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Comparisons of Different Controller for Position Tracking of DC Servo Motor

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ABSTRACT: The accurate position control of DC servo motor is an important issue in industrial.This paper present position tracking of DC servo motor using different control strategy. Control strategy is requires to minimizing the steady state error. Here consider the no of controller like PID controller using different tuning method and MPC controller. This paper identifies and describes the design choices related to a PID controller and predictive controller for a DC servo motor. Performance of these controllers has been verified through simulation using MATLAB/SIMULINK software. According to the simulation results the Comparisons between PID (ZN), PID (GG) and MPC controller are given in this paper. The tuning method was more efficient in improving the step response characteristics such as, reducing the rise time, settling time and maximum overshoot in Position control of DC servo motor. Model predictive controller method gives the best performance and superiority of MPC method compare to other controller.

KEYWORDS: ***MPC, ZN, GG, PID, LQR***

I.INTRODUCTION

Recently, DC servo motors have been widely used as robotics manipulation, actuator for automation control process, mechanical motion and direct drive application. Thus, we consider DC servo motor for position tracking because DC motor has some limitation to precision measurement of position rather than speed. For dc servomotor, rotor inertia are very small and time constant are extremely small. Therefore the result of motors has very high torque-to-inertia ratios for commercially available application. Thus, present work is based on DC servo motor SISO system for position control using control tool MATLAB. First, It is used to obtain the transfer function using mathematical model to design the PID controller. Then effectiveness of the design is checked by using MATLAB/Simulink. It was created simulation model at the MATLAB programmed and design a proportional integral derivative controller. Generally, DC servo motors has uncertain and nonlinear characteristics which degrade performance of PID controller. As we know motor is fast dynamic system and its sampling time is in milliseconds, this work intended to implement MPC on fast dynamic system. This work is to design a MPC controller for servo motor systems.

Then after also create a MPC controller for achieve a better performance compare to PID controller. Take a comparison of Single Input Single Output Model Predictive Control has been carried out with respect to standard PID Controller of MATLAB. Automatic control of DC servo motor rotation angle has played a important role in the advance Electromechanical Engineering. There are many types of dc servo motors use in a wide range of industrial application that require high performance on position control such as numerically controlled machinery, robotics, weapon industry, automation, speed control of alternators and other mechanism where the starting and stopping functions are quickly and accurately. The servomotors used in many industries today are used in a closed-loop servo system. According to literature review of different control strategy first is Sliding Mode Control (SMC) has good robustness but some limitation is chattering in output results. Second is fuzzy logic approach giving a simpler, quicker and more reliable solution but it is less robust. Third is Linear Quadratic Regulator (LQR) and Linear Quadratic Gaussian (LQG) methods, which operate on a finite horizon without capability to handle constraints. The predictive control strategy overcomes the limitation of the other conventional techniques. Predictive control has ability to do on-line constraints handling in a systematic way.Thus, here consider the Model Predictive Control to get best performance. Several methods have been accommodated in this paper for determining the good performance of servo system. Like that PID controller which is first found by Ziegler- Nichols tuning method and second found by Good-Gain tuning method.

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II. BASICS OF DC SERVO MOTOR

The DC servo motor is basically a torque transducer that converts electric energy into mechanical energy. The small laboratory motors are servomotors, which is uses for positioning control in a variety of automation applications. DC servo motor is an electromechanical device in which the electrical input determines the position of motor armature. The armature is driven by an external DC voltage that produces the motor torque and the motor speed. The DC servo motor is used extensively in control systems, it is necessary to establish mathematical models of dc servo motors for analytical applications.

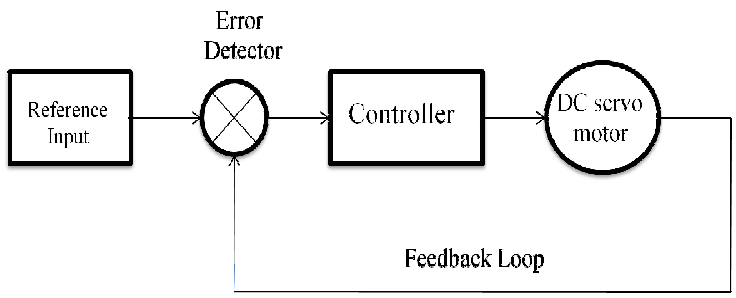

Fig 1: Basic servo system block diagram

The servomotors used in many industries today are used in a closed-loop servo system. A reference input is sent to the error detector which compare error signal with feedback signal and generate the error signal. Error signal given to the controller to minimize the error. Controller output fed to the DC servo motor to control the speed as well as Position of the servomotor. Directly mount the servomotor in a feedback device (like as an encoder or tachometer). This device changes mechanical motion into electrical signals and is used as a feedback loop. This feedback loop is then sent to the error detector, which compares the actual operation with that of the reference input. If there is an error, that error is fed directly to the controller, which makes the necessary corrections. In many servo systems, both velocity and position are monitored and measured. A normal servo is used to control an angular motion of between 0 and 180 degrees. The 360° rotation servos are continuous rotation servo. With the continuous rotation servo you can only control the direction and speed of the servo, but not the position of shaft. PWM is used for the control signal of servo motors. However, unlike DC motors it’s the duration of the positive pulse that determines the position, rather than speed, of the servo shaft.Servo motors work with full torque at high speeds. Servo motors have a position sensing device attached to the drive motor that reports the actual position of the motor shaft back to the motor controller.

III. SYSTEM MODEL AND SPECIFICATION

In this dc servo motor can be consider as a linear SISO system having 3rd order transfer function.The speed and position of a DC servo motor can be varied by controlling the field flux, the armature resistance or the terminal voltage applied to the armature circuit. The three most common speed control methods are field resistance control, armature voltage control, and armature resistance control. Here we consider the armature voltage control because servo motor is less sensitive to change in field current. In torque equation field flux is large enough. Thus, every small change in armature current Ia becomes much sensitive to the servo motor. As the armature of DC servo is less inductive and more resistive, time constant of armature winding is small enough. Thus dynamic response of armature controlled DC servo motor is much faster than that of field controlled DC servo motor.

The main disadvantage of field control of DC servo motor is that the dynamic response to the error is slower because of longer time constant of inductive field circuit. The field is an electromagnet so it is basically a highly inductive circuit hence due to sudden change in error signal voltage, the current through the field will reach to its steady state value after certain period depending upon the time constant of the field circuit. Thus, field controlled DC servo motor mainly used in small servo applications. Thus, here consider the armature controlled DC servo motor system. Motor Model specific parameters are also gives at the below.

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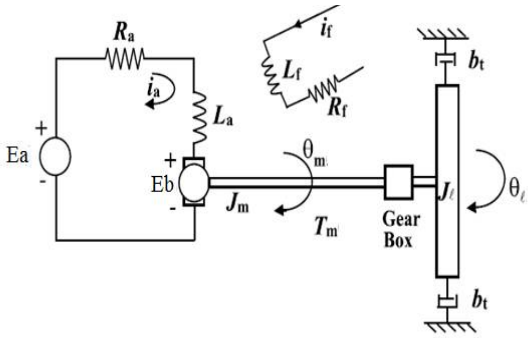

Fig 2: Armature controlled DC servo motor

The torque T is delivered by the motor is proportional to the product of the armature current Ia and the air gap flux Φ.

$$T = \varphi . i_a$$
$$\varphi = k_f . i_f$$

Where, k_f is constant. The torque can be written as,

$$T = k_f . i_f . k_a . i_a$$
$$T = K . i_a$$

Where, k_a is also propositional constant. The back emf is proportional to the angular velocity,

$$e_b = k_b . \frac{d\theta}{dt}$$

The speed of an armature controlled DC servo motor is controlled by the armature voltage Ea, which is supplied by a power supply .The differential equation for the armature circuit is by using Kirchhoff's voltage law,

$$L_a \frac{di_a}{dt} + R_a i_a + e_b = e_a$$

The armature current creates the torque which is applied to the inertia and friction is

$$J \frac{d^2\theta}{dt^2} + B \frac{d\theta}{dt} = T$$

Taking the Laplace transforms of the above three differential equations,

$$e_b(s) = k_b . s . \theta(s)$$

$$(L_a s + R_a) I_a(s) + k_b . s . \theta(s) = E_a(s)$$

$$(J s^2 + B s)\theta(s) = K . i_a(s)$$

$$\theta(s) = \frac{K}{(J\, s^2 + \, Bs)} \left[\frac{E_a(s) - \; k_b . s . \theta(s)}{(L_a s + \; R_a)} \right]$$

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$$\theta(s) = \frac{K\,E_a(s) - K\,k_b.s.\theta(s)}{(J\,s^2 + Bs)(L_a s + R_a)}$$

$$\frac{\theta(s)}{E_a(s)} = \frac{K}{JL_a s^3 + (JR_a + BL_a)s^2 + (BR_a + Kk_b)s}$$

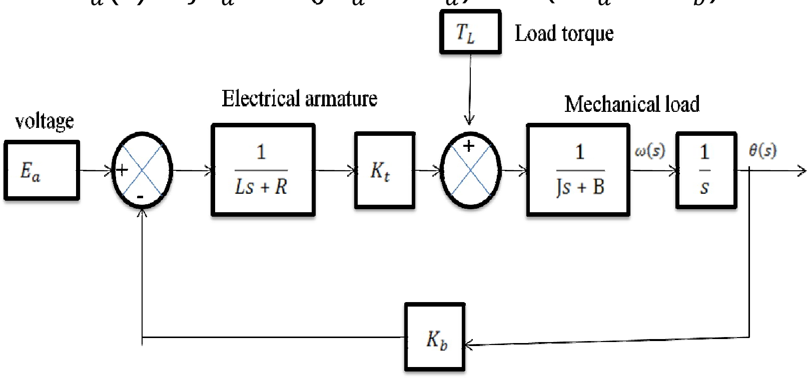

Fig 3. Model of DC servo motor

This transfer function is the Position control of DC servo motor. Estimation of model is done by system identification tool in MATLAB. According to this find the DC servo motor parameters to find the final system model transfer function.Finally, the transfer function of the DC servo motor is given as,

$$\frac{\theta(s)}{E_a(s)} = \frac{0.023}{0.0046s^3 + 0.0269s^2 + 0.03053s + 0.001533}$$

DC servo motor parameter

1) J-moment of inertia 0.02 kg.m^2 2) Kt-torque constant 0.023 NM/A 3) K_b-electromotive force constant 0.023 Vs/rad 4) b_m-linear viscous friction 0.03 Nms/rad 5) R-resistance 2 Ω 6) L-inductance 2.3 mH

IV. PID CONTROLLER FOR DC SERVO MOTOR

In the open loop control of actual DC servo motor that the motor positions start to drift over time indicating continuous addition of error within the same system. Second handed that should have no way to enforce the output of the motor to track the input voltage in the absence of any feedback loop. For open loop system feedback gain is not presented. Thus, it cannot give accurate output of shaft position for servo motor. To overcome this problem we used feedback loop in the system. In feedback path consider the feedback devices like Potentiometer, encoder, resolver etc. Its output compare with the desirable (Reference) input and generate the some error signal is degrade by using a controller. Controller output is control signal fed to the system model to control the position of servo motor. For controller purpose first use conventional PID of different tuning method.

Now a day's PID controllers are mostly used in the different industry. Position control of motor systems is normally unstable when they are implemented in closed loop system. The PID controller algorithm involves three separate parameters: Proportional, Integral and derivative values, denoted P, I, and D. these values can be interpreted in terms of time: P depends on the present error, I on the accumulation of past errors, and D is a prediction of future errors, based on current rate of change. PID controller tuning for positional control of motor are a time consuming task, therefore much effort has been given to analyze the servo system. Apply Conventional PID tuning method Ziegler-Nichols and Good-Gain method for position control of DC servo motor.

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$$U(t) = k_p * e(t) + k_i \int_0^t e(t)\, d(t) + k_d \frac{de(t)}{d(t)}$$

Where,
Kp : Proportional gain, a tuning parameter
Ki : Integral gain, a tuning parameter
Kd : Derivative gain, a tuning parameter
e(t) : Error = Set Point – Present Value
t : Time or instantaneous time

Methods of PID tuning:

No of PID tuning method are available for system control. Conventional PID tuning method, Ziegler-Nichols, Pole placement, Good-gain method and other soft computing method also present to gets accurate system output. Here two methods are applied first Ziegler-Nichols (Z-N) and second Good-Gain method for PID tuning.

[1] Z-N Method

Ziegler-Nichols method is a conventional PID tuning method. This method also known as online or continues cycling or ultimate gain tuning method. Ziegler-Nichols represented two methods way 1) Step response method 2) Frequency response method. Here applied based on the frequency response method for tuning the PID controller. In this method derivative time (Td) is set to zero and integral time (Ti) set to infinity. This is used to get the initial PID setting of the systems. It has ultimate gain and frequency (K_u and P_u) from initial graph. Critical gain (Ku) and periodic oscillations (Pu).Values of Kp , Ki and Kd are determined using the given formulasKp=0.6*Ku ,$Ki = Kp/Ti$ and $Kd = Kp * Td$. Where, Kp , Ti , Td are calculated by using the formulas given in below table, Pu=2Π/ ω.

Table 1: Z-N tuning parameter

Control type	k_p	T_i	T_d
P	$0.5k_u$	inf	0
PI	$0.45k_u$	$0.833P_u$	0
PID	$0.6k_u$	$0.5P_u$	$0.125P_u$

[2] Good-Gain method

It used to give the control loop better stability than the Ziegler-Nichols' methods. The Ziegler-Nichols' methods are designed to give an amplitude ratio between subsequent oscillations after a step change of the set. This is often regarded as poor stability. The Good Gain method gives better stability. However, the Good Gain method does not require the control loop to get into oscillations during the tuning, which is second benefit compared to the Ziegler-Nichols methods.

V. SIMULINK MODEL OF PID CONTROLLER FOR DC SERVO MOTOR

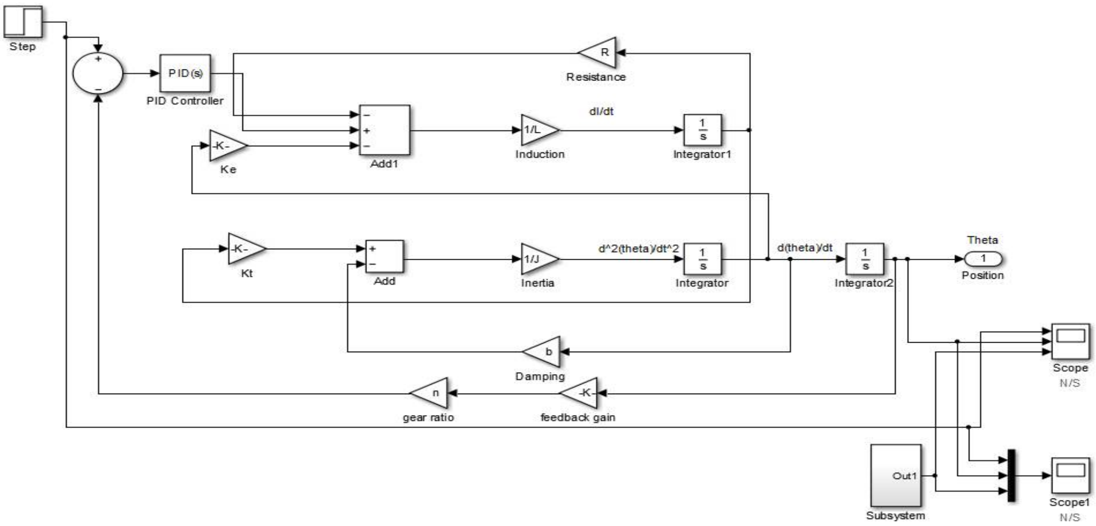

Fig 4: Block diagram of closed loop PID Controller for DC servo motor

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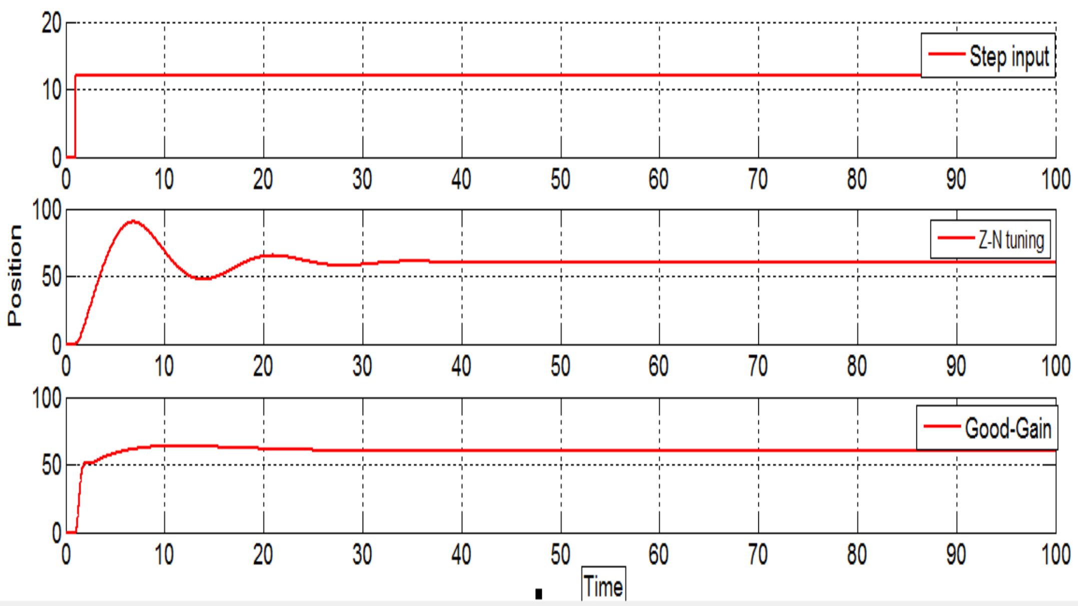

Fig 5: Simulink Results of DC servo motor with PID controller

VI. MPC CONTROLLER FOR DC SERVO MOTOR

MPC (Model Predictive Controller) is a latest method of process control. For Process control of industries like as Petrochemical plants, paper mills, and Oil refineries etc. The models used in MPC are generally representing the behavior of complex dynamical systems. MPC is not just the name of one or some specific computer control algorithms but control methods which make an explicit use of a model of the process to obtain the control signal by minimizing an objective function. MPC controllers used for almost all kinds of systems, linear or nonlinear, continuous or discrete, integrated or distributed. The various MPC algorithms only difference between them is the model used to represent the process and the noises and the cost function to be minimized. Model Predictive Control (MPC) is a no of control in which the current control signal is determined such that desirable output behaviour results in the future. The process of

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construction of model from the input and the output data is known as model identification.Thus we need the ability to efficiently predict the future output behaviour of the system. By using a state-space model, the current information required for predicting ahead is represented by the state variable at the present time. A cost function is minimized subject to constraints to compute an optimal vector (u (k), u (k+1), u(k+2),.., u (k+1)) controls of future input signals at sample k over a specified time horizon, which is usually called control horizon . Finally the optimal value of control vector is then applied to the plant. Predictive horizon defines as at each sampling time instant k, the model of the plant (system) is used to predict the future behavior of the controlled plant over a specified time horizon. MPC controller has easy tuning method.MPC Minimize the operating cost and meeting constraints (optimization, economic).Superior for processes with large number of manipulated and controlled variables (Multivariable, MIMO).

$$J = \sum_{i=1}^{N} W_{xi}(r_i - x_i)^2 + \sum_{i=1}^{N} W_{ui} \Delta ui^2$$

xi = i -th controlled variable
r_i = i -th reference variable
ui = i -th manipulated variable
W_{xi}= weighting coefficient reflecting the relative importance of xi
W_{ui} = weighting coefficient penalizing relative big changes in ui.

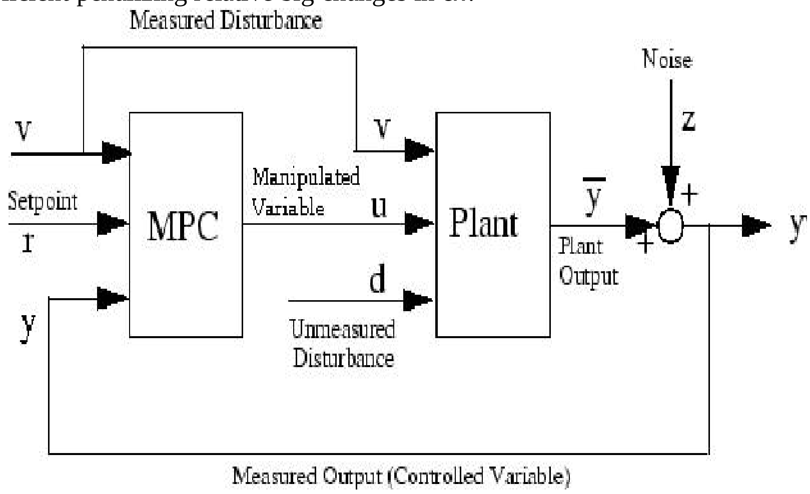

Fig 6: Block Diagram of a SISO Model Predictive Control Toolbox

The information about the controlled process and prediction of the response of the process values according to the manipulated control variables are done by the process model. In order to design a good controller for a plant, model is usually required a controller designed on the basis of a model often works well than the one designed without a model. The object of this model is to predict the latest value taken by the noise (Disturbance).The process of construction of model from the input and the output data is known as model identification. There are mainly three components are available in MPC structure like as, the process model, the cost function and the optimizer. Then the error is reduced by the minimization of the cost function. Usually the cost function depends on the error between the future reference variable and the future controlled variable within limited time horizon. In the last step various types of optimization techniques are used and the output gives to the input sequence for the next prediction horizon.

The first step in a design is to define the plant model in MATLAB m-file. To implement MPC on DC servo motor system, first it must be simulated in software. Then after makes Simulink model of MPC controller in Simulink as shown in above figure. Design of model predictive controller is consider some parameters: Prediction and Control Horizons, weight on manipulated variables and output variables, Models for measurement noise and for unmeasured

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input and output disturbances. Increase the PH makes system critically damped with minimum settling time and no peak overshoot, further increase in PH makes system over damped increasing settling time.

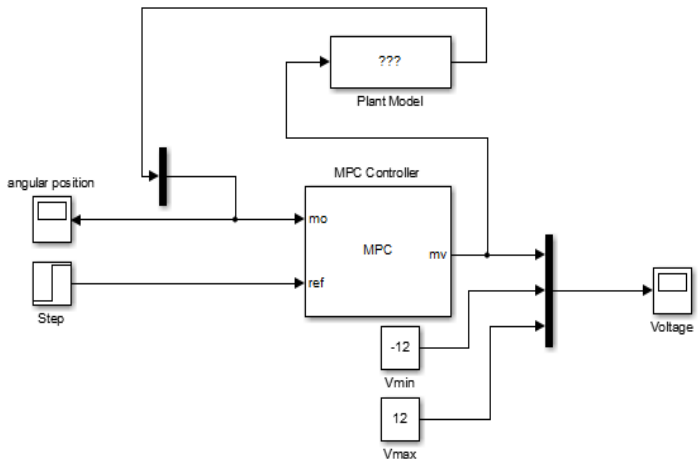

Fig 7: Simulink model of MPC for DC servo system

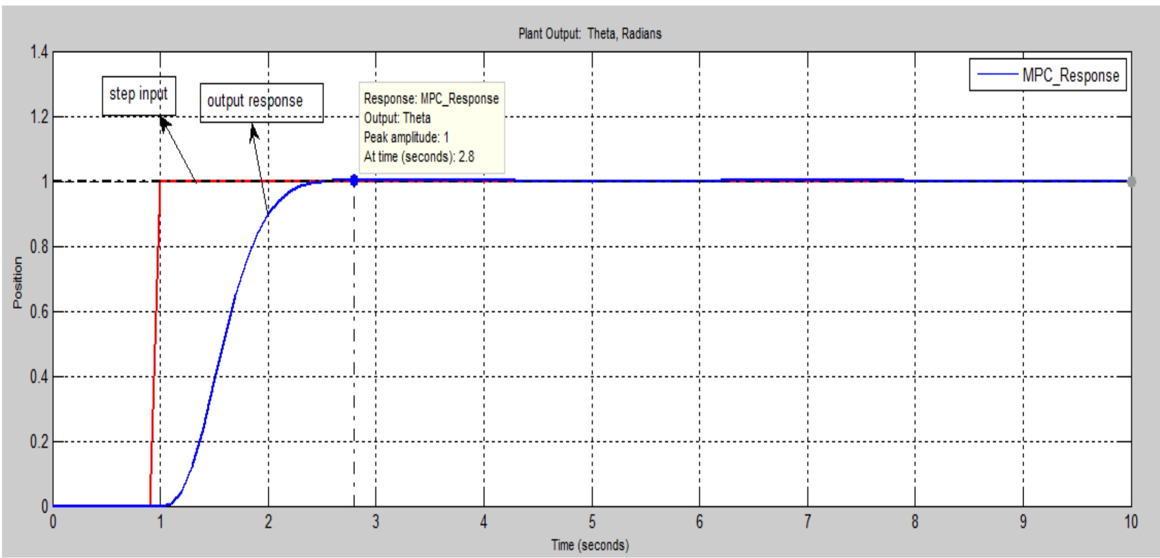

Fig 8: Simulation results of MPC controller for DC servo motor

Since, we can seen from above figures closed loop PID system response has very large rise time and settling time. And Peak Overshoot is also higher percentage. Using PID tuning we get rise time 4.03(sec), settling time 30.4(sec) and peak overshoot is 15.3(%). Using the PID controller for different tuning method we get better performance compare to without controller. It has good performance but not sufficient for high performance system. So that, applied other control strategy MPC controller for DC servo motor. It has very less rise time and settling time. Rise time is 1.57(sec), settling time is 2.8(sec) and Peak overshoot is 0(%) So that, MPC controller gives higher accuracy compared to PID controller.

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Table 2: Performance comparisons of different methods

Sr.No.	Performance Index	Z-N PID tuning	Good-Gain PID Tuning	MPC
1	Rise time	5.2(sec)	4.03(sec)	1.57(sec)
2	Settling time	96.7(sec)	30.4(sec)	2.8(sec)
3	Peak Overshoot	24.7(%)	15.3(%)	0(%)
4	Steady state error	5(%)	2.5(%)	1.25(%)

Here, we can seen from table closed loop system response has very large rise time and settling time. And Peak Overshoot is also higher percentage. Using the PID controller we get better performance compare to without controller. However, for PID controller we need to tune the control parameter by using different tuning method. Thus, we would used two PID tuning method first, Ziegler- Nichols and second, Good-Gain. Ziegler- Nichols has more accurate transient response compare to closed loop system without controller such as, rise time, settling time and Peak overshoot is less. It has good performance but not sufficient for high performance system. So that, applied other method Good-Gain. It has very less rise time and settling time. And Peak overshoot is also very less compare to Z-N method. But it is not sufficient small parameter to achieve the good performance of servo system. Thus, MPC controller is used to get best performance of servo system.MPC has very small rise time 1.57 sec only compare to PID controller. Also, settling time is very less compared to other controller. MPC has zero percentage Peak overshoot.

VII.CONCLUSION

The basics concept of PID controller should be completed. The simulation of Closed-Loop DC servo motor using PID controller and MPC controller are done in MATLAB. Also applied two PID tuning method for Position control of DC servo motor. The use of the PID algorithm for control does not guarantee optimal control of the system or system stability. Thus, we use the higher performance controller Model Predictive Controller to achieve best system performance.MPC controller has very small rising time, less peak overshoot and less settling time.

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BIOGRAPHY

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