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Fractional Order Controllers versus Integer Order Controllers

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Abstract

Most industrial applications are using classical, integer order type PID controllers due to the widely known characteristics such as: simplicity, the existence of tuning methods based on process model and the provided robustness performances. However, in recent years, academic and industrial world's attention has been focused on fractional order PID controllers.
This paper presents the general approach of the calculation and the fractional order systems as they are documented in the literature, and the transfer functions for the fractional order PID controllers. In simulation experiments, conducted in Matlab, processes described by the first-order transfer functions and dead time, classical and fractional order PID controllers obtained by Zeigler-Nichols tuning method were considered.

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1. Introduction

The concept of fractional PID controller (FOPID) was introduced by Podlubny, which proposed a generalized $PI^{\lambda}D^{\mu}$ controller, involving a λ order integrator and a μ order differentiator [3,10,13]. He proved the superiority of the FOPID controller than the classical PID controller when it is used for the control of fractional-order systems.

In principle, compared with classical PID controllers, which have three tuning parameters, the fractional-order controllers provide a greater flexibility in the design process, being based on five tuning parameters, but their settings can be more complex. Therein, in the literature are presented several approaches and design methods. Thus, the Ziegler-Nichols tuning method for FOPID controllers has been reported in [14], other tuning methods being

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proposed in [3,10,12]. The main modules available in Matlab software, along with usage information and tutorials are available to users in [1,2,15].

In recent decades, in addition to theoretical research on fractional-order derivation and integration, a large number of applications based on the fractional-order calculus were proposed in various fields such as long transmission line, electrochemical processes, dielectric polarization, identification and modeling of the thermal systems, colored noise, chaos, signal processing, information theory, applied computer science, dynamic systems identification, automatic control. Two examples of representation of real phenomena by fractional models are developed in [7] and an analog electronic implementation of a fractional-order system is reported in [8].

In this section of the paper a short review of studies on FOPID controllers, as presented in the literature is presented. In subchapter 2 the concepts related to the fractional-order systems and FOPID controllers are presented. In Section 3 Matlab simulation of various PID controlled systems, tuned by the classical Zeigler-Nichols method, FOPID dedicated Zeigler-Nichols respectively are tested and the final considerations are provided in conclusions section.

2. Fractional-Order Systems

Frequently, standard dynamic systems and standard controllers used in their case are specified by input-output integer order mathematical models. For their analysis and design of the controllers, due to its simplicity, the Laplace transform is used.

While the calculation based on fractional order existed about 300 years, due to its high complexity and lack of mathematical appropriate mechanisms, the theory and the control of the fractional-order dynamical systems were marginally treated. In recent years, a series of mathematical methods for their study were developed, which illustrates that, in fact, the most real systems are of fractional-orders or arbitrary-order type that can include also the integer-order ones [3,13].

By definition, the integro-differential operator ${}_aD_t^q$ is a notation used in the fractional calculus and include the fractional derivative in a whole expression [4,8,10]:

$$ {}_aD_t^q = \begin{cases} \dfrac{d^q}{dt^q},\ q > 0 \\ 1,\ q = 0 \\ \displaystyle\int_a^t (d\tau)^{-q},\ q < 0 \end{cases} \tag{1} $$

where q is of fractional-order type.

This operator applied to a function $f(t)$ leads to the extended Caputo form that is defined as follows [3,10,13]:

$$ {}_aD_t^q f(t) = \begin{cases} \dfrac{1}{\Gamma(m-q)} \displaystyle\int_0^t \dfrac{f^{(m)}(\tau)}{(t-\tau)^{q+1-m}} d\tau,\ m-1 < q < m \\ \dfrac{d^m}{dt^m} f(t),\ q = m \end{cases} \tag{2} $$

where m is the first integer value greater than q; $\Gamma(x) = \int_0^\infty t^{x-1} e^{-t} dt$ - gamma function.

Assuming the case of null initial conditions and applying the Laplace transform will lead to the following result: