

## Research Article

# Design of PI Controllers for Hydraulic Control Systems

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The paper proposes a procedure for design of PI controllers for hydraulic systems with long transmission lines which are described by models of high order. Design is based on the combination of the IE criterion and engineering specifications (settling time and relative stability) as well as on the application of  $D$ -decomposition. In comparison with some known results, the method is of graphical character, and it is very simple (solving nonlinear algebraic equations is eliminated). The paper presents the algorithm of software procedure for design of the controller. The method is compared with other methods at the level of simulation, and its superiority is shown. By applying the Nyquist criterion, it is shown that the method possesses robustness in relation to non modelled dynamics.

## 1. Introduction

The first heuristic rules for selection of parameters of the PI controller were given by Ziegler and Nichols in 1942 [1]. Since then, numerous papers have been devoted to determination of parameters of the controller, according to different types of assumed controlled processes. It is estimated that more than 95% of controllers used in industry are PID controllers, and most of them are PI controllers [2]. The performed analysis connected with the efficiency of control contours in industrial production has shown that PI controllers are used to a large extent, but they are commonly tuned in a bad manner [3, 4]. According to [4], only 20% of controllers in industry operate well, while 30% of them have poor performance due to the incorrectly tuned controller. In [5], based on research in process industry, the managers and engineers reach a common conclusion that tuning of parameters of PI and PID controllers is an important and difficult problem that deserves more attention. According to [6], the PI controller is the most frequently used control algorithm in process industry. The reason for that is its relatively simple structure, which can be easily understood and implemented in practice. Despite its wide application, there is still a need for improved tuning of parameters of the PI controller [7]. The heuristic method proposed by Ziegler and Nichols has the great advantage because it requires very little information about the

process. However, this method has significant disadvantages, and it gives very bad damping (it is usually  $\xi = 0.2$ ) [7]. Small damping leads to degradation of the system and very bad performances from the aspect of relative stability and robustness.

Most PI controllers in process industry operate in the regime of set point value. Therefore, it is of principal importance to efficiently solve the problem of load disturbance rejection [8]. Reference [9] considers optimal tuning of controllers. It is shown that the IE criterion (integrated error) is in direct relation with integral gain of controllers. Those results are further expanded in [10], where it is proposed to have optimal load disturbance rejection with constraints on the function of system sensitivity and the weighting coefficient of the given value. The problem is reduced to solving nonlinear algebraic equations. The Newton-Raphson method is used for solving these equations. The initial conditions are the critical factor in this method.

Reference [11] presents a simple procedure for tuning of the PI controller. The problem is reduced to minimization of the IE criterion with the constraint that the Nyquist curve of the loop transfer function has a tangent in its left semiplane, parallel to an imaginary axis. The result of the procedure is explicit formulas for proportional and integral gains. Reference [12] proposes a new procedure for tuning of ideal PID controllers in series with the first-order noise filter.

















