Design and Simulation of DC MOTOR Speed Controller using Pole Placement Technique and MATLAB

Ahmed Abdelrahman A.A.[1], Asaad Musaab Ali Yousif[2], Abubker Dahab[3], Mohammed Ahmed A.A.[4] and Abdalbagy Ahmed M.[5]

[1]**Department of Electrical and Computer Engineering, Karary University, Omdurman, Sudan**
mogwari2000@yahoo.com

[2]**Department of Electrical and Computer Engineering, Karary University, Omdurman, Sudan**
abuasgad14@gmail.com

[3]**Department of Electrical and Computer Engineering, Karary University, Omdurman, Sudan**
asaadm.mosap@gmail.com

[4]**College of Post Graduate Studies, Karary University Omdurman, Sudan**
moh204b40@yahoo.com

[5]**College of Post Graduate Studies, Karary University Omdurman, Sudan**
abdalbagya55@gmail.com

Abstract

Motor speed is very important in rotating machinery applications. This thesis describes DC motor speed control based on pole placement feedback control technique. The pole assignment technique specified closed –loop poles such a system where the reference input always zero is called regulator system. The problem of regulator poles (closed –loop poles) at desired location is called pole assignment problem. And this can be done if the system is completely state controllable. Controller's objective is to maintain the speed of rotation of motor shaft with a particular step response. By using pole placement technique specifies state feedback and get good results are as enable Overshoot less than 1.73%, Settling time less than 1.16 sec, No steady state error and MATLAB 2013 software.
Keywords: DC Motor, Speed Control, Pole Placement Technique.

Introduction

Control theory is an interdisciplinary branch of engineering and mathematics that deals with the behavior of dynamical systems. The usual objective of control theory is to determine solutions for the proper corrective action from the controller that result in system stability.

High performance motor drives are necessary parts of industrial applications. A DC motor drive system with high performance has special characteristics such as good dynamic speed command tracking and load regulating response. DC motors are well known for their excellent control of speed for acceleration and deceleration [1].

PID Controllers

PID Controllers used in large quantities for the choice when controller needed a closed loop. PID provides the designer huge options if designer want to change the dynamics of system. Almost in any industry 90% controllers are PI controllers while the rest 10% are PID and other controllers. If everything goes in right direction then designer can get following advantages. P part reduces step time to reach to designed position. This part removes the steady state error. I integral part removes the overshoot got by p. D part used to reach error but if system is noisy then D part not used [2].

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Pole Placement Controller

Pole Placement controller provides excellent control as designer can adjust the time to reach on the reference point by adjusting poles. This controller use most straight forward design. It starts with assumption that what controller wants to do. From the assumption symbolic characteristic equation is formed, and poles determined which leads to design overshooting rise time. In this controller mostly equation is 2nd order and most equation has more that 2 poles.

By this way equation can be formed and model is formulated as discrete transfer function. Disturbance model is not used when designer use pole placement design. Integrator design is used to drive steady state to 0. In Pole Placement poles are placed in closed loop transfer function in reasonable position [2].

Fuzzy Controller

Fuzzy controller is an innovative technology that modifies the design of systems with engineering expertise. Fuzzy logic use human knowledge to implement a system. It is more effective than PID controller as its reach to its reference level in less time. It is mostly use in that no mathematical equations for handling system. Common sense, human thinking and judgment are fuzzy rules. It helps engineers to solve non linear control problems. It mathematically emulates human knowledge for intelligent control system and complex application [2].

Previous Studies

It presents an overview of Proportional Integral control (PI) and Artificial Intelligent control (AI) algorithms. AI and PI controller are analyzed using Matlab [Simulink] software motor. The main objective is illustrates how the overshoot and steady state error of the DC motor can be controlled using different controllers. The simulation results demonstrate that the responses of DC motor with an AI control which is Fuzzy Logic Control shows satisfactory well damped control performance. The results shows that Industrial DC Motor model develop using its physical parameters and controlled with an AI controller give better response, it means it can used as a controller to the real time DC Motor transient error [3].

It presents a novel method for design and simulation of a DC motor closed loop control system in Field Programmable Gate Array device (FPGA). The digitally designed PID controller is more advanced, beneficial and therefore produces a better response, as compared to the analog PID with velocity measurement. It can be implemented on system-on-chip devices easily. MATLAB Xilinx system generator toolbox based on Fixed-Point Arithmetic is used to design the digital PID controller using DSP architecture, plot the responses of the control system and generate the VHDL source code. The control system consists of a digital PID, the model of a real DC motor, a real and new incremental optical shaft encoder model, encoder to rpm and position blocks. Results show that the proposed system leads to lower the steady state error [4].

Many industrial applications require high performance rotating electric drives. A proposed D C drive have precise speed control, stable operation in complete range of speed and good transient behavior with smooth and step less control. The purpose of developing a simulation using PI and PID control system is to get steady state and transient response of drive system. Once the type of controller has been decided then the design and analysis are done. It show focuses modeling of separately excited DC motor for the analysis of machine under any condition and compares the step response of system with and without PI and PID controller [5].

Presents the simulation and experimental investigation into the development of PID controller using MATLAB/SIMULINK software. The simulation development of the PID controller with the mathematical model of DC motor is done using Ziegler–Nichols method and trial and error method. The PID parameter is to be tested with an actual motor also with the PID controller in MATLAB/SIMULINK software. In order to implement the PID controller from the software to the actual DC motor data acquisition is used. From the

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simulation and the experiment, the result performance of the PID controller is compared in term of response and the assessment is presented [6].

When the impulsive modes of the system are both controllable and observable, it is shown in this paper that these modes can be eliminated by almost any constant output feedback. For a strongly controllable and observable generalized system, after its impulsive modes are eliminated, the poles of the system can be assigned arbitrarily by state feedback. Even if the states are not available, the paper adopts an efficient method to design a compensator for the system [7].

The problem of designing a compensator to obtain arbitrary pole placement in the system consisting of the plant and compensator in cascade is considered. The design uses only those state variables which can be measured. It is shown that for a controllable observable plant a compensator of order β=min☐(v_c-1,v_o-1) is sufficient to achieve this result. Here v_c and v_o is the controllability and observability index of the plant. This result is obtained by first showing that any multi-input multi-output linear time-invariant system may be made controllable (observable) from a single input (output) using only output feedback. The main result is then proved in a constructive manner which explicitly relates the compensator parameters to the coefficients of the desired characteristic polynomial [8].

ABDUL LATIF AIZAT presents an overview of motor speed control to develop the pole placement controller to control the speed of DC motor and implement the controller into ladder diagram which connected to plc. Finally analysis of response is made after the pole placement is implemented into the system [9].
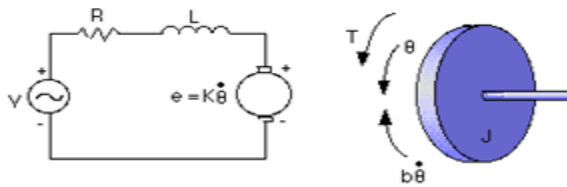

Figure 1: Free Body Diagram of DC- Motor Speed

System Equation

The Motor Torque

The motor torque is related to armature current (ia) by constant factor (kt) is given by:

$$T = K_t * ia \qquad (1)$$

The back emf is related to the rotational velocity is given by:

$$E = K_w * wr \qquad (2)$$

In SI unit(which we will use) kt (armature constant) is equal kw (motor constant).

From the Figure (1) we can write the following differential equations based on Newton's law combined with Kirchhoff's law

$$J * wr + b * wr = k * ia \qquad (3)$$

$$L\frac{di}{dt} + R * ia = ua - K * wr \qquad (4)$$

$$\frac{dia}{dt} = -\frac{R}{L}ia - \frac{k}{L} wr + \frac{1}{L} u \qquad (5)$$

$$\frac{d}{dt} wr = \frac{k}{J} ia - \frac{B}{J} wr \qquad (6)$$

The state equation can be written as:-

$$\dot{x}(t) = Ax(t) + Bu(t) \qquad (7)$$

$$y(t) = Cx(t) + Du(t) \qquad (8)$$

From the both equations (5) and (6) above, it can be representing in vector form in other word state space equation

$$\begin{bmatrix} \frac{dia}{dt} \\ \frac{d}{dt} wr \end{bmatrix} = \begin{bmatrix} -\frac{R}{L} & -\frac{k}{L} \\ \frac{k}{J} & -\frac{B}{J} \end{bmatrix} \cdot \begin{bmatrix} ia \\ wr \end{bmatrix} u \qquad (9)$$

$$Y = \begin{bmatrix} 0 & 1 \end{bmatrix} \begin{bmatrix} ia \\ wr \end{bmatrix} + \begin{bmatrix} 0 \end{bmatrix} u \qquad (10)$$

In order to make the DC motor modeling , the values of the physical parameters should be assumed. these values of parameter are derived

(J)   Moment of inertia of the rotor   0.02215 kg.m^2
(b)   Motor viscous friction constant   0.002953 N.m.s
(Ke)   electromotive force constant   1028 V/rad/sec

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(Kt)   Motor torque constant   1.28 N.m/Amp
(R)   Electric resistance   11.2 Ohm
(L)   Electric inductance   0.1215 H

Modern control design is especially usefully in multivariable systems. One approach in modern control systems accomplished by the use of state feedback is known as pole-placement design .the pole-placement design allows all roots of the system characteristic equation to be placed in desired locations. This results in a regulator with constant gain vector k.

After create a state space and output equation , the substituting the parameters into vector form:

$$\begin{bmatrix} \frac{dia}{dt} \\ \frac{d}{dt}wr \end{bmatrix} = \begin{bmatrix} -92.1811 & -10.535 \\ 57.7878 & -0.1333 \end{bmatrix} \begin{bmatrix} ia \\ wr \end{bmatrix} + \begin{bmatrix} 8.2305 \\ 0 \end{bmatrix} u$$

$$Y = \begin{bmatrix} 0 & 1 \end{bmatrix} \begin{bmatrix} ia \\ wr \end{bmatrix} + [0]u$$

Table 1.1: Parameter of DC Motor Plant (Subsystem)

A, n × n constant matrix	[-92.1818 -10.535;57.7878 -0.1333]
B, n×1 constant matrix	[250; 0]
C, 1×n constant matrix	[0 1]
D, feed forward	[0]

Before pole placement can be applied, we shall choose the control signal to be
U=-k x
The control signal u is determined by an instantaneous state such a scheme is called state feedback. The 1×n matrix, k is called the state feedback gain matrix, In MATLAB place command calculates the appropriate gains to place the pole at desired position in the Laplace s-domain Recall that pole placement control use state feed back to generate the proper command input,

$$\dot{x}(t) = Ax(t) + Bu(t)$$

And a vector p of desired self-conjugate closed –loop pole locations. Place computes gain matrix k such that the state feedback, U=-k x places the closed –loop poles at the location p.

First method to find the matrix gain, k is by using the MATLAB command (prompt). In MATLAB prompt, use the coding

k=place(A,B,P) to obtain the gain values. k=place (A,B,P) computes feedback gain matrix, k that achieves the desired closed loop pole locations p, assuming all the inputs of the plant are control inputs. The length of p must match the row size of A matrix.
Other method is by determining the gain matrix, k by using mathematical calculation. To obtain the k value, first is finding the poles, p value by varying the percentage of overshoot (%OS) and settling time (TS). But to vary the values, must refer to the Bench mark of motor. For the Clifton precision servo motor model, the bench mark is referring to table below

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Table 1.2: The Bench Mark for the Clifton Precision Servo

the percentage of ov (%OS)	<1.73%
settling time (TS)	<1.16s

The poles, p equation:

$$P1=-\alpha+ j\,\omega \text{ and } p2=-\alpha- j\,\omega \qquad (11)$$
$$\alpha=\xi\,\omega n \qquad (12)$$
$$w=\omega n \sqrt{1-\xi 2} \qquad (13)$$

The damping ratio is one the compares the exponential decay frequency of the envelope to the natural frequency . We define the damping ratio, ξ to be:

$$\xi=\frac{\text{exponential decay frequency}}{\text{the natural frequency}(\frac{rad}{second})}$$

But as we vary the %OS, the inverse %OS equation allows one to obtain the damping ratio, ξ. The inverse is giving by:-

$$\xi=\frac{-\ln(\%OS/100)}{\sqrt{\left(\pi+\ln\left(\%\frac{OS}{100}\right)\right)2}} =0.7906 \qquad (14)$$

The natural frequency, wn of second order system is the frequency of oscillation of the system without damping we can obtain the natural frequency value by the settling time, TS equation

$$Wn=4/\xi\, TS=3.1624 \qquad (15)$$

After solving the term of damping ratio and natural frequency which is equation 14 and 15, substitute the values into equation 12 and 13 when α and w are solve. Next is substituting α and w into equation 11 which is the poles equation.

$$\alpha=-2.5002,\ \omega=1.9364$$

$$p1=-2.5002+1.9364j,\ p2=-2.5002-1.9364j$$

Necessary and Sufficient Condition for Arbitrary Pole Placement

Consider a control system defined by Equation (7). Let the control signal selected be $u=-kx$. Substituting control signal into Equation (7), we have:

$$\dot{x}=Ax-BKx=(A-BK)x \qquad (11)$$

The solution of the above equation is given as:

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

The eigenvalues of the matrix $(A-BK)$ are nothing but desired closed loop poles. The necessary and sufficient condition for arbitrary pole placement is that the system is completely state controllable. If suppose the system is not completely state controllable then there are eigenvalues of a matrix $(A-BK)$ that cannot be controlled by state feedback. The eigenvalues of matrix $(A-BK)$ are called regulator poles. These regulator poles when placed in left half of s-plane then $x(t)$ approaches zero as time t approaches infinity. The problem of placing the closed-loop poles at the desired location is called a pole placement problem [10].
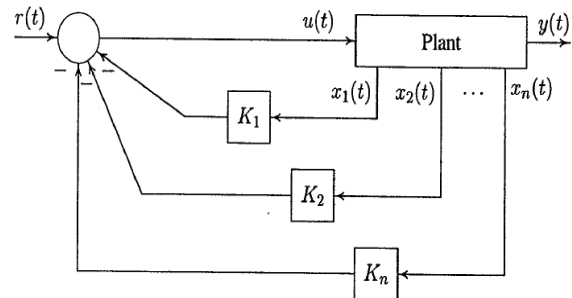

Figure 2: Control System Design via Pole Placement Controller

There are many methods to obtain k in MATLAB code in Appendices used Ackermann's method
$k_1=-10.6086\ and\ k_2=-1.2603$ in the code write parameters A,B,C and D, damping ratio, $\xi=0.7906$, the natural frequency value ω =3.1624 after that get poles from second order equation by using Ackermann's method to obtain k after that apply state feedback(closed –loop) equation and transfer function in the time from 0 to 10 step 0.1 run m file to plot step response of compensated system
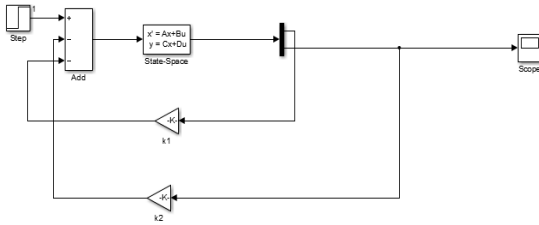
Figure 3: Simulink of Pole Placement Design

Methodology

In this research the mathematical model of the DC motor is presented so as to control the speed of the DC motor using pole placement techniques by obtain the state feedback and using MATLAM to evaluate them and simulation.

Simulation Results

The simulink state space model can be used to obtain the response. A simulink model is constructed as shown in figure (1) the state space description diag box is open. And A, B, C and D constants are entered in the appropriate box in MATLAB matrix notation. The simulation parameters are set to appropriate values.
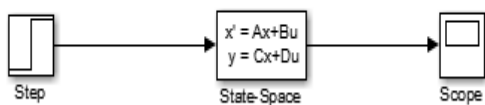

Figure 4: Simulation Block Diagram

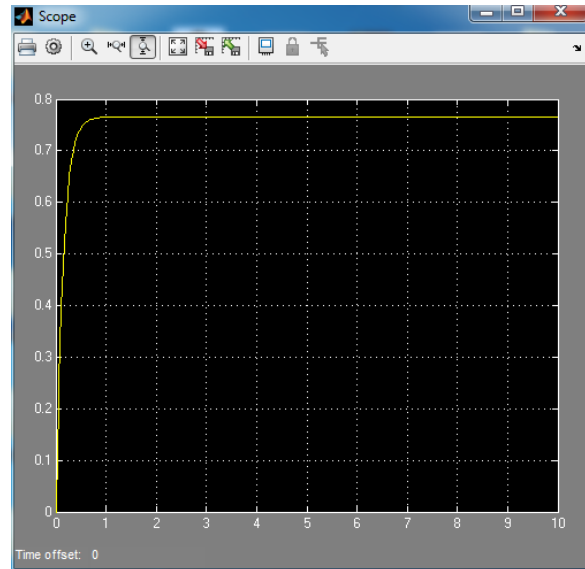The file is opened and is run in the simulink window. The simulation results is response shown in fig (4) below

Figure 5: Uncompensated Step Response

Adding a Pre Compensator

From this plot we see that the steady-state error is too large. One approach for eliminating the steady-state error is to simply scale the input so that the output in turn is scaled to the desired level. This is little challenging in our example because we have two states to consider. Therefore, we need to compute what the steady-state values of both states should be, multiply them by the chosen gain k, and use the result as our "reference" for computing the input u. This can be done in one step by adding constant gain pre compensator after the reference as shown in the following schematic.
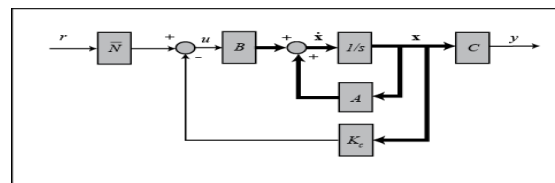

Figure 6: Adding Constant Gain Pre Compensator

We can find ne in MATLAB code from apply state feed back in the system we get step response which satisfy the specifications mentioned above.

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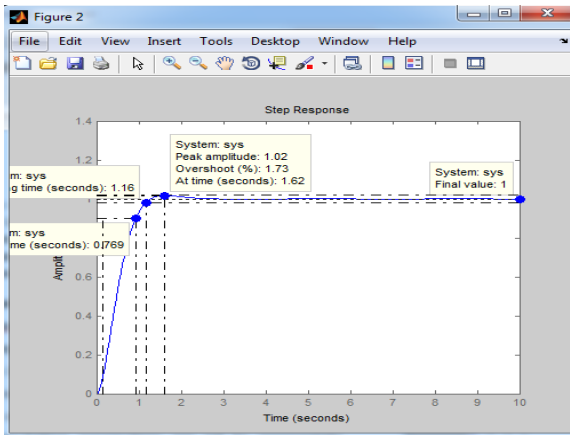**ISSN: 2319-6564**
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Figure 7: The Compensate Step Response

From the figure above we have:

1. Settling time less than1.16 second.
2. Overshoot less than 1.73%.
3. No steady state error.

Conclusion

As we mentioned previously the control speed of DC motor is really problem in engineering field. However deciding to control it by using pole placement technique specifies state feedback and get good results are as enable Overshoot less than 5% , Settling time less than 2 sec, No steady state error

List of Symbols

J -Moment of inertia of the motor
B -Damping ratio of the mechanical system
K –Electromotive force constant
R –Electric resistance
L - Electric inductance
ia - Electric current
W r - Speed /velocity
x – State vector (x – vector)
U -Control signal (input)
A –n × n constant matrix, system matrix
B - n × n constant matrix, input matrix
C - 1 × n constant matrix, output matrix
D - 1 × 1 constant matrix, feed forward matrix
K - Gain matrix (for the controller)
P - Poles

%OS - Percentage overshoot
Ts - Settling time
ξ - Damping ratio
wn –Natural frequency

Code system

```
os=input('enter over shoot')
ts=input('inter settling time')
zeta=-log(os)/sqrt(pi^2+(log(os)^2))
wn=4/(zeta*ts)
A=[-92.1811 -10.5350;57.7878 -0.1333];
B=[8.2305;0];
C=[0 1];
P=roots([1 2*zeta*wn wn^2])
num=[wn^2]
den=[[1 2*zeta*wn wn^2]]
[A2,B2,C2,D2]=tf2ss(num,den)
sys1=tf(num,den)
k=acker(A,B,P)
A1=A-B*k;
ne=-(([0 1]*([A1]^-1)*[8.2305;0]))^-1
[n d]=ss2tf(A1,B*ne,C,0)
sys=tf(n,d)
t=0:0.01:10;
[x  y]=step(sys,t);
plot(y,x)
figure
step(sys,t)
```

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