Design of PID Controllers for High Order Systems

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Abstract: This paper proposes a general method for a PID controller design based on the D-decomposition. The effectiveness of the proposed method is verified by simulation in MATLAB program environment on the example of the high order plant. The simulation results show a good robustness with respect to the unmodeled dynamics, as well as superiority to some methods of a controller tuning. The proposed method is suitable for on line real-time realization and for auto tuning of the PID controller.

Keywords: PID controller, D-decomposition, relative stability, settling time, robustness

1. INTRODUCTION

In spite of all advances in a control of industrial processes in the last 50 years a PID controller is still the most common controller in the industry [1-5]. It is common practice that the PID controller has a hierarchical structure on the lowest level, that is, regardless of the process order the control is performed using the zero-order PID controller. Because of the widespread use of PID controller it is highly desirable to have an efficient method for tuning of controller parameters regardless of the order process [6-9]. This paper proposes the procedure for design of the PID controller for systems of high order. The starting point is a requirement which establishes a direct relation between the IE criterion and the integral gain (the higher the integral gain, the smaller the value of the IE criterion). The result is extended by introducing engineering specifications (settling time and relative stability). It results in a simple and efficient procedure for design of the PI controller for systems of high order.

2. DESIGN PROCEDURE OF PID CONTROLLER

Since the problem of disturbance load rejection is reduced to the minimization of IE criteria, it is also considered in this paper, but engineering constraints are introduced on:

i) relative stability
ii) settling time

This is the basis for development of a simple graphical method based on D-decomposition [9-16].
The transfer function of the PI controller is:

$$W_R = K_p + \frac{K_i}{s} + K_d \cdot s \tag{1}$$

The transfer function of the process is represented in the form:

$$W_P(s) = \frac{N(s)}{M(s)} = \frac{\sum_{k=0}^{m} b_k s^k}{\sum_{k=0}^{n} a_k s^k}, \quad m \le n \tag{2}$$

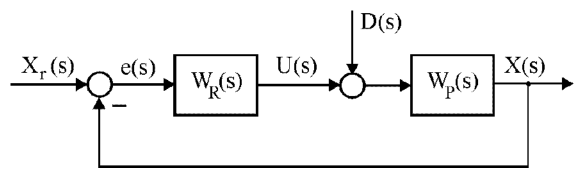

Fig. 1 *Automatic control system*

The characteristic equation of the automatic control system from Fig1 is determined by the equation:

$$f(s) = 1 + W_R(s) W_P(s) = 0 \tag{3}$$

$$f(s) = 1 + (K_p + \frac{K_i}{s} + K_d s) \cdot \frac{N(s)}{M(s)} = 0 \tag{4}$$

$$f(s) = s \cdot M(s) + (K_d s^2 + K_p s + K_i) \cdot N(s) = 0 \tag{5}$$

$$f_1(s) = s \cdot M(s) = \sum_{k=0}^{n} a_k s^{k+1} \tag{6}$$

By connecting (5) and (6), the final expression for the characteristic equation of the automatic control system in the complex domain is obtained as follows:

$$f(s) = f_1(s) + (K_d s^2 + K_p s + K_i) \cdot N(s) = 0 \tag{7}$$

Taking into account (7), it is necessary to express the complex number s in a suitable form and use it for establishing the relation between the damping degree ξ and the variable parameters of the controller, K_d , K_p and K_i contained in the characteristic equation (7) for the automatic control system. This is how the area from the "s" plane below the straight line ξ=const. (Fig. 2), is mapped in the area of the corresponding damping coefficient represented by the curve ξ=const., in the parameter plane of tuning parameters of the controller (K_p, K_d) with the condition for observation of the integral gain K_i as a parameter that fulfills the condition of minimum of IE criteria for the corresponding level of the damping coefficient ξ.

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