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A STUDY ON FRACTIONAL ORDER CONTROLLER (IMC BASED)

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***Abstract* - FOPID controller is the one of the controllers designed by fractional order concept. This report starts discussion with some basic ideas of PID and fractional calculus and the definitions used in it and literature survey done in fractional calculus, then introduction of FOPID controller and its tuning methods. Any controller has its importance only with some good tuning technique. In this report a classical tuning approach is discussed for tuning in which some specifications are used for obtaining parameters of controller. To use this method modulus, phase and phase slope of process is required. A method to find those parameters also discussed in this report.**

In PID and FOPID controller Internal Model Control (IMC) approach is the one which got attention now a days. Here introduction of IMC approach, implementation and design of IMC model is presented. Application of this technique on different systems is given and finding controller transfer function in standard form as PID. After that some conclusions are drawn by applying proposed IMC-PID procedure on a first order and second order system with/without time-delay term and also compare the results with Smith Predictor for time-delayed system. Modelling of DC motor as system and controller design through IMC-PID and FIMC approach is given and respective simulations are done from which some conclusions are drawn.

I. INTRODUCTION

The application of fractional calculus in control technology is a fractional order controller. As the name suggests, unlike the integer order that moves between integer numbers (order belongs to integer numbers), the fractional order moves along the real axis whose order belongs to the real number. However, it is recommended for process control applications that order should be between "0" and "2." It has been stated in some literatures that when order greater than "2" in the application of control goes to unstable process operations. There are different types of controllers, such as FOPID controller, TID controller, FO control fractional lead-lag compensator, CRONE controller. In the recent few years FOPID controllers more attract the researchers and a considerable attention. FOPID have more flexibility in the controller design because they have five parameters. In recent past, I. Podlubny have been proposed FOPID controllers in time domain and Petras proposed in frequency domain which is capable of improving the closed loop performance of a system over an integer order controller. In recent time, the application of fractional derivatives has become quite apparent in modelling mechanical and electrical properties of real materials. Fractional integrals and derivatives have found wide application in the control of dynamical systems, when the controlled system or/and the controller is described by a set of fractional order differential equations. In the present work a fractional order system has been represented by a higher integer order system, which is further approximated by second order plus time delay (SOPTD) model. The approximation to a SOPTD model is done by reducing the real and approximated system's two norm. In addition, the effectiveness of a fractional order controller in meeting a set of frequency domain requirements is calculated on the basis of an integer order PID frequency response and a PID fractional order controller (FOPID) built for the approximate SOPTD model.

FRACTION CALCULUS - Fractional calculus deals with integer theory and number derivatives. It also simplifies the integer order notation and the incorporation of "n" folds. The derivatives and integrals of fractional order provide a powerful tool for memory classification [1]. Fractional calculus is also three centuries old as is integer calculus, but it is not popular in the research field. Many researchers have been using this as a tool for their research work in various areas of science and engineering such as control engineering, mechanical, chemical, signal processing, etc. since the last few decades.

FRACTION ORDER CONTROLLER - Fractional order controller (FOC) have received a significant attraction in the last few years from both academic and industrial point of view. Fractional order controllers have more flexibility in design when comparison with conventional Integer order controllers. The Fractional order controllers (FOC) are less sensitive to changes of parameters of a controlled system as well as controller. Fractional order controllers are classified in four categories for process control applications. Out of these two are important and deserves special worth. They are “Podulbny’s FOPID or $PI^{\lambda}D^{\mu}$ controller” and “Oustaloup’s CRONE controller and its three generations”. Other some of the fractional order (FO) controllers are “Fractional order lead-lag compensator” and “Fractional order phase shaper”.

FOPID CONTROLLER - FOPID controller is proposed by I. Podlubny in 1994 [1]. They are capable of improving the closed loop performance of a system over a simple Integer order PID structure. This is because they have five parameters to select which are three in the case of conventional PID controllers. The design of FOPID controllers is simple and they will show good performance. They will give less percentage overshoot and small settling time for slow process systems. A Fractional order controller can attain the property of Iso-damping very easily. Systems having this property have constant overshoot in closed loop step responses for different values of control gain i.e. Systems are robust against gain variations.

Fractional PIDs are generalisations of PIDs. The output of Fractional PIDs is the linear combination of the input, a fractional integral of the input and a fractional derivative of input.

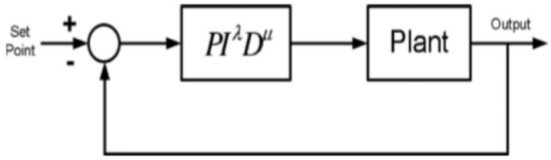

Figure 4.1: General block diagram of fractional PID controller

The generalized transfer function of this fractional PID controller is given by

$$C(S)=\frac{U(S)}{E(S)} = k_p + \frac{k_i}{s^{\lambda}} + k_d s^{\mu} \ , (\lambda, \mu \geq 0) \qquad 1.$$

Where, C(s) is the controller output, U(s) is the control signal, E(s) is the error signal, K_p is the proportional constant gain, K_i is the integral constant gain, K_d is the derivative constant gain, is the order of integration, μ is the order of differentiation.

- If λ=1 and μ=1, then it is classical PID controller.
- If λ=0 and μ=1, then it is classical PD controller.
- If λ=1 and μ=0, then it is classical PI controller.
- If λ=0 and μ=0, then it is classical P controller.

Advantages of Fractional PID controller over Conventional PID controller:

- Five different specifications can be achieved in FOPID by varying five parameters, which is not possible in the case of IOPID.
- The property of Iso-damping can easily achieve by FOPID when compared to IOPID.
- For higher order systems, if we use conventional PID controller the performance of the controller weakens. Whereas in case of FOPID, it provides improved results even with the higher order systems.

- Fractional PID controller gives better results for a system with more time delay than conventional PID controller.
- As fractional PID have five parameters for tuning it is more robust and stable whereas integer order PID provides lower robust stability.
- It is complex and difficult to control the system which has nonlinearities by using conventional PID controller but fractional PID controller performs better in those cases.
- In case of Non-minimum phase system fractional PID controller attain better response.

TUNNING OF FOPID - Tuning is the process for getting the optimum values of parameters of controller according to system requirements. For example, in case of PID controller, tuning will be done for getting the optimum values of K_p, K_d, and K_i Whereas in case of FOPID K_p, K_d, K_i, λ and μ.

Tuning of most of the controllers is always a challenging task. In case of fractional PID controller there are five parameters to be tune. So, it is a quite a complex task and challenging. According to D. Valerio and J.Costa tuning methods can be divided into three different categories:

- Rule base methods
- Analytic methods
- Numerical methods

Apart from the above methods, self-tuning and auto-tuning methods are also used for tuning of fractional order controllers.

INTERNAL MODEL CONTROL - The controller with IMC strategy is becoming widespread nowadays because of its design which is in obvious mode and also because of its tuning procedures. Combining this with the widespread PID controllers guarantees meeting most of the control objectives, such as set point reference tracking, zero steady state errors, low overshoot acceptable, reduced settling time, disturbance rejection and robustness to modelling uncertainty. Along with these advantages simple tuning procedure make the IMC-PID controller the perfect resolution for many practical applications [10]. One nice thing about the IMC procedure, is that it results in a controller with an only one tuning parameter, the IMC filter (λ). We will find that the IMC law, for a number of common process transfer functions, is equivalent to PID-type feedback controllers.

APPLICATION OF IMC AND FIMC CONTROLLER -

DC Motor Speed: System Modelling : A common actuator in control systems is angular speed of the DC motor. It directly provides rotary motion and, coupled with wheels or drums through shaft and cables, can provide translational motion. The electric equivalent circuit of the armature and the free-body diagram of the rotor are shown in the figure 7.1.

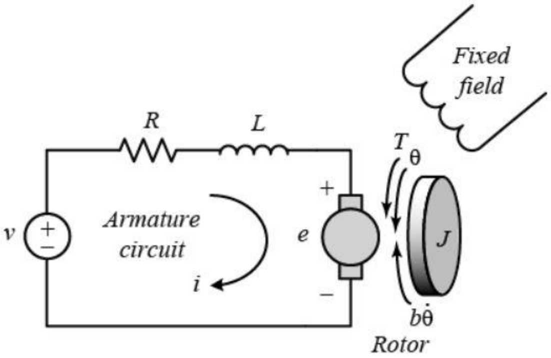

Figure 7.1: Free-Body Diagram of DC motor

From this example, we will assume that the input of the system is the voltage source (V) applied to the motor's armature, while the output is the angular speed of the shaft $(\dot{\theta})$. The rotor and shaft are taken to be rigid. We further assume a viscous friction model, that is, the friction torque is proportional to shaft angular velocity.

Transfer Function:

$$s^2 J\theta(s) + sb\theta(s) = KI(s) \quad 2.$$

$$LsI(s) + RI(s) = V(s) - Ks\theta(s) \quad 3.$$

We can derive an open-loop transfer function by eliminating $I(s)$ from above equations no 2. and 3., where the angular speed is taken as the output and the armature voltage is taken as the input.

$$P(s) = \frac{\dot{\theta}(s)}{V(s)} = \frac{K}{(Js+b)(Ls+R)+K^2}\left[\frac{\frac{rad}{sec}}{V}\right] \qquad 4.$$

CONCLUSION

One of the most important aspects in control engineering consists in an accurate modelling of the process which is to be controlled. In a wide range of applications, an accurate model of the process is difficult to be obtained. In such cases it is difficult to tune the controller used to control that system. The method of tuning presented for fractional order controllers yields a robust controller despite the lack of an actual process model. One of the most important aspects in control engineering consists in an accurate modelling of the process which is to be controlled. In a wide range of applications, an accurate model of the process is difficult to be obtained. In such cases it is difficult to tune the controller used to control that system. The method of tuning presented for fractional order controllers yields a robust controller despite the lack of an actual process model. In this paper analysis and design of controller is done by transfer function approach. Only some performance indices are checked by plotting step response and bode plot using MATLAB Simulink.

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