Control Loop with Rejection Attenuation

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Abstract **– The present article deals with the technical design of a control loop with rejection attenuation, and it is mostly intending for devices with automatic control of a physical parameter, providing that the controlled system is a device with the oscillating, and little damped response. The article presents the theoretical framework for control loops, mathematical expression of adjustable parameters of controllers, as well as new technical design.**

Keywords **– Control Loop, Response, Controller, Attenuation, Technical Parameters.**

1. Introduction

In the currently applied technical design, control loops for various physical parameters (position, angular velocity, temperature, etc.) are designed so that the outputs of the controlled system are connected to sensors which send their signals to the controller and subsequently, on the basis of the comparison thereof to the desired values of relevant parameters. The controller generates a signal in the controlling element of the controller and sends it to the actuator.

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The output of the actuator is the actuating signal which then represents the input for the controlled system; the output of such system is the controlled parameter or other potential outputs characterising the status of the controlled system. The inputs for the controlled system also include disturbance variables that represent the impact of the environment around the controlled system.[6] Their effects are suppressed by the control loop as a result of the functioning feedback and the controller's function. [7], [8]

Such design is appropriate for multiple cases in which the properties of the controlled system are similar to those of linear systems with monotonic response. In the case of controlled systems that are oscillating and with low attenuation, the function of the control loop is maintained, but its properties are not unsuitable for certain applications (e.g., in actuators of feeding devices for pressure casting etc.). Such properties are typical for oscillating systems and in the case of, for example, servo systems, they show the following features:

- Stability of the system is achievable, but wavy and oscillating curves may appear;
- A limited range of adjustable parameters of the controller with regard to the potential methods of maintaining the system stability;
- The static characteristics of the system are linear; the frequency characteristics show resonance overshoot; and transient characteristics (response) show overshoot;
- The system is sensitive to changes in parameters and changes in load (low parameter invariability). [5]

In such cases, it is appropriate to suppress or completely eliminate, without changing the function and structure of the control loop. The above listed drawbacks which either do not occur in linear and non-oscillating systems, or their impact is significantly lower. Therefore, there is a natural tendency to supplement the oscillating control loop with the functional blocks that would give the entire system the properties of a linear system without resonances and overshoot, or very similar properties.

2. Control loops and mathematical expression thereof

Recently, several papers have been published on 2-DOF (two-degrees-of-freedom) controllers [1], [7]. This is probably due to the fact that such controllers possess suitable properties and, above all, they are easily accessible. 2-DOF PID controllers usually have three basic forms: ideal, parallel, and serial. Most publications deal with the ideal form of the 2-DOF PID controller. Therefore, this form is described by the values of adjustable parameters and the weights of desired parameters [1], [7]. Much less attention is paid to serial 2-DOF PID controllers. This is the main reason why it is necessary to compare individual structures and forms of such controllers and define the conversion formulas facilitating conversion of their configurable parameters and weights of the desired parameters.

PID controllers have three basic forms [1], [7]:

a) Ideal

$$G_c(s) = K_p\left(1 + \frac{1}{T_1 s} + T_D s\right), (1)$$

b) Parallel

$$G_c(s) = K_p + \frac{K_1}{s} + K_D s, (2)$$

c) Serial

$$G_c(s) = K'_p\left(1 + \frac{1}{T'_1}\right)\left(1 + T'_D s\right), (3)$$

in which: $K_p$and K'_p is the gain (for the parallel form, the "proportional setpoint weight" term is used); T_1 and T'_1 are integral time constants; T_D and T'_D are derivative time constants; K_1 is the integral setpoint weight; K_D is the derivative setpoint weight. [7]

2.1 Setting the PID control loop theoretically

In this theoretical part we present how to set the PID parameters of the LSMsPM controller, which is represented by the first-order transmission function.

$$F_{LSMsPM}(s) = \frac{1}{1 + T_n s} \quad (4)$$

The time constant Tn expresses the current bandwidth of the torque generator (GM), ω0_GM = 1 / Tn. If we apply PID controller control to the FLSMsPM (s) transmission function, we get the resulting transmission expressed as:[7],[11].

$$F_{LSMsPM}(s) = \frac{\left(K_P + \frac{K_I}{s} + K_d s\right) \cdot \frac{K_f}{mT_n}}{s^4 + \frac{1}{T_n}s^3 + \frac{K_d K_f}{mT_n}s^2 + \frac{K_P K_f}{mT_n}s + \frac{K_I K_f}{mT_n}} \quad (5)$$

After comparing the denominator of the transfer function (5) with the coefficients of the polynomial [12],[13]:

$$s^4 + 2\omega_0(\xi + k)s^3 + \omega_0^2(1 + k^2 + 4k\xi)s^2 + 2\omega_0^3 k(1 + k\xi)s + k^2\omega_0^4 \quad (6)$$

we get relations for individual PID gain values of the control algorithm:

$$K_I = \frac{k^2\omega_0^4}{K_f} mT_n \quad (7)$$

$$K_P = \frac{2\omega_0^3 k(1 + k\xi)}{K_f} mT_n \quad (8)$$

$$K_d = \frac{\omega_0^2(1 + k^2 + 4k\xi)}{K_f} mT_n \quad (9)$$

in which: $K_p$and K'_p is the gain (for the parallel form, the "proportional setpoint weight" term is used); T_1 and T'_1 are integral time constants; $T_D$and T'_D are derivative time constants; K_1 is the integral setpoint weight; K_D is the derivative setpoint weight. [7]

Combined positive feedback with regulator structure can greatly increase the efficiency of simple positive feedback whenever significant interference occurs, and that could affect the outcome of the entire regulatory process.

Ideally, the combined positive feedback can completely eliminate the effect of output interference. Of course, the addition of combined feedback will also have an impact on the overall price of the product, and therefore it should be considered whether it will be used effectively in the case. [2],[3] The adjustable parameters include other conversion mathematical formulas which change the parallel form into the ideal form; the serial form into the ideal form; the ideal formula into the parallel formula; or the serial formula into the parallel formula, etc.

3. Fundamentals of the proposed technical design

The above listed drawbacks are eliminated by the control loop with rejection attenuation. The proposed technical solution is based on the application of the tendency to supplement the control loop with the functional blocks that give entire system the properties of a system with monotonic transient characteristics. [8]

The result is that the drawbacks of the oscillating control loop with low attenuation are suppressed or completely eliminated without changing the function and structure of the control loop. In such a case, the control loop is supplemented with the rejection block with dynamic characteristics that compensate the resonance overshoot of the frequency characteristics of the controlled system and, hence, the entire system changes from the oscillating system to the damped system, without deteriorating the dynamic properties of the system. [8], [9]

The dynamic part of such rejection block possesses the properties facilitating the suppression of unsuitable properties within dynamic part of the controlled system.

The control loop with rejection attenuation consists of the block of controlling elements regarding the controller, D/A converter, rejection block, actuator, controlled system, block of sensors, and A/D converter.

The input line is connected to the block of controlling elements of within the controller 1 which is connected through line 10 to the block of D/A converter 2, and the D/A converter 2 is connected to the rejection block 3. The rejection block is connected through line 12 to the actuator 4 which is connected through line 13 to the controlled system to which the output line 14 is connected. The input of multidimensional disturbances 8 enters the controlled system 5, and the output is the multidimensional terminal 17 connected to the block of sensors 6 which is connected through the multidimensional terminal 16 to the A/D converter 7 which is connected to the block of controlling elements of the controller 1 through the multidimensional terminal 15.

Where the rejection block is not applied, the system may have a form of an oscillating system with damping, with relevant overshooting and with certain resonant frequency. By integrating the rejection block, set to the maximum of its attenuation to this frequency, the entire system becomes significantly attenuated. The system is monotonous, without the oscillations of controlled parameters. [4]

The rejection block 3 contains one or more rejection elements which are set to various values of attenuation frequency.[10] In this case, the rejection block 3 creates, within the range of such frequencies, the attenuation band covering the range of the occurrence of resonant frequencies of the non-attenuated system due to non-stationarity of its parameters during changes in its load.

The rejection element, a part of the rejection block, is a proportional element with the amplification sharply reduced to the value close to zero at the selected pre-set frequency (attenuation frequency). Such reduction and a subsequent increase back to the initial amplification are referred to as rejection.

The control loop with rejection attenuation shows, when operated, the properties which are much more favourable than with the original design.[8]

Such system has, above all, the same control time, but no overshooting and significantly lower dynamic error of control, and it facilitates the application of higher values of constants within the controlling elements. This results in increased invariability of the system to disturbances as well as their parameter invariability (robustness). [8]

The technical design is explained in more details in Drawing 1 which depicts the overall arrangement of the blocks of the functional parts of the device. [14]

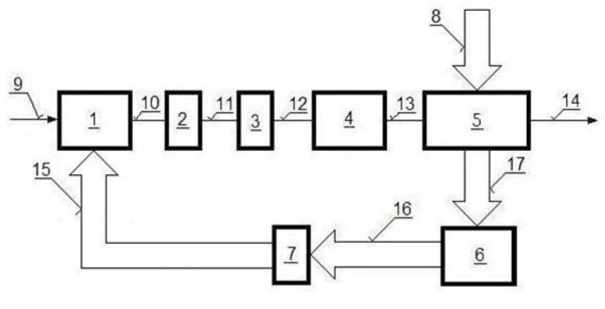

Fig. 1 Overall arrangement of functional parts according to the proposed technical design (source: author)

Legend : 1 – block of controlling elements of the controller; 2 – A/D converter; 3 – rejection block; 4 – actuator; 5 – controlled system; 6 – block of sensors; 7 – A/D converter; 8 – input of multidimensional disturbances; 9 – inlet line; 10, 11, 12, 13, 14 – lines; 15, 16, 17 – multidimensional terminals.

4. Conclusion and industrial application

A device based on the proposed design may be applied wherever there is a requirement of automatic control of certain physical parameter in which the controlled system is a device with the properties of an oscillating system with low attenuation. When the automatic control is applied, the status of the actuator is monitored by relevant sensors and the tuning commands are issued by the controller. In the case of electric actuators, such automatic control applies mainly to velocity, torque, or the rotation angle of a shaft. For such cases, the most suitable is a direct-current motor.[13]

The operation of devices used for the production of the command variable, devices for obtaining signals with feedback parameters, as well as controllers and actuators, requires the sources of additional energy.

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