A PID TUNING PROCEDURE FOR TRACKING CONTROL OF AN OVERHEAD CRANE

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Abstract

In this paper, a PID tuning procedure is developed to control of an overhead crane. To enable the crane to reach a desired position, one must use a controller strategy. This work presents a simple and enough efficient approach to control of the overhead crane based on design of a PID controller. Hence, Ziegler-Nichols method is used to start setting of gains of PID controller, but a tuning procedure is developed to obtain better results. The criterion to tune the PID controller is considered the tracking response of trolley and minimum oscillation of pendulum. Finally, some simulation are performed which discussed the capability of the presented method for control of the overhead crane.

Keywords: PID tuning, Overhead crane, Control, Track.

I. INTRODUCTION

The overhead have received a lot of interests in transportation and industrial application, due to their low cost, easy assembly and less maintenance. They are composed of a platform moving in a fixed support, while a pendulum is suspended from a point on the platform. For the sake of minimum transportation time, high tracking accuracy, and swing angle, dynamic modeling and motion control of the gantry crane system becomes an appealing task in the field of control Science [1-5]. Moustafa et al. [6] proposed optimal control of the overhead cranes. They presented a nonlinear dynamic model of the systems which considered travel, traverse, and hoisting/lowering motions of the crane. Rahn et al. [7] used a feedback law to stabilize the hoisting angle of a flexible overhead crane. Frang et al. [8] used a nonlinear coupling law to control the overhead robot. Moreover, an input-shaping control law is proposed in [9] to control the motion of the crane. In this method, the input control profile is determined as unwanted oscillation during travel and residual pendulations are avoided. Also, a hybrid input-shaping strategy and a PD-type fuzzy logic control scheme are implemented in [10] to control a gantry (overhead) crane system. however this method if effective, but the input-shaping method leaks from being an open loop control scheme, and is not robust to disturbances and parameter uncertainties [11]. Mahfouf et al. [12] designed a fuzzy logic-based controller to damp the sway angle of overhead crane. Moreover, in [13], a nonlinear modeling and anti-swing control method for the overhead cranes is presented. Yu et al. [14] used a perturbation technique to separate the slow and fast dynamics of the gantry crane model. Then, they used a feedback control strategy including two independent PD controllers to track the pre-defined motion profile and suppress payload pendulations, respectively. Liu et al. [15] proposed an adaptive sliding mode fuzzy control method for the overhead system. Moreover, a neural based method is used in [16] to control the motion of the crane.

In this paper, a PID tuning procedure is developed to control of an overhead crane. Hence, Zigler-Nichols method is used to start setting of gains of PID controller, but a tuning procedure is developed to obtain better results. The criterion to tune the PID controller is considered the tracking response of trolley and minimum oscillation of pendulum. Finally, some simulation are performed which discussed the capability of the presented method for control of the overhead crane.

II. DYNAMIC MODEL OF SYSTEM

In this section, dynamic model of the gantry carne is presented. The dynamic equation of the system is derived using Lagrange principle. Figure 1 shows an overhead crane.

Moreover, the parameters of the overhead system are presented in Table 1.

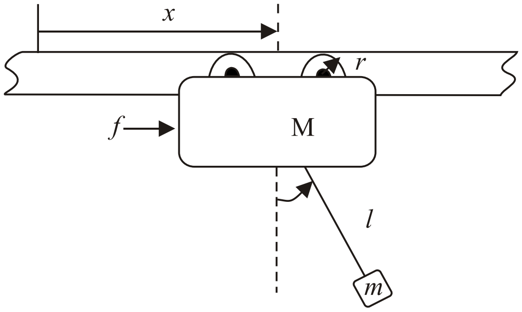

Fig. 1. The overhead crane

Table 1. Parameters of the overhead crane

Parameters	Nomenclatures
Cart position	x
Cart velocity	$\dot{x}$
Pendulum angular displacement	θ
Pendulum angular velocity	$\dot{\theta}$
Pendulum length	l
Mass of the cart system	M
Payload mass	m
Gravitational constant of earth	g
Radius of wheels of cart	r
DC motor voltage of cart	e
Force exerted to cart	f
Motor armature resistance	R
Motor torque constant	k

Using the Lagrange principle, the nonlinear dynamic equations of the system can be presented as [17]:

$$(M+m)\,\dot{x}+ml\dot{\theta}\cos\theta-ml\dot{\theta}^2\sin\theta=f$$

$$\dot{x}\cos\theta+l\dot{\theta}+g\sin\theta=0 \tag{1}$$

Beside, the linear force is originated from the torque of motor of trolley [18]:

$$T=rf$$

$$T=\frac{k}{R}e-\frac{k^2}{R}\omega$$

$$\dot{x}=r\omega \tag{2}$$

Where ω is the angular velocity of DC motor and is related to the velocity of the cart by Eq. 2.

Furthermore, by combination of Eq. 1 and Eq. 2, the nonlinear equation of the overhead crane can be summarized as follows:

$$(M+m)\,\dot{x}+ml\dot{\theta}\cos\theta-ml\dot{\theta}^2\sin\theta=\frac{1}{r}\left(\frac{k}{R}e-\frac{k^2}{Rr}\dot{x}\right) \tag{3}$$

$$\dot{x}\cos\theta+l\dot{\theta}+g\sin\theta=0$$

Moreover, the state vector is defined as, $\overrightarrow{X}=[x\,\dot{x}\,\theta\,\dot{\theta}]^T=[x_1\;x_2\;x_3\;x_4]^T$, and the equation are linearized. Thus, the following equations are obtained:

$$\dot{\overrightarrow{X}}=A\overrightarrow{X}+Bu \tag{4}$$

$$y=C\overrightarrow{X}+Du$$

Where the matrices are:

$$A=\begin{bmatrix} 0 & 1 & 0 & 0 \\ 0 & -\dfrac{k^2}{Rr^2M} & \dfrac{mg}{M} & 0 \\ 0 & 0 & 0 & 1 \\ 0 & \dfrac{k^2}{Rr^2Ml} & -\dfrac{(M+m)g}{Ml} & 0 \end{bmatrix} \quad B=\begin{bmatrix} 0 \\ \dfrac{k}{RrM} \\ 0 \\ -\dfrac{k}{RrMl} \end{bmatrix} \tag{5}$$

$$C=[1000] \quad D=0$$

III. PID CONTROL FORMULATION AND SIMULATION RESULTS

In this section, the PID controller is designed. The first try to obtain the gains of the controller are done based on Ziegler-Nichols method are estimated, And then tuning procedure is continued. A plan of controller is shown in figure 2:

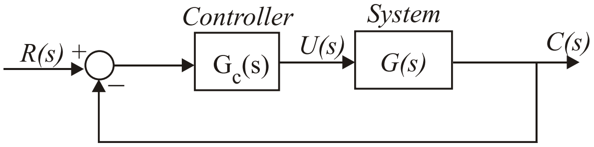

Fig. 2. The controller plan

In Fig. 2, the transfer function of the PID controller is shown as and the transfer function of the system is which can be obtained from Eq. 5:

$$TF = C\,(SI - A)^{-1}\,B = \frac{X(s)}{E(s)}$$

$$= \frac{krls^2 + krg}{MRr^2\, ls^4 + lk^2\, s^3 + (M + m)\, gRr^2\, s^2 + gk^2\, s} \tag{6}$$

Furthermore, the transfer function of controller is [19]:

$$G_c(s) = K_p\left(1 + \frac{1}{T_i\, s} + T_d\, s\right) = K_p + \frac{K_1}{s} + K_d\, s \tag{7}$$

Where K_p, K_1, K_d are the gains of proportional, integral, and derivative controls, respectively.

The parameter values of the system are presented in Table 2:

Table 2. Parameter values of the overhead crane

Parameter values	Parameter
Pendulum length	$l = 0.3302$ m
Mass of the cart system	$M = 1.073$ kg
Payload mass	$m = 0.23$ kg
Gravitational constant of earth	$g = 9.81$ m/s^2
Radius of wheels of cart	$r = 0.006$ m
Motor armature resistance	$R = 2.6\ \Omega$
Motor maximum voltage	$e_{max} = 12$ V
Motor torque constant	$k = 0.00767$ Vs/rad

Thus the transfer function of the system is written as:

$$TF = \frac{1.52s^2 + 45.15}{3.316s^4 + 1.943s^3 + 119.6s^2 + 57.71s} \tag{8}$$

Using the Ziegler-Nichols method [17], the first estimation for control gains are obtained as

$$K_{cr} = 6.94,\ P_{cr} = 13.96,$$

$$K_p = 0.6\,K_{cr} = 4.16,\ T_i = 0.5P_{cr} = 6.98,$$

$$T_d = 0.125P_{cr} = 1.74,\ K_d = K_p\,T_d = 7.24,$$

$$K_i = \frac{K_p}{T_i} = 0.61$$

It must be noticed that the simulations are performed in Simulink of MATLAB. For four tuning attempt as it is shown in table 3, the following results can be achieved via PID controller:

Table 3. Characteristic of response of the system

K_p	K_i	K_d	N	**Maximum percent overshoot of** x	**Settling time of** x	**Maximum voltage of motor**
4.16	0.61	1.74	1	55.8028	10.4409	5.9
2	0.2	2.2	1	31.6678	5.4799	6.2
1.2	0.01	3	1	12.0139	4.6423	7.3
1.2	0.005	3	2.5	2.1715	2.748	8.7

As the input reference is assumed to be a unit step, the trolley displacement of the overhead crane is depicted in Fig. 3:

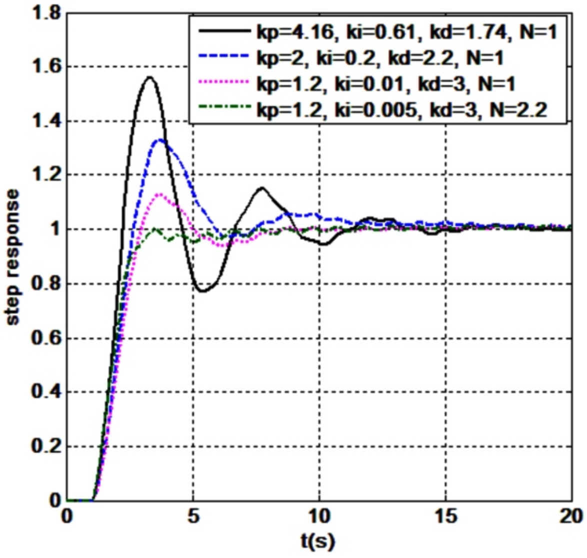

Fig. 3 The displacement of the cart

According to Fig. 3, as the first try of PID tuning are done via Ziegler-Nichols method, but the better response can be achieved by continuing the tuning process.

III. SUMMARY

In this paper, a PID tuning procedure has been developed to control of an overhead crane. Hence, Ziegler-Nichols method has been used to start setting of gains of PID controller, but a tuning procedure has been developed to obtain better results, and some simulation has been performed which shows the capability of the tuning procedure to control of the overhead crane.

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