ADVANTAGE OF CRONE CONTROLLER FOR LEVEL PROCESS AND DC MOTOR SYSTEM COMPARED WITH PID,H-∞ CONTROLLERS

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Abstract – Fractional order controllers are more suitable for optimal response of any system compared to our conventional controllers like PID, H-∞ controllers. The main aim is the application of different controlling techniques on two systems, first one, level process and second, speed control of DC motor . Objective is to formulate a controller so as to achieve the water level control in the level process and speed control in the DC motor . Controllers are formulated on a nominal plant and analyzed when the systems parameters are perturbated. Integer order PID, H-∞ controller,CRONE [Commande Robuste d'Ordre non Entier or Fractional order robust control] are used. Integer order PID controller is formulated based on performance specifications like stability degree, bandwidth, rejection level of measured noise, rejection level of output disturbance, plant input sensitivity. For level process system first and second generation CRONE controlling technique is used for designing fractional order controller. The CRONE controlling technique is also used for speed control of DC Motor. 1st and 2nd generation CRONE controllers are applied for dc motor with parameter variations in form of temperature variation and the frequency and step response of the systems for the CRONE controller, H-∞ and PID controllers is observed.

Key Words: Transfer function of level process and dc motor system, Integer order PID, H-∞ controllers, first and second generation crone controllers.

1. INTRODUCTION

The water level control of the level process carried and compared using different methods. Integer order PID and fractional order controller using CRONE controlling technique. The PID and the generalized PID controllers are a priori fixed, which means that the computation of these controllers transfer functions are done directly according to the user specifications (stability degree, bandwidth, rejection level of the measured noise, rejection level of the output disturbance). Concerning the CRONE controller, the posterior synthesis method is used. In this case, the definition of the controller is made with respect to the open loop constraints. One of earliest forms of a PID controller was developed by Elmer Sperry in 1911 [1]. However, the first published work presenting a PID controller by Russian American engineer Nicolas Minorsky in 1922 [2]. The generalized PID controller, where the integration and differentiation order can be any positive and real number less than the unit, was proposed while tuning rules proposed by Ziegler and Nichols for integer PIDs [3-4]. Several tuning methods were and still are proposed for this purpose in order to get the optimal values of the integration and differentiation orders [5]. Most recently, the CRONE controller, also based on the fractional integration and differentiation, was introduced in three generations [6]. However, a main difference, other than the way used to synthesize these controllers, is encountered. The number of parameters to be defined differs between these controllers. PID needs to define three parameters, and the CRONE controller needs four parameters. Nowadays, the use of the fractional controllers is almost necessary in almost all engineering domains.

1.1 TRANSFER FUNCTION OF A LEVEL PROCESS SYSTEM

The level process of a system is nothing but to control the water level in a tank .This process is used in many boilers and steam chambers.

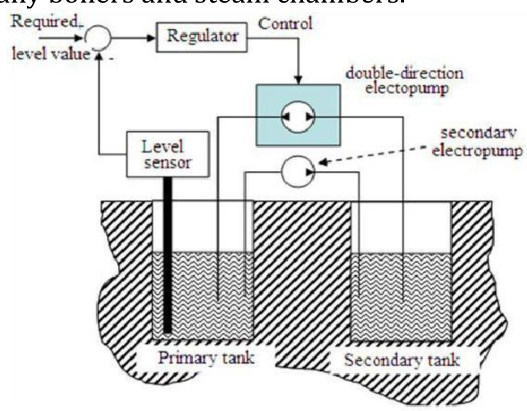


Figure 2.1: Block diagram of the level process system

The transfer function of level process system is obtained from the linearized plant of the system and is given below

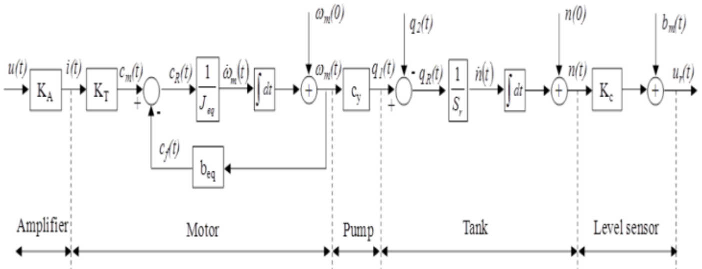


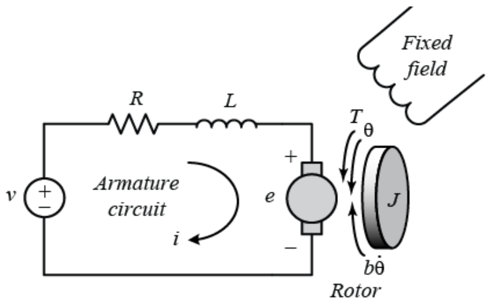
Figure 1: Block diagram of linearized plant of a level process system

the obtained transfer function of the linearized plant of level process system is

$$G(s) = \frac{Y(s)}{U(s)}\bigg|_{d=0} = C[sI - A]^{-1}B = \frac{k}{(s(1+s/\omega_0))}$$

1.2 TRANSFER FUNCTION OF A D.C SYSTEM

The dynamic model of a separately excited D.C motor is given and the transfer function is derived from it



The speed of dc motor is directly proportional to armature voltage and inversely proportional to flux in field winding.The obtained transfer function between rotor position and armature voltage is

$$\frac{\theta(s)}{V_a(s)} = \left[\frac{K_t}{(R_a + sL_a)(Js^2 + Bs) + K_b K_t s}\right]$$ and

the perturbations in this motor like temperature variation is also considered

2. DESIGN OF INTEGER ORDER PID CONTROLLER

PID consists of three basic coefficients; proportional, integral and derivative which are varied to get optimal response. The design of integer PID controller is as follows

The PID controller consists of a gain, an integration of order 1 and a derivation of order 1. Two different arrangement of the PID controller exist the parallel arrangement and the cascade arrangement. The cascade arrangement will be treated. Its transfer function can be presented as follows

$$C_{PID}(s) = C_0 C_I(s) C_D(s)$$

Here,

$$C_I(s) = \left(\left(1 + \frac{s}{\omega_i}\right) / \left(\frac{s}{\omega_i}\right)\right) \text{ and } C_D(s) = \left(\left(1 + \frac{s}{\omega_b}\right) / \left(1 + \frac{s}{\omega_h}\right)\right),$$

Where ω_i, ω_b, and ω_h are the transitionalfrequencies and C_0 is a constant. Transitional frequencies are frequencies at which gain equals to unity.In order to calculate these parameters, the user constraints are used. In the following, the method to calculate the optimal values of the PID parameters is shown.

Here we are introducing constants as follow

$$a = \omega_h/\omega_b, b = \omega_u/\omega_i \text{ and } \omega_m = \sqrt{\omega_b \omega_h}$$

Inserting ω_u in the above transfer function of PID leads to the following transfer function

$$C_{PI^\lambda D^\mu}(s) = C_0\left(\frac{1+bs/\omega_u}{bs/\omega_u}\right)\left(\frac{1+\sqrt{a}s/\omega_u}{1+s/\sqrt{a}\omega_u}\right)$$

The above equation represents integer order PID controller transfer function.

3. DESIGN OF H-∞ CONTROLLER

H-∞ (i.e. "H-infinity") methods are used in control theory to synthesize controllers achieving stabilization with guaranteed performance .The phrase H∞ control comes from the name of the mathematical space over which the optimization takes place . H∞ is the space of matrix-valued functions that are analytic and bounded in the open right-half of the complex plane defined by Re(s) > 0; the H∞ norm is the maximum singular value of the function over that space.H-∞ controller synthesis employs two transfer functions which divide a complex control problem into two separate sections, one dealing with stability, the other dealing with performance

S(s)=1/(1+GK)

T(s)=GK/(1+GK)

From the above transfer function and using state space. The generalized plant P(s) is given as,

$$\begin{bmatrix} z_1 \\ z_2 \\ z_3 \\ z_4 \end{bmatrix} = \begin{bmatrix} w_s & -w_s G \\ 0 & w_{ks} \\ 0 & w_{kG} \\ I & -G \end{bmatrix} \begin{bmatrix} w \\ u \end{bmatrix}$$

$$G = \begin{bmatrix} A & B \\ C & D \end{bmatrix}, w_s = \begin{bmatrix} A_s & B_s \\ C_s & D_s \end{bmatrix}$$

$$w_{KS} = \begin{bmatrix} A_{KS} & B_{KS} \\ C_{KS} & D_{KS} \end{bmatrix}, w_t = \begin{bmatrix} A_t & B_t \\ C_t & D_t \end{bmatrix}$$

a possible state space realization for P(s) can be written as

$$P = \begin{bmatrix} w_s & -w_s G \\ 0 & w_{ks} \\ 0 & w_{TG} \\ I & -G \end{bmatrix} = \begin{bmatrix} A & B_1 & B_1 \\ C_1 & D_{11} & D_{12} \\ C_2 & D_{21} & D_{22} \end{bmatrix}$$

(4.7)

From (6) and (7) we can write a mixed sensitivity problem as

$$P = \begin{bmatrix} w_{KS} \\ W_{ks} KS \\ w_t T \end{bmatrix}$$

our objective is to find a rational function controller K(s) and to make the closed loop system stable satisfying the following expression

$$\min \|P\| = \min \begin{bmatrix} w_t s \\ w_{ks} ks \\ w_t T \end{bmatrix} = \gamma$$

4.DESIGN OF CRONE CONTROLLER

CRONE control-system design is a frequency-domain approach for the robust control of uncertain (or perturbed) plants under the common unity-feedback configuration (Fig 5.1). The controller or open-loop transfer function is defined using integro-differentiation with non-integer (or fractional) order. The required robustness is that of both stability margins and performance, and particularly the robustness of the peak value (called resonant peak) of the complementary sensitivity function. [26]

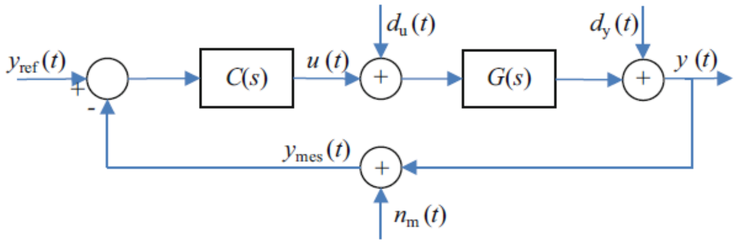


Figure 4.1: Control diagram

The CRONE controller is designed using the open-loop constraints which mean it is based on the posterior synthesis method. CRONE controllers are [26]

- In the first generation, the constant phase $n\pi/2$ characterizes this controller around frequencyω_u. When the frequency ω_u varies, the constant phase controller doesn't contribute to the phase margin variations.
- In the second generation, a phase change is observed in the plant when varying the frequencyω_u.
- **4.1 FIRST GENERATION CRONE CONTROLLER**

The first generation CRONE strategy is particularly appropriate when the desired open-loop gain crossover frequency ω_{cg} is within a frequency range where the plant frequency response is asymptotic. The CRONE controller is defined within a frequency range $[\omega_A, \omega_B]$ around frequency ω_{cg} from the fractional transfer function of an order n integro-differentiator [26]

$$C_F(s) = C_0 S^n$$

The ideal fractional version $C_F(s)$of the controller can also be defined by a band-limited transfer function using corner frequencies

$C_F(s) = C_0\left(\frac{1+s/\omega_1}{1+s/\omega_h}\right)^n$ with $\omega_1 < \omega_A$ and $\omega_h > \omega_B$

For the CRONE controller an order n_I band-limited integrator and an order n_F low-pass filter must be included. Then, the first generation CRONE controller is defined by [26]

$$C_F(s) = C_0\left(1+\frac{\omega_I}{s}\right)^{n_I}\left(\frac{1+s/\omega_1}{1+s/\omega_h}\right)^{n}(1+s/\omega_F)^{-n_F}$$

4.2 SECOND GENERATION CRONE CONTROLLER

For problems of control effort level, it is sometimes impossible to choose an open-loop gain crossover frequency within an asymptotic behaviour frequency band of the plant. Thus when the desired ω_{cg} is outside an asymptotic behaviour band, the previous CRONE controller defined cannot ensure the robustness of the closed-loop system stability margins
the CRONE approach defines the open-loop transfer function (in the frequency range $[\omega_A, \omega_B]$ previously defined) by that of a fractional integrator:

$$\beta(s) = \left({}^{\omega_{cg}}/_{s}\right)^{n}$$

Complementary sensitivity function $T(s)$, and sensitivity function $S(s)$, can be expressed as

$$T(s) = \frac{\beta(s)}{1+\beta(s)} = \frac{1}{1+\left(\frac{s}{\omega_{cg}}\right)^{n}}$$

And

$$S(s) = \frac{1}{1+\beta(s)} = \frac{\left(\frac{s}{\omega_{cg}}\right)^{n}}{1+\left(\frac{s}{\omega_{cg}}\right)^{n}}$$

For the CRONE controller to manage the control effort level, and the steady-state errors, the fractional open-loop transfer function has to be band-limited and complexified by including integral and low-pass effects. The fractional open-loop transfer function is defined by

$$\beta(s) = K\left(1+\frac{\omega_1{}'}{s}\right)^{n_l}\left(\frac{1+s/\omega_h}{1+s/\omega_1}\right)^{n}(1+s/\omega_h{}')^{-n_h}$$

When the nominal open-loop transfer is determined, the fractional controller $CF(s)$ is defined by its frequency response

$$C_F(j\omega) = \frac{\beta(j\omega)}{G_0(j\omega)}$$

whose phase is variable and where $G_0(j\omega)$designates the nominal frequency response of the plant.
The synthesis of the rational controller $C_F(s)$, consists in identifying ideal frequency response $C_F(j\omega)$ by a of a low-order transfer function. The parameters of a transfer function with a predefined structure are adapted to frequency response$C_F(j\omega)$. The rational integer model on which the parametric estimation is based, is given by

$$C_R(s) = \frac{B(s)}{A(s)}$$

where $B(s)$ and $A(s)$ are polynomials of specified integer degrees n_B and n_A

5. SIMULATIONS AND RESULTS

For the level process system using PID controller

$$C_{PID} = \frac{13937s^2+99s+0.092}{51s^2+s}$$

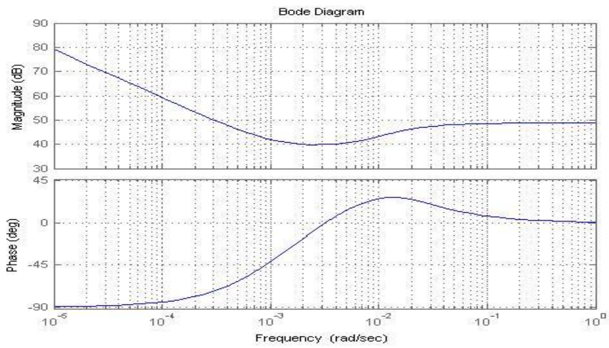


Fig 5.1 Frequency response of PID controller

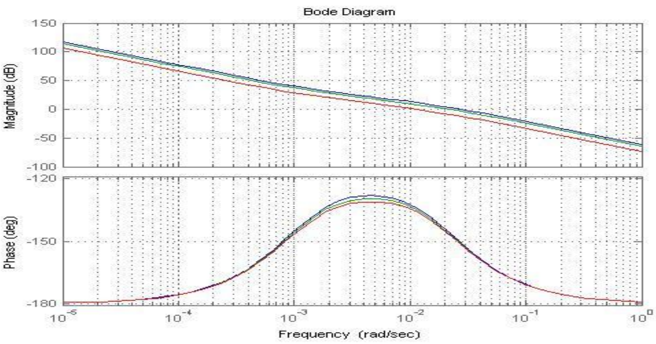


Fig5.2 The open loop bode plot of PID controller

This PID controller is applied to the level process system. The step response of closed loop system with PID controller at three operating points of a level system is as follows

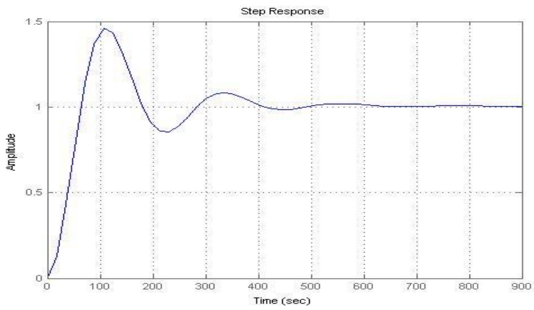


Fig 5.3 Step response closed loop system with PID controller at 1st operating point

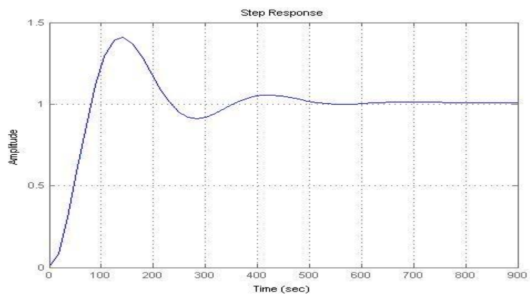


Fig5.4 Step response of closed loop system with PID controller at 2nd operating point

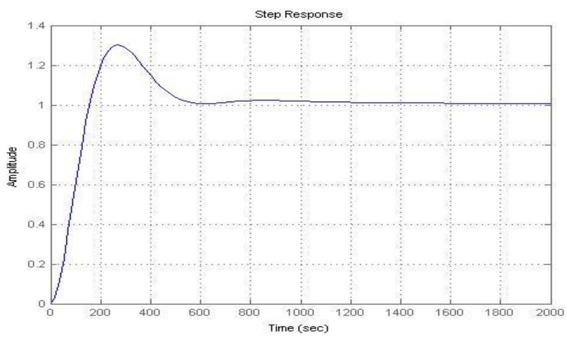


Fig 5.5 Step response of closed loop system with PID controller at 3rd operating point

The frequency response using H-∞controller for the level process system at the three operating points is given as follows

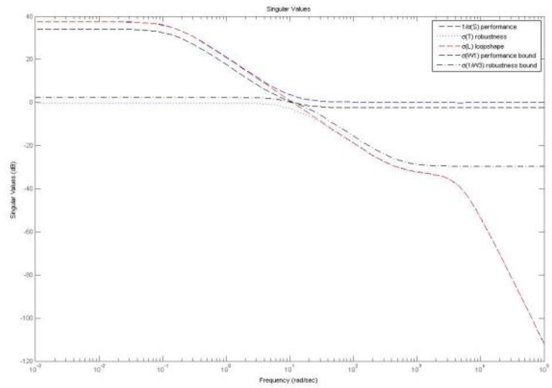


Fig 5.6 Response for H-∞ controller

The frequency response for level process system using first and second generation CRONE controller is

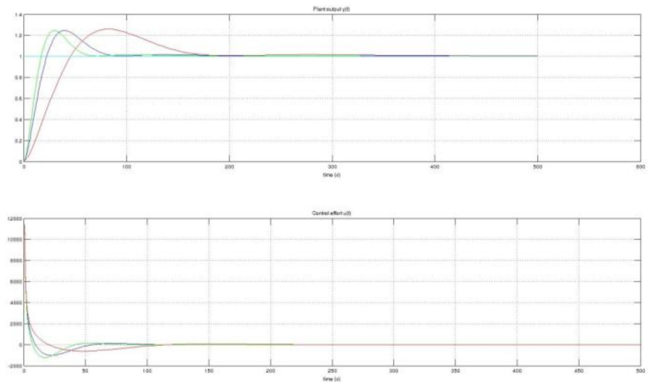


Fig 5.7 step response with 1st generation CRONE for three operating point's level process system.

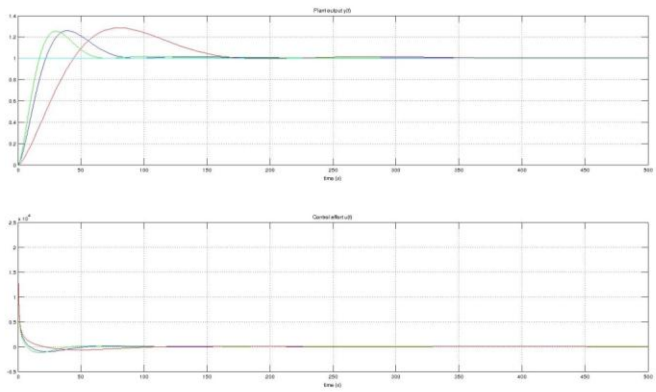


Fig5.8 step response with 2nd generation CRONE controller at 3operating points

The step response of speed control of D.C motor using H-∞ controller is

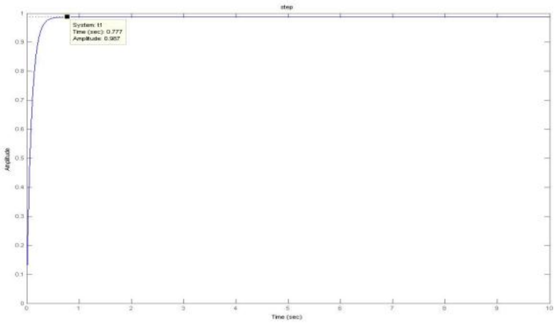


Fig 5.9 step response of DC Motor

The step response of speed control of DC motor using 1st and 2nd generation CRONE controller is

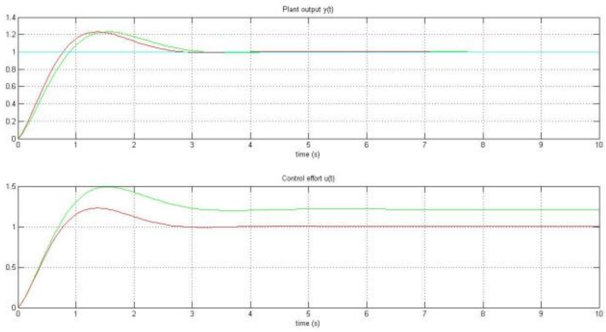


Fig5.10 step response of speed control of DC Motor using 1st generation CRONE controller

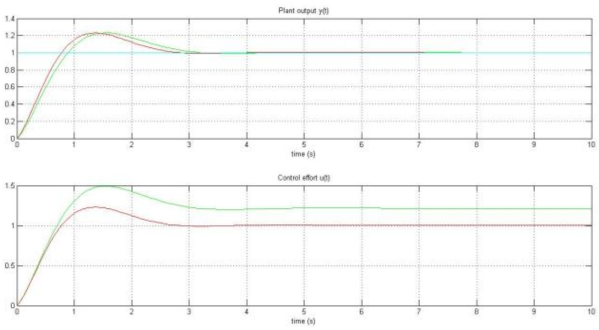


Fig 5.11 step response of speed control of DC Motor using 2nd generation CRONE controller

7. CONCLUSION

The Integer order PID controller is applied to a level process system. The response of the plant at different operating points with controllers is obtained. The 1st and 2nd generation CRONE controller applied to level process system and compared with integer order PID controller. By comparing the step,frequency response ,we can say CRONE controller is giving better performance compared with PID controller. This CRONE controller is applied to speed control of DC Motor. First and second generation CRONE controllers applied to speed control of DC Motor. Parameter variations in DC Motor due to temperature is considered and evaluated. Comparing step response of 1st and2ndgeneration CRONE controller's 2nd generation CRONE controller giving better performance than 1st generation CRONE controller.

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