the I controller based on algorithm (2) on the plant is different at positive and negative *e(t)* in the general case, i.e. it is asymmetric. Because of this, the controller with this property can be called the asymmetric I (aI) controller.

The unit set point step response followed by the Y_d drop (Y_d =0.5) of the control system (Fig.1) with the plant $G_1(s)$, based on the aI controller, is presented in Fig. 3. The results are obtained on condition that *D(t), N(t)* =0. It is seen that the employment of the aI controller in comparison with the I controller allows us to achieve short t_S and low M_S of the positive and negative set point step response at the same time (compare dependences presented in Figs. 3 and 2). This is possible because during the positive set point step response the $dY_a(t)/dt$ is predominantly positive and the behavior of the control system is determined by the controller parameter K_{ip} that is adjusted to dynamics of the plant associated with $dY_a(t)/dt \geq 0$. On the other hand, during the negative set point step response the $dY_a(t)/dt$ is mainly negative and the transient of the control system is

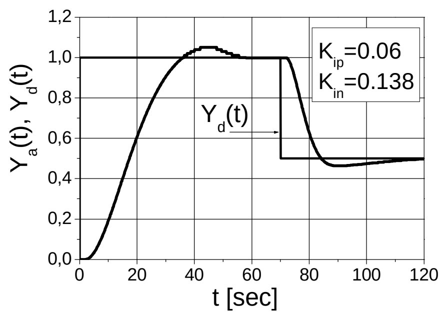

Fig. 3. The unit set point step response followed by the Y_d drop of the control system with the plant $G_1(s)$ based on the aI controller

determined by the parameter K_{in} that is tuned to dynamics of the plant associated with $dY_a(t)/dt < 0$.

It is of interest to investigate the load disturbance response of the control system. For this purpose the unit set point step response followed by the positive ($D(t)$ = 1) and negative ($D(t)$= -1) unit load disturbances of the control system (Fig. 1) with the plant $G_1(s)$ based on I and aI controllers with parameters given in Figs. 2 and 3 was investigated on condition that $N(t)$ =0. The results of investigation are presented in Fig. 4. They show that the control system based on the aI controller operates stably under the influence of the analyzed load disturbances. In case shown in Fig.4c it operates more stably than using the I controller. The employment of the aI controller instead of the I controller does not worsen the load disturbance rejection of the analyzed control system, moreover in the situation presented in Fig.4b it allows improving this characteristic.

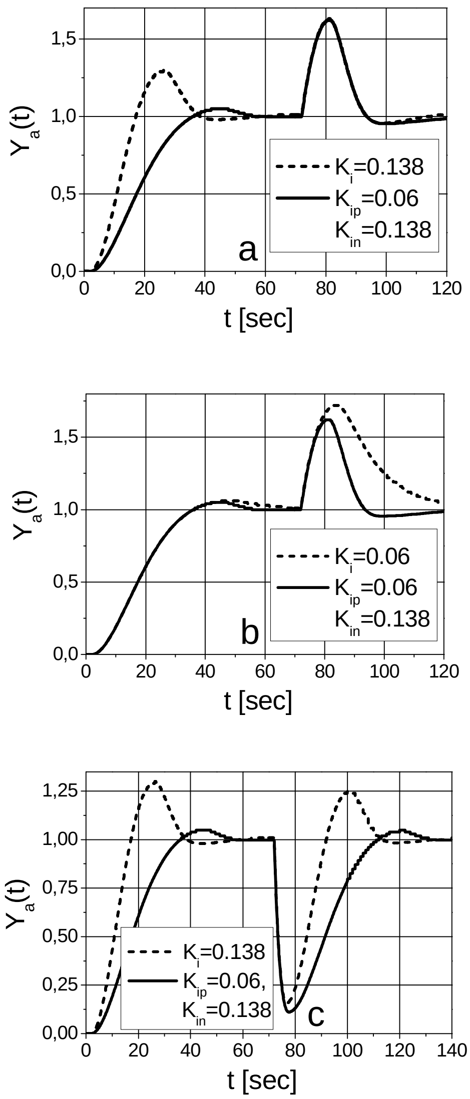

Fig. 4. Unit set point step response followed by the positive (a, b) and negative (c) unit load disturbances of the control system with the plant $G_1(s)$ based on I (dashed line) and aI (solid line) controllers. The I controller is adjusted to dynamics of the plant associated with $b = 2$ (a, c) and $b = 7$ (b)

The actual controllers used in industry often operate in the environment of high electromagnetic disturbances (EMD). The EMD compatibility of the controller depends not only on the design but also on the control algorithm used. One of the advantages of the I control algorithms is that controllers based on the pure integral control method provide higher EMD compatibility as compared to the controllers that include Proportional and Derivative terms.

The unit set point step response followed by the Y_d drop of the control system (Fig.1) with the plant $G_1(s)$ was simulated for the case when the sinus noise $N(t)$ with the amplitude of 0.05 and frequency of 50 Hz produced by the EMD sums up with the feedback signal of the analyzed control system (Fig.1). The investigation was performed for the case when the aI and asymmetric PID (aPID) [4] controllers are used on condition that $D(t)$ =0. The results are presented in Fig. 5. It is seen that the noise practically does not affect the transient of the control system based on the aI controller (Fig 5a). However, the control system based on the aPID controller operates not stably in such a case (Fig 5b). On the other hand, the results presented in Fig. 5 reveal the drawback of the proposed aI controller – long settling time of $Y_a(t)$ as compared to the case when the aPID controller is used and controllers are not affected by the EMD (Figs. 5a and 5b, solid lines). Because of this, the aI controller should be employed for control of the plants with the asymmetric dynamics in case when the duration of the response transient is nonessential but the easily adjustable and EMD compatible controller is needed.

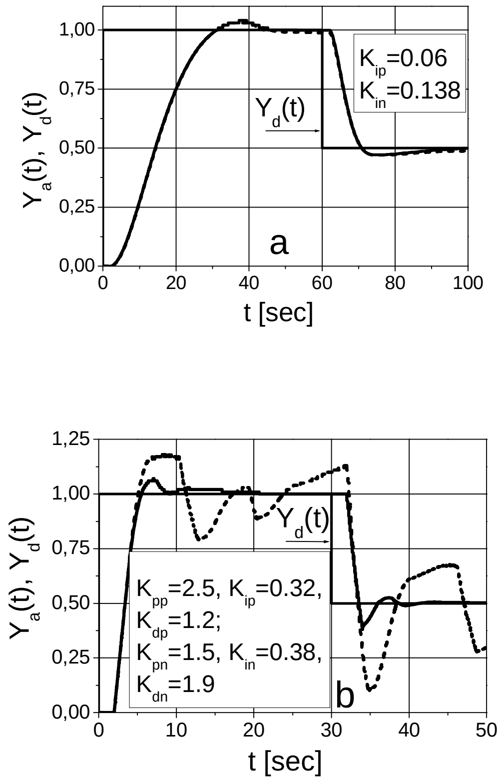

Fig. 5. The unit set point step response followed by the Y_d drop of the control system with the plant $G_1(s)$ based on the aI (a) and aPID (b) controllers affected by the sinus noise (dashed line) and not effected by noise (solid line) (the amplitude of noise 0.05, frequency 50 Hz; the parameters of the aPID controller with the index p act at positive values of $e(t)$ and with the index n – at negative values)

Conclusions

The simulation results show that application of the proposed aI controller in respect of the I controller enables improving the transient performance of the analyzed control system with the plant that is characterized by the asymmetric dynamics.

The aI controller should be employed for control of the plants with the asymmetric dynamics in case when the duration of the response transient is nonessential but the easily adjustable and EMD compatible controller is needed.

Acknowledgements

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The modification of the Integral controller adapted for control of plants with the asymmetric dynamics is presented. A feature of analyzed plants is that the dynamics of the plant output parameter during the rise and decay is different. The algorithm used in the proposed controller switches the value of integral constant of the controller when the sign of the error changes. This feature enables achieving improved transient performance of the analyzed control system as compared to the case when the classical Integral controller is used. The proposed controller is characterized by higher electromagnetic disturbance compatibility as compared to the asymmetric controllers that include Proportional and Derivative terms. The investigation of the control system based on the developed controller was performed using the electronic circuit simulation program Spice. Ill. 5, bibl. 7 (in English; summaries in English, Russian and Lithuanian).

В. Злосникас, А. Башкис. Интегральный регулятор для объектов управления с несимметричной динамикой // Электроника и электротехника. – Каунас: Технология, 2008. – № 1(81). – С. 15–18.

Представлена модификация интегрального регулятора, разработанного для объектов управления с несимметричной динамикой. Отличительная особенность анализируемого объекта управления в том, что динамика объекта при увеличении и уменьшении управляемого параметра является разной. Алгоритм в предлагаемом регуляторе дискретно меняет значение интегральной постоянной при изменении знака ошибки управления. Это позволяет улучшить параметры переходных процессов системы управления по сравнению со случаем, когда применяется классический интегральный регулятор. Предлагаемый регулятор также имеет более высокую помехоустойчивость по сравнению с несимметричными регуляторами, включающими пропорциональное и дифференциальное звенья. Исследование системы управления с разработанным регулятором производилось при помощи программы моделирования электронных схем Spice. Ил. 5, библ. 7 (на английском языке; рефераты на английском, русском и литовском яз.).

V. Zlosnikas, A. Baškys. Valdomųjų asimetrinės dinamikos objektų integralinis reguliatorius // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2008. – No. 1(81). – P. 15–18.

Pristatomas modifikuotas integralinis reguliatorius, skirtas asimetrinės dinamikos objektams valdyti. Valdomieji asimetrinės dinamikos objektai pasižymi tuo, kad valdomajam parametrui didėjant ir mažėjant jų dinamika yra skirtinga. Algoritmas, naudojamas siūlomame reguliatoriuje, diskretiškai keičia integravimo koeficiento vertę, keičiantis valdymo paklaidos ženklui. Tai leidžia pagerinti valdymo sistemos su objektais, turinčiais asimetrine dinamiką, pereinamųjų procesų parametrus, palyginti su tuo atveju, kai naudojamas klasikinis integralinis reguliatorius. Siūlomas reguliatorius taip pat pasižymi didesniu atsparumu elektromagnetiniams trukdžiams nei asimetriniai reguliatoriai, turintys proporcingąją ir diferencijuojančiąją grandis. Valdymo sistema su siūlomu reguliatoriumi buvo tiriama elektroninių schemų modeliavimo programa Spice. Il. 5, bibl. 7 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).