Position Control of DC Motor by Compensating Strategies

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Abstract - As the technology is growing the new applications are coming into existence which needs both speed control as well as position control for better and efficient performance. We have many speed control techniques such as armature voltage control, field control etc. In addition to these control techniques for better performance of the systems we need to design an algorithm which is helpful for DC position control. For this we make use of the control system techniques such as controllers, feed-back networks and compensation techniques. This will lead to automatic control of position of the DC motor without manual interference. During any system functioning much nonlinearity such as dead zone, saturation, backlash, practical amplifier performance etc. are introduced into the system which effects the functioning of the system resulting in Undesirable outcomes. So in this section we will design the control system by taking into consideration all the nonlinearities.

Key words - Mathematical model; DC motor; Lag Compensator.

1. INTRODUCTION

In this section we will study the advantages and disadvantages of various compensation techniques; by taking into consideration the steady state response and the cost constraints the lag compensation is proved to be the best. So we will design an ultimate position control system by using lag compensation technique. To design an algorithm for DC position control system to meet a set of given specifications and to study the performance of the system under various non-linearities.

Position control system

Position control system is a closed loop control system whose output is the desired angular position of the DC motor. The motor whose position is to be controlled is connected in a closed loop system in which the motor forms the plant. The other accessories which are necessary for the position control such as compensators, integrators, comparators, gears, amplifiers etc. are connected in the same loop.

the desired angular position is given as reference input to the system at the comparator. The other input to the comparator is the actual output which is the angular position of the given DC motor. The comparator compares the desired and actual signals and produces an error signal which will be fed to the controller which sends the necessary actuating signal to the DC motor which in turn results in change in the functioning of the motor in order to obtain the desired position.

Mathematical model of dc motor

The resistance of the armature is denoted by R (ohm) and the self-inductance of the armature by L (H). The torque (N-m) seen at the shaft of the motor is proportional to the current I (A) induced by the applied voltage (V),

$$\tau = K_m i$$

Where Km, the armature constant, is related to physical properties of the motor. The back (induced) electromotive force, emf (V), is a voltage proportional to the angular rate seen at the shaft,

$$v_{emf} = K_b \omega$$

where Kb, the emf constant, also depends on certain physical properties of the motor. The mechanical part of the motor equations is derived using Newton's law, which states that the inertial load J (kg·m²) times the derivative of angular rate ω (rad/sec) equals the sum of all the torques (N.m) about the motor shaft. The result is this equation

$$J\frac{d\omega}{dt} = -K_f \omega + K_m i$$

Where, ωKf is a linear approximation for viscous friction. The electrical part of the motor equations can be described by

$$\frac{di}{dt} = -\frac{R}{L}i - \frac{K_b}{L}\omega + \frac{1}{L}v_{app}$$

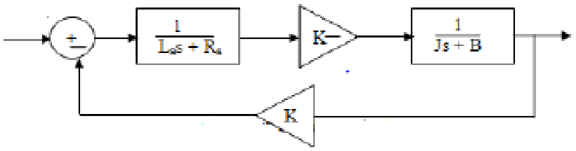
Given the two differential equations, you can develop a state-space representation of the DC motor as a dynamic system. The current i and the angular rate are the two states of the system. The applied voltage, apply, is the input to the system, and the angular velocity ω is the output.

$$\frac{d}{dt}\begin{bmatrix} i \\ \omega \end{bmatrix} = \begin{bmatrix} -\frac{R}{L} & -\frac{K_b}{L} \\ \frac{K_m}{J} & -\frac{K_f}{J} \end{bmatrix}\begin{bmatrix} i \\ \omega \end{bmatrix} + \begin{bmatrix} \frac{1}{L} \\ 0 \end{bmatrix} v_{app}$$

$$y = \begin{bmatrix} 0 & 1 \end{bmatrix}\begin{bmatrix} i \\ \omega \end{bmatrix} + [0]v_{app}$$

DC motor block diagram:

With the advent of the control systems, any system can be represented in the form of a block diagram in which each block represents the specific components of the system and the connectivity between each block for proper functioning is obtained by using the lines. The DC motor can also be represented in the form of block diagram as shown below in fig

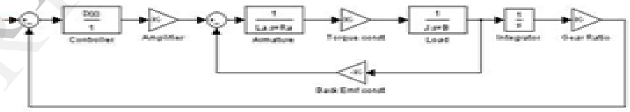


Block diagram of dc motor

The various blocks in the above block diagram represent the various parts of the DC motor such as the armature circuit, field circuit and the friction. The transfer function of the DC motor taking the armature excitation as the input and the angular position of the shaft is taken as the output is derived in the next section.

DC MOTOR POSITION CONTROL SYSTEM:

The DC motor whose angular position is to be controlled is placed in a closed loop control system. In this circuit the other accessories which are needed to perform the control operations and which are helpful for that are placed in the system. The DC motor block diagram consists of the following functional blocks i.e. armature block, load block, torque constant and back emf constant. The output of the DC motor in the form of angular speed which is sensed by tachometers and is fed as input to an integrator. The integrator integrates the angular speed with respect to time to produce an output which is in the form of angular position. This angular position is fed back as one of the inputs to the comparator. The other input to the controller is the desired angular position. The comparator compares the actual position with the desired position and gives the error signal if there is any deviation. The error signal is amplified by the amplifier. Thus the position of the DC motor is controlled by the above closed loop control system.



Compensators:

The position control of a DC motor is designed by implementing some control techniques such as the compensators. Basically there are 3 compensators. They are:

- Lag compensator.
- Lead compensator.
- Lag-Lead compensator.

A compensator is needed to meet the performance Specifications; the designer must realize a physical device that has the prescribed transfer function of the compensator. Numerous physical devices can be used for this purpose. In fact, many noble and useful for physically constructing compensators may be found in the literature.

If a sinusoidal input is applied to the input of a network, and the steady-state output (which is also sinusoidal) has a phase lead, then the network is called a lead network. (The amount of phase lead angle is a function of the input frequency.) If the steady-state output has a phase lag, then the network is called a lag network. In a lag-lead network, both phase lag and phase lead occur in the output but in different frequency regions; phase lag occurs in the low-frequency region and phase lead occurs in the high-frequency region. A compensator having a characteristic of a lead network, lag network, or lag-lead network is called a lead compensator, lag compensator, or lag-lead compensator.

LAG COMPENSATION:

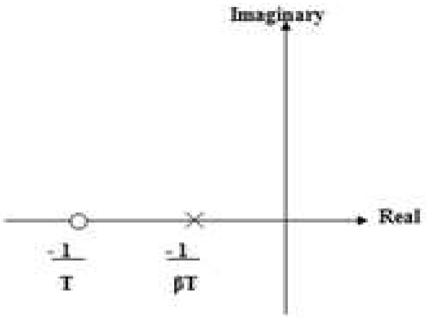
Lag compensation network where in the phase of output voltage lags the phase of input voltage for sinusoidal input.

The transfer function of phase-Lag network is given by

$$\frac{E_0(s)}{E_i(s)} = \frac{(1 + sT)}{(1 + s\beta T)}$$

$$\beta > 1 \text{ and } \quad \beta = \frac{R_1 + R_2}{R_2} \quad , \quad T = R_2C$$

Where



The pole zero plot of the lag compensator

Lag-Lead Compensation:

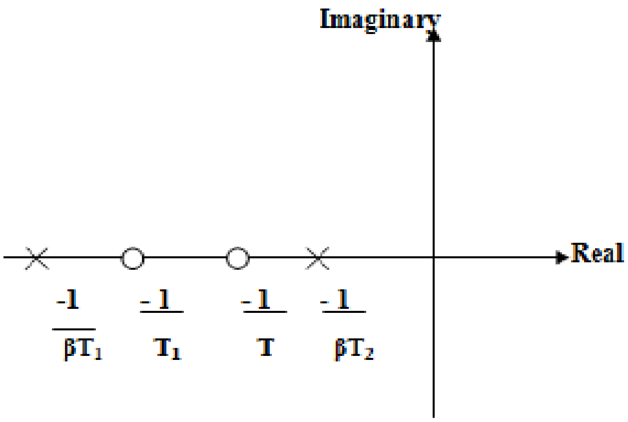
Introduction to phase-lead compensation network in a control system shifts the gain crossover frequency point to a higher value and, therefore, the band width is increased thus improving the speed of response and over shoot is reduced but the steady state error does not show much importance.

$$\frac{E_0(s)}{E_i(s)} = \frac{\alpha\,(1 + sT_1)}{(1 + s\beta T_1)}\;\frac{(1 + sT_2)}{(1 + s\alpha T_2)}$$

$$T_1 = R_1C_1 \text{ and } T_2 = R_2C_2 \text{ ,} \alpha<1,\ \beta>1,\ \alpha\beta = 1.$$

The phase margin can be improved to any desired value by employing lead compensation even though the uncompensated system may be absolutely unstable. The lead compensation results in increased bandwidth and faster speed of response.

For higher order systems and for systems with large error Constants, large leads are required for compensation, resulting in excessively large bandwidth which is undesirable from noise. Transmission point of view. For such systems lag compensation is preferred provided the uncompensated system is not absolutely unstable.



Pole-Zero Plot of Lag-Lead Compensation:

The lag compensation, on the other hand , reduces system bandwidth and slows down the speed response. For large specified error constant and moderately large bandwidth, it may not be possible to meet the specifications through either lead or lag compensation. Under such circumstances we go for lag-lead compensator wherein for a specified error constant, the lag-section is used to provide part of the phase margin and the lead section provides the rest of it as well as gives the desired bandwidth.

NON LINEARITIES

The nonlinearities included in the system are:

1. Backlash, Dead zone, Ramp disturbance, Step disturbance, Practical amplifier.

The Backlash block implements a system in which a change in input causes an equal change in output. However, when the input changes direction, an initial change in input has no effect on the output. The amount of side-to-side play in the system is referred to as the *dead band*. The dead band is centered about the output.

The Dead Zone block generates zero output within a specified region, called its dead zone. The lower and upper
limits of the dead zone are specified as the **Start of dead zone** and **End of dead zone** parameters. The block output depends on the input and dead zone:

If the input is within the dead zone (greater than the lower limit and less than the upper limit), the output is zero.

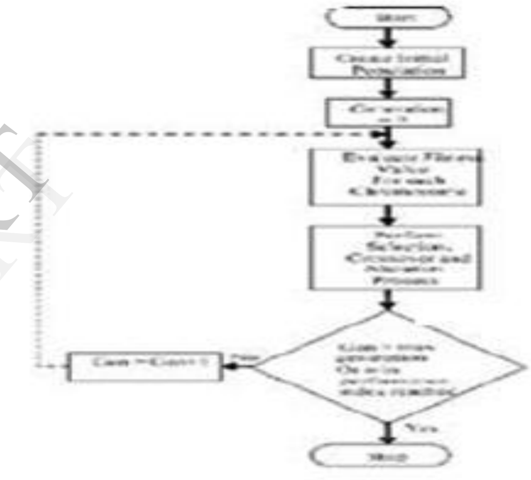
If the input is greater than or equal to the upper limit,
the output is the input minus the upper limit.

If the input is less than or equal to the lower limit, the
output is the input minus the lower limit.

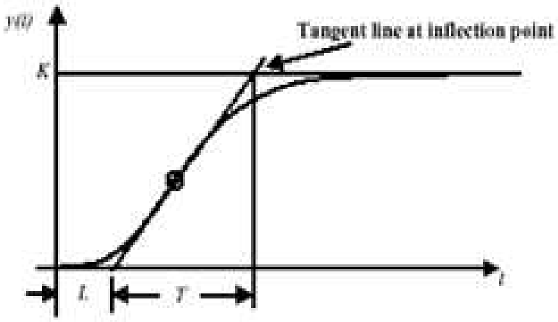
The Saturation block imposes upper and lower bounds on
a signal. When the input signal is within the range specified by the **Lower limit and Upper limit** parameters, the input signal passes through unchanged. When the input signal is outside these bounds, the signal is clipped to the upper or lower bound. The practical amplifier is more influenced by the noise signals. So, it is also considered as one of the nonlinearity.

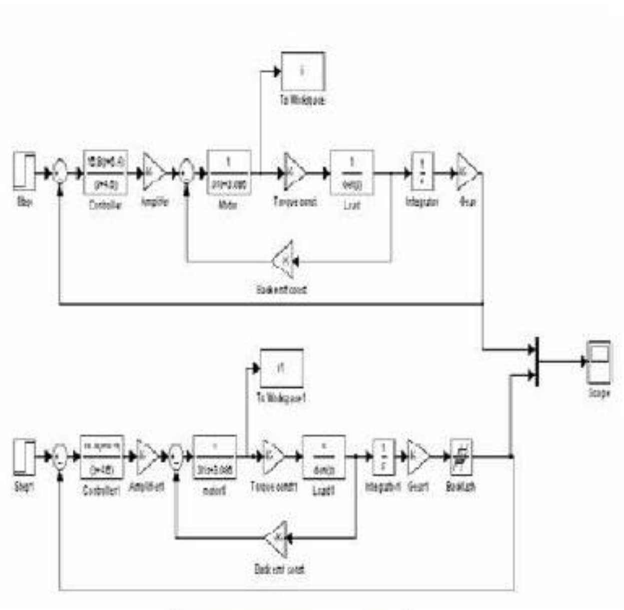
ZIGLER NICHOLS-ALGORITHM:

PID controllers are probably the most commonly used controller structures in industry. They do, however, present some challenges to control and instrumentation engineers in the aspect of tuning of the gains required for stability and good transient performance. These rules are by and large based on certain assumed models of different types
of motors. The Ziegler-Nichols algorithm used for providing tuning of a Dc Position control is shown below:



Response of zigler nichlos





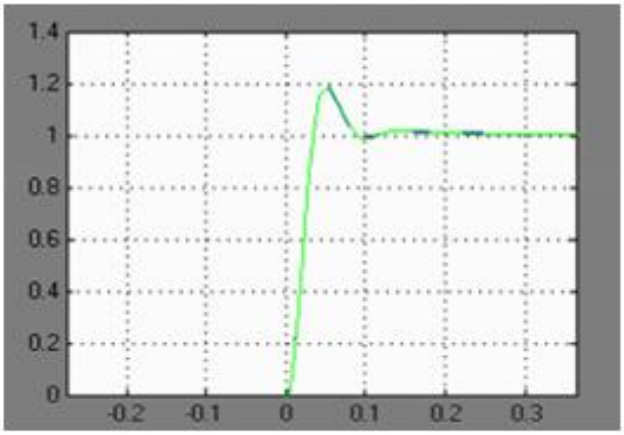
Non Linearity-Backlash

Backlash

If we introduce backlash into the loop the transient response is getting affected after the backlash dead band width crosses. At backlash = 0.04 the following parameter are measured

Mp = 20% Tr = 0.035 sec. Ts = 0.09 sec

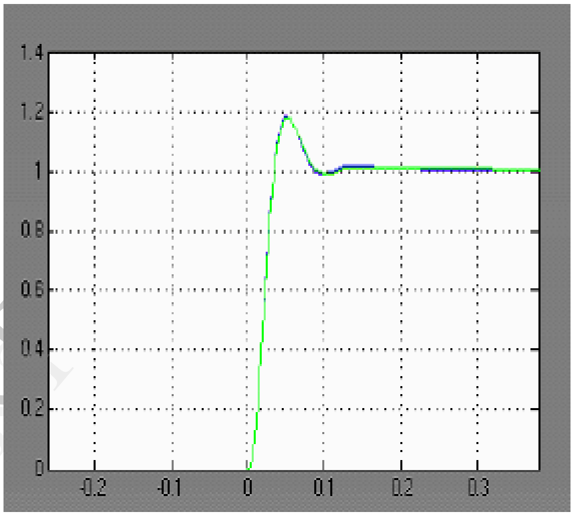
Output for Backlash



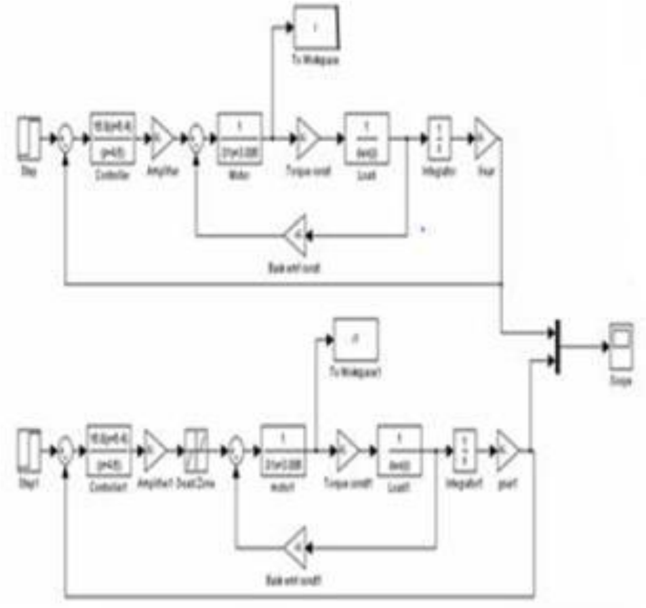
Time offset = 0

Dead zone

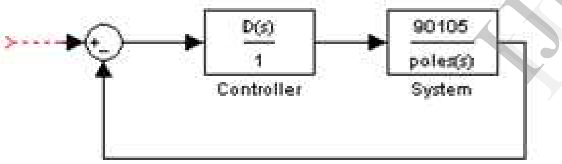
With the increase of dead zone period the settling time is increased. For a settling time of 0.7 sec the dead zone limit is - 0.35 to +0.35.At dead band -0.35 to +0.35 the time domain parameter are measured as follows. Above this limit specifications are not being met.



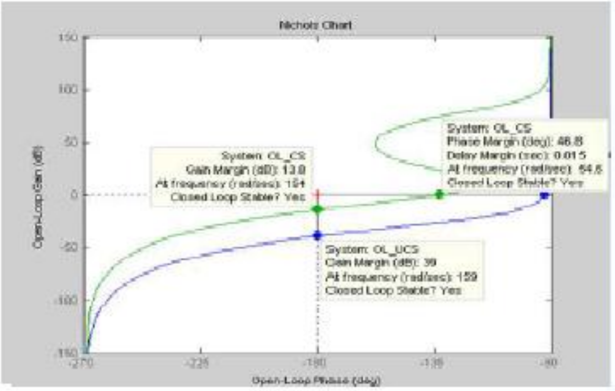
Output for dead zone non linearity
Mp = 18.32%. Tr = 0.03sec. Ts = 0.15 sec



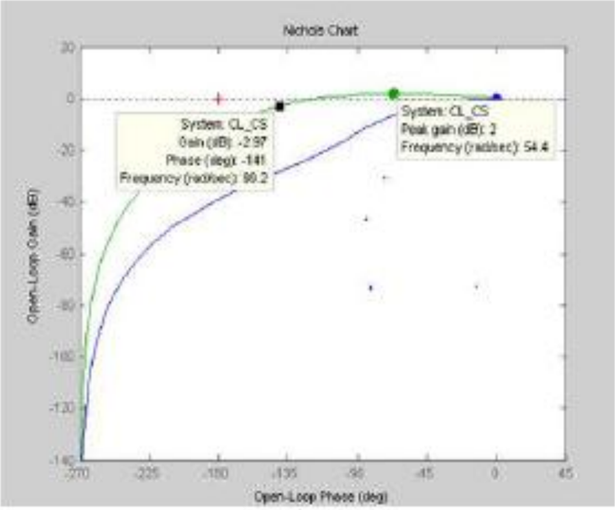
Matlab outputs by using lag compensation



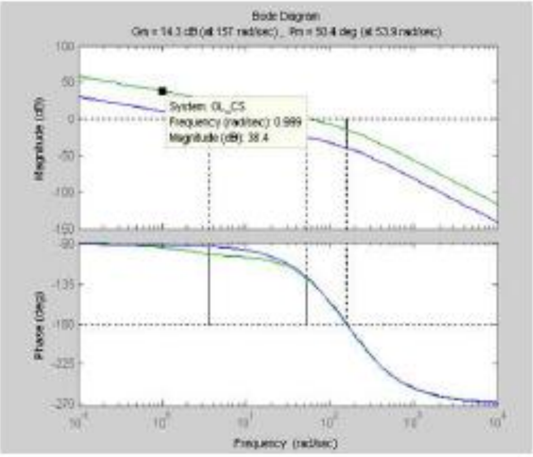
The simplified block diagram position control of dc motor



Nichols Chart for Open-Loop System with Lag Compensator



Nichols Chart for Closed-Loop system with Lag Compensator



Bode Diagram for Designed Lag Compensator

So our controller is satisfying all the requirements. Here we are meeting all the requirements through some cost we are paying in the form of speed of the response. Now if we have a lead compensator we can speed-up the system but it has adverse effect on the current output of the amplifier.

The current output of the amplifier is usually limited in order to prevent damage to the amplifier and to the motor. For this case this limit is 5A. A practical performance measure of the system is the linear range of the servomechanism, defined as that level of error signal which produces 5A of current in the motor when the motor is at standstill. The linear range for our compensated system is 0.1589V (For 4.9996A).

Conclusion:

The design followed by the author gives good response characteristics but it is very expensive to go for a lag-lead compensator. So we designed a lag compensator which has
almost same performance characteristics but it has somewhat less speed. The extension of this project work can be done by considering different types of controllers in tuning the Dc motor and we can also extend the same to different types of motors combined with different types of controllers. By using this Ziegler-Nichols algorithm probably a stochastic method of approach of genetic algorithm can be implemented which will give more accurate results when compared with the results obtained without tuning of the PID Controllers. It was found that the designed linear quadratic gave the best steady state and transient responses performances. It fully eliminated the
Steady state error with the least transient settling time. There is no overshoot and the system is completely stable. The reason is that the other compensator designs are mostly based on trial and error.

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