



DC MOTOR SPEED CONTROLLER DESIGN USING POLE ASSIGNMENT TECHNIQUE FOR INDUSTRIAL APPLICATION

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ABSTRACT

This paper describes DC motor speed control based on pole assignment feedback control technique. The present pole assignment technique specifies all closed-loop poles. Such a system where the reference input always zero is called a regulator system. The problem of shifting the regulator poles (closed-loop poles) at the desired location is called pole assignment problem, and this can be done if and only if the system is completely state controllable. Controller's objective is to maintain the speed of rotation of the motor shaft with a particular step response.

Results obtained were compared with another controller applied to the DC motor based on Proportional Integral Derivative (PID) control. The controller was designed and tested using MATLAB 7 programming language.

PID

MATLAB 7

KEYWORDS: DC motor, Speed control, PID controllers, Pole assignment technique

INTRODUCTION:

An electric motor is an electromechanical device that converts electrical energy into mechanical energy. This mechanical energy is used, for example, for rotating a pump impeller, fan or blower, driving a compressor, lifting materials etc. Electric motors are used at home (mixer, drill, fan) and in industry.

The purpose of a motor speed controller is to take a signal representing the demanded speed, and to drive

a motor at that speed. The controller may or may not actually measure the speed of the motor. If it does, it is called a Feedback Speed Controller or Closed Loop Speed Controller, if not it is called an Open Loop Speed Controller. Feedback speed control is better, but more complicated.

In modern intelligent motion applications especially in industry, the demand to the accurate speed and position control is increasing. In the mean time, it is also expected that control systems should be reliable,

cost effective, robust and, having with low volume weight and maintenance requirement. [Ayasun and Karbyaz, 2007]

Because of the improvements in computers software packages for modeling and simulations, many authors tried to build controllers to control the speed of a DC motor.

[Ayasun and Karbyaz, 2007] describe the MATLAB/SIMULINK realization of a DC motor speed control methods, namely field resistance, armature voltage and armature resistance control methods, and feedback control system for DC motor drives. They studied the torque/speed characteristics for different field resistance, armature voltage and different armature resistance, showing how the speed of the motor vary for different PI gain values.

[Sharaf, Elbakush and Altas, 2007] present a novel PID dual loop controller for a solar photovoltaic (PV) powered industrial permanent magnet DC (PMDC) motor drive. MATLAB /SIMULINK was used in the analysis.

[Silva, Carvalho, Vasconcelos and Soares, 2007] present a remote experiment for controlling a DC motor. The experiment is controlled using a PID algorithm programmed in LabView environment.

[Roubal, Augusta, and Havlena, 2005] present the procedure of the control design, including a description of a system, an identification of its parameters, a simple and an advanced controller design based on optimal control.

[Aung, 2007] gave an analyze how to choose DC motor to be balance with their applications of especially for Wheeled Mobile Robots (WMR). Specification of DC Motor that can be used with desire WMR is to be determined by using MATLAB Simulink model.

MOTOR MODEL

Generally, the rotational speed of a DC motor is proportional to the voltage applied to it, and the torque is proportional to the current. Speed control can be achieved by variable battery tappings, variable supply voltage, resistors or electronic controls.[speed controller,2008]

A simple motor model is shown in Fig. 1. The armature is modeled as a circuit with resistance R_a

connected in series with an inductance L_a , e_a and e_b represent a voltage source and the back emf (electromotive force) in the armature when the rotor rotates respectively. [Ogata-1998, Ogata-2002, Dorf and Bishop-2005].

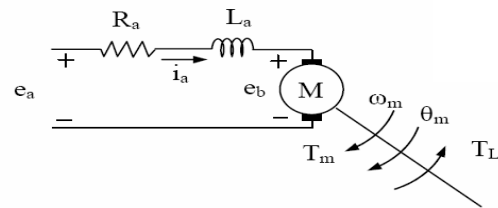


Fig. 1 DC Motor Model.

The motor torque T_m is related to the armature current, i_a , by a torque constant K_t ;

$$T_m = K_t i_a \quad (1)$$

The back emf, e_b , is relative to angular velocity by;

$$e_b = K_b \omega_m = K_b \frac{d\theta_m}{dt} \quad (2)$$

From Fig. 1 we can write the following equations based on the Newton's law combined with the Kirchoff's law. [Ogata, 1998]

$$L_a \frac{di_a}{dt} + R_a i_a = e_a - K_b \frac{d\theta_m}{dt} \quad (3)$$

$$J_m \frac{d^2\theta_m}{dt^2} + B_m \frac{d\theta_m}{dt} = K_t i_a \quad (4)$$

There are several different ways to describe a system of linear differential equations. The plant model will be introduced in the form of **state-space representation** and given by the equations:

$$\begin{aligned} \dot{x} &= Ax + Bu \\ y &= Cx + Du \end{aligned} \quad (5)$$

According to equations from (2) to (4), the state space model will be:

$$\begin{bmatrix} \dot{i}_a \\ \dot{\omega}_m \\ \dot{\theta}_m \end{bmatrix} = \begin{bmatrix} -R_a/L_a & -K_b/L_a & 0 \\ K_t/J_m & -B_m/J_m & 0 \\ 1 & 1 & 0 \end{bmatrix} \begin{bmatrix} i_a \\ \omega_m \\ \theta_m \end{bmatrix} + \begin{bmatrix} 1/L_a \\ 0 \\ 0 \end{bmatrix} e_a \quad (6)$$

$$\dot{\omega}_m = [0 \quad 1 \quad 0] \begin{bmatrix} i_a \\ \omega_m \\ \theta_m \end{bmatrix} \quad (7)$$

Fig.2 shows the closed loop control system for the DC motor in the form of a block diagram. [Aung,2007].

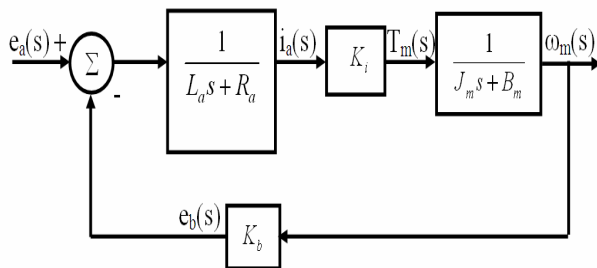


Fig. 2 DC-Motor System Block Diagram

POLE ASSIGNMENT TECHNIQUE:

In this section a design of a commonly called Pole-Placement or Pole-assignment technique will be presented. All state variables are assumed to be measurable and available for feedback. If the system is considered completely state controllable, then poles of the closed-loop system may be placed at any desired locations by means of state feedback through an appropriate state feedback gain matrix.

In the conventional approach to the design of a single-input-single-output control system a designed controller (compensator) such that the dominant closed-loop poles have a desired damping ratio ζ and an undamped natural frequency ω_n . In this approach, the order of the system may be raised by 1 or 2 unless pole-zero cancellation takes place.

In brief the pole assignment technique is somewhat similar to the root locus method in that a closed loop poles are placed at desired locations. The basic difference is that in root locus design only the dominant closed loop poles are placed at the desired locations, while in the pole assignment technique all the closed loop poles are placed at the desired locations. [Ogata-1998, Ogata-2002, Dorf and Bishop-2005].

For a control system of eq. (5) and depending on the pole assignment the control signal will be:

$$u = -Kx \quad (8)$$

Fig.3 shows the control model that is based on the pole assignment.

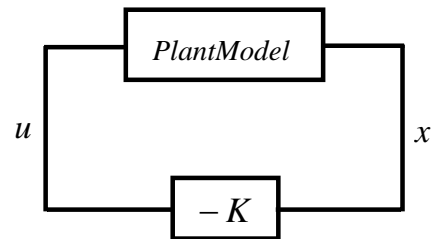


Fig. 3 Closed Loop Control System

This means that the control signal u is determined by the instantaneous state, Substituting eq. (8) into eq. (5) gives

$$\dot{x}(t) = (A - BK)x(t) \quad (9)$$

The solution of this equation is given by

$$x(t) = e^{(A-BK)t} x(0)$$

Where $x(0)$ is the initial state caused by external disturbances. The stability and transient response characteristics are determined by the eigenvalues of matrix $(A - BK)$. The eigenvalues of matrix $(A - BK)$ are called regulator poles. If these regulator poles are placed in the left-half s-plane, then $x(t)$ approaches 0 as t approaches infinity. The problem of placing the regulator poles (closed-loop poles) at the desired location is called a pole assignment problem. [Ogata-1998, Ogata-2002, Dorf and Bishop-2005].

CHOOSING THE LOCATION OF DESIRED CLOSED LOOP POLES:

The first step in the pole assignment technique is to choose the location of the desired closed loop poles. The most frequently used approach is to choose such

poles based on experience in the root locus design, placing a dominant pair of closed loop poles and choosing other poles so that they are far to the left of the dominant closed loop poles.

Note that if the dominant closed loop poles are placed far from the $j\omega$ axis, so that the system response becomes very fast, the signals in the system become very large, with the result that the system may become nonlinear. This should be avoided. [Ogata,2002]

PID TECHNIQUE:

The Proportional Integral Derivative (PID) controller calculation (algorithm) involves three separate parameters; the proportional, the integral and derivative values. The proportional value determines the reaction to the current error, the integral value determines the reaction based on the sum of recent errors, and the derivative value determines the reaction based on the rate at which the error has been changing, as shown in Fig. 4.

By tuning the three constants in the PID controller algorithm, the controller can provide control action designed for specific process requirements. The response of the controller can be described in terms of the responsiveness of the controller to an error, the degree to which the controller overshoots the set point and the degree of system oscillation. [Ogata-1998, Ogata-2002, Dorf and Bishop-2005].

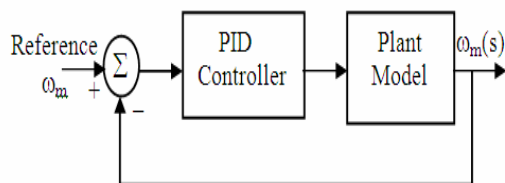


Fig. 4 PID Controller System Block Diagram

SIMULATION RESULTS:

This section presents simulation results for the speed control of a DC motor given in Appendix (A) using pole assignment technique through feedback control system. The steps of the PID controller and pole

assignment design and comparison between them based on time domain is given in the flowchart of Fig. 5.

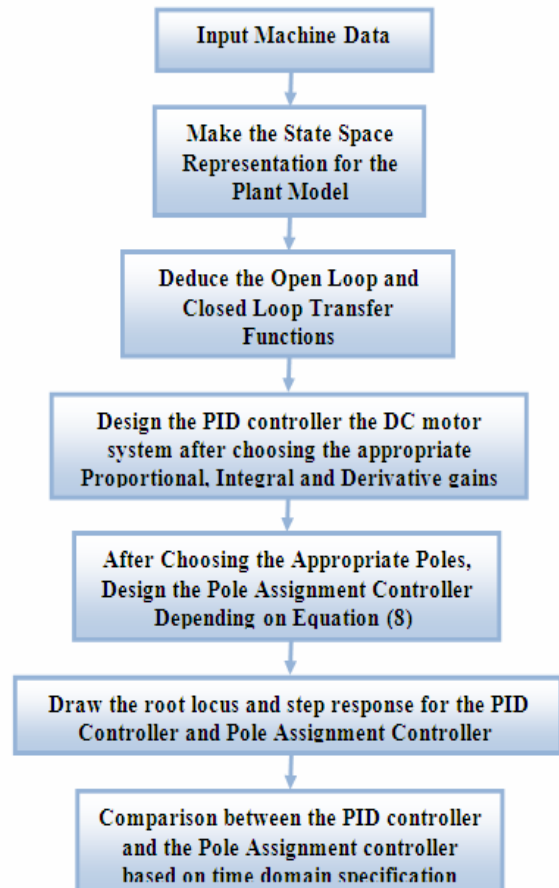


Fig.5 Flowchart for the Controller Design Procedure

In many practical cases, the desired performance characteristics of control systems can be given in terms of transient-response characteristics.

The open loop transfer function of the DC motor according to the selected data can be given as in eq. (10), with two poles $(-0.0575+j0)$ and $(-1.95+j0)$:

$$TF_{open-loop} = \frac{0.23}{0.0055s^2 + 0.010025s + 0.000559} \quad (10)$$

To examine the accurate speed and position control, the time domain specifications (Settling time; Peak amplitude, Maximum overshoot) the close loop control system should be studied.

The closed loop transfer function of the DC motor according to the selected data can be given as in eq.(11), with two poles $(-1+j1.96)$ and $(-1-j1.96)$:

$$TF_{\text{closed-loop}} = \frac{0.23}{0.0035s^2 + 0.010025s + 0.02356} \quad (11)$$

The closed loop step response (with unity feedback control) is shown in Fig. 6, which shows that the settling time of 3.83second and peak amplitude of 1.17.

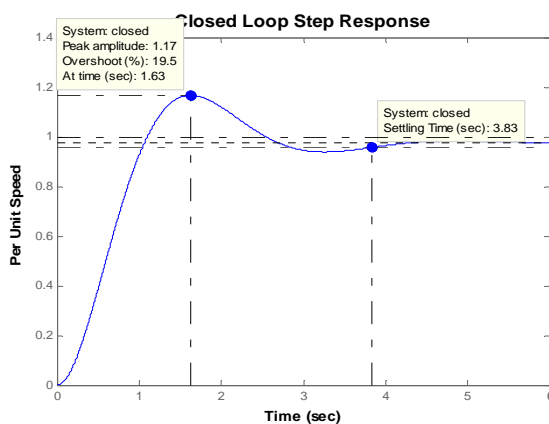


Fig. 6 Closed Loop Speed Step Response

Fig. 7 shows the step response for the PID controller which gives settling time of 2.76 sec and the peak amplitude of 1.85.

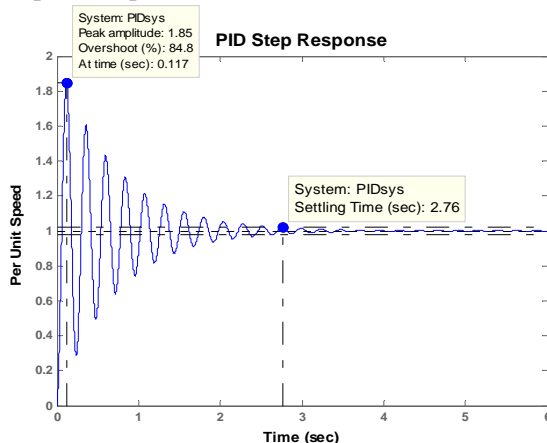


Fig. 7 PID Speed Step Response

Fig. 8 shows the root locus for the pole assignment technique where the closed loop roots $(-1+j1.96)$ and $(-1-j1.96)$ are shifted to $(-2.025 + j0.7)$ and $(-2.025 - j0.7)$, this shift was done by tray and error to give more stability for the system.

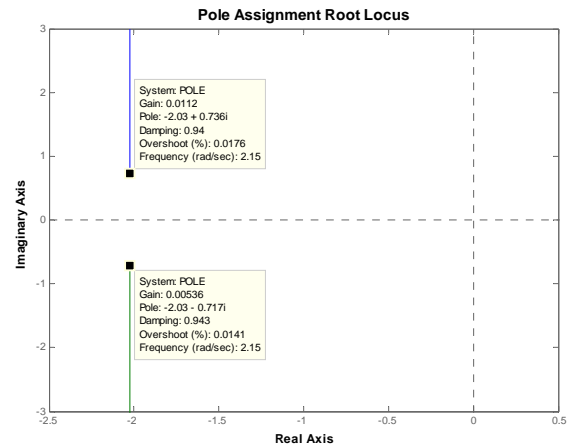


Fig. 8 Pole Assignment Root Locus

Fig. 9 shows the step response for the Pole Assignment controller which gives settling time of 2.43 sec and peak amplitude of 1.

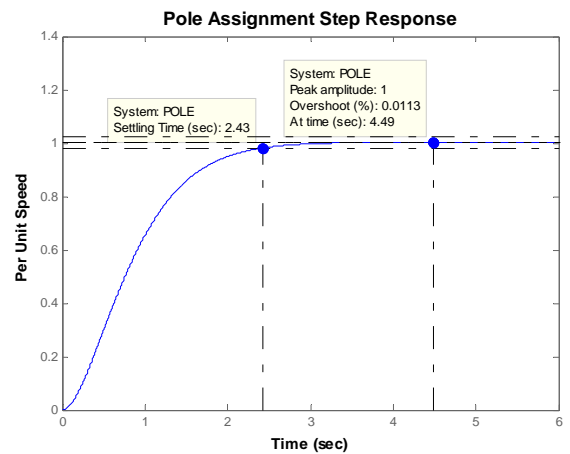


Fig. 9 Pole Assignment Speed Step response

Table 1 summarizes the values of settling time, peak amplitude and overshoot for the three different control systems, which are given previously, it is clear that the pole assignment controller is better.

Table 1: Time response specification for three speed control systems

	Settling Time	Per Unit Speed	Over shoot
Closed Loop With Unity Feedback	3.83 sec	1.17	19.5%
PID Controller	2.76 sec	1.85	84.8%
Pole Assignment Controller	2.43 sec	1	0.0113%

Drawing the plots of the closed loop with unity feedback and with PID controller and with Pole Assignment are clear indicated in Fig.10

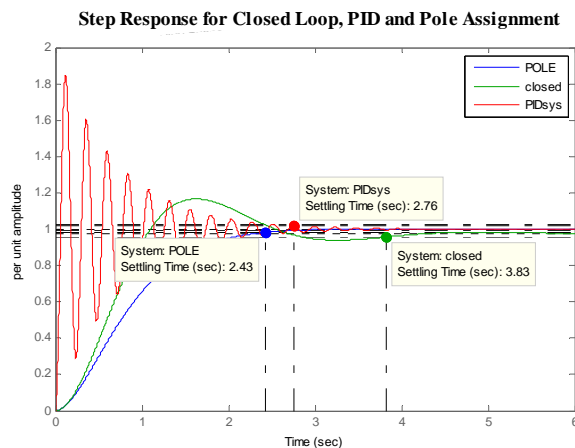


Fig. 10 Closed Loop, PID and Pole Assignment Speed Step responses

CONCLUSION

The paper presents a controller design for a dc motor speed control based on Pole Assignment technique which has been compared with another type of controller like the PID controller and with only closed loop unity feedback (no controller).

Table 1 and Fig. 10 above shows the time response specifications which indicates clearly that using the Pole Assignment Technique as a speed controller for the DC motor is a very efficient, since it shifts the left hand poles to a stable region far away from the critical area.

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**LIST OF SYMBOLS**

A = $n \times n$ constant matrix
 B = $n \times 1$ constant matrix
 B_m = viscous friction coefficient (kgm²/s)
 C = $1 \times n$ constant matrix
 D = constant
 $e_a(t)$ = applied voltage (V)
 $e_b(t)$ = back emf (V)
 $i_a(t)$ = armature current (A)
 J_m = moment of inertia of rotor (kgm²)
 K_i = torque constant (Nm/A)
 K_b = back emf constant (V/rad/s) ($K_b = K_i$)
 L_a = armature inductance (H)
 R_a = armature resistance (Ω)
 $T_L(t)$ = load torque (Nm)
 $T_m(t)$ = motor torque (Nm)

u = control signal
 x = state vector
 y = output signal
 ϕ = magnetic flux in the air gap (Weber, Wb = Vs)
 $\theta_m(t)$ = rotor displacement (rad)
 $\omega_m(t)$ = rotor angular velocity (rad/s)
 ω_n = undamped natural frequency
 ζ = damping ratio

APPENDIX A

DC motor data are: $E = 12$ Volt
 $J_m = 0.01$ kgm², $B_m = 0.00003$ kgm²
 $K_i = 0.023$ Nm/A, $K_b = 0.023$ Nm/A
 $R_a = 1\Omega$, $L_a = 0.5$ H