Position Control

HexaMotor



**Experiment objectives**:

• Introduction to second order systems.

• Coulomb Friction identification and handling.

• System identification using position close loop step reponse.

• System identification using position close loop frequency reponse.

• Position control implementation based on second order system modeling.

• Lead-Lag compensator controller design and implementation.

• Force FeedForward implementation - compliant motor control.

# Introduction

In the field of motor control, mastering both velocity and position control is essential for a wide range of applications. While the previous lab experiment delved into the nuances of velocity control and the fundamentals of a DC motor, this experiment pivots to emphasize position control. Position control, vital for accurate maneuvering and precise positioning of mechanisms, demands its own unique approach. This experiment outlines objectives ranging from system identification using step and frequency responses to the design and actual implementation of control strategies.

## First order approximation

While in the previous experiment the full equations of the DC motor were presented and the first-order approximation was derived, in this experiment we will contrinue working with the first-order approximation of the DC motor.

First-Order Transfer Function:

* 1. ;

## Coulomb friction

Recall from the previous experiment that Coulomb friction, which remains constant irrespective of motor speed, contributes to system non-linearity and can pose challenges in control implementation, particularly at low speeds. We identified this friction by applying a controlled voltage to the DC motor, observing the threshold voltage initiating rotation.

## Second order systems

When discussing control systems, a second order system is frequently encountered. It can be described by the standard second-order transfer function:



Where:

*K* – is the system gain.

– is the undamped natural frequency.

ζ– is the damping ratio.

The system's response is primarily characterized by its damping ratio ζ and natural frequency

Several performance metrics can be derived from the above standard form:

**Percent Overshoot (%OS)**:

It defines the amount by which the transient response exceeds the steady-state value. For a step response, the percent overshoot is given by: It should be noted that overshoot occurs only when <1 (underdamped case).

**Rise Time (Tr)**:

The time it takes for the response to rise from 10% to 90% of its final value for an underdamped system. While there's no direct closed-form formula, for many systems with a damping ratio between 0.4 and 0.7, the rise time is approximately:

**Settling Time (Ts)**:

The time for the system response to stay within a certain percentage (usually 2% or 5%) of its final value. It's given by for a 2% settling time.

**Peak Time (Tp)**:

The time it takes for the response to reach its first peak. For an underdamped system: where is the damped frequency.

**Natural Frequency (**​**)**:

It's the frequency at which the system would oscillate if there were no damping (i.e., ζ=0).

## PID controller

As previously discussed in our prior experimentation, the PID controller is a predominant feedback control algorithm extensively employed in industrial applications due to its efficiacy across diverse scenarios and its systematic tuning methodology.

The PID controller is characterized by three fundamental components:

**Proportional (P):** This component yields a control action that is directly proportional to the instantaneous error. The magnitude of this response is governed by the proportional gain

**Integral (I):** Concerned with the aggregation of error over time, this action aims to nullify any persistent steady-state error.

**Derivative (D):** This term offers a control action based on the rate of error change, effectively anticipating potential future errors and generating a preemptive control response.

## Lead-Lag Compensator

Lead and lag compensators are essential tools in control theory, particularly in the design of feedback control systems to meet transient and steady-state response specifications:

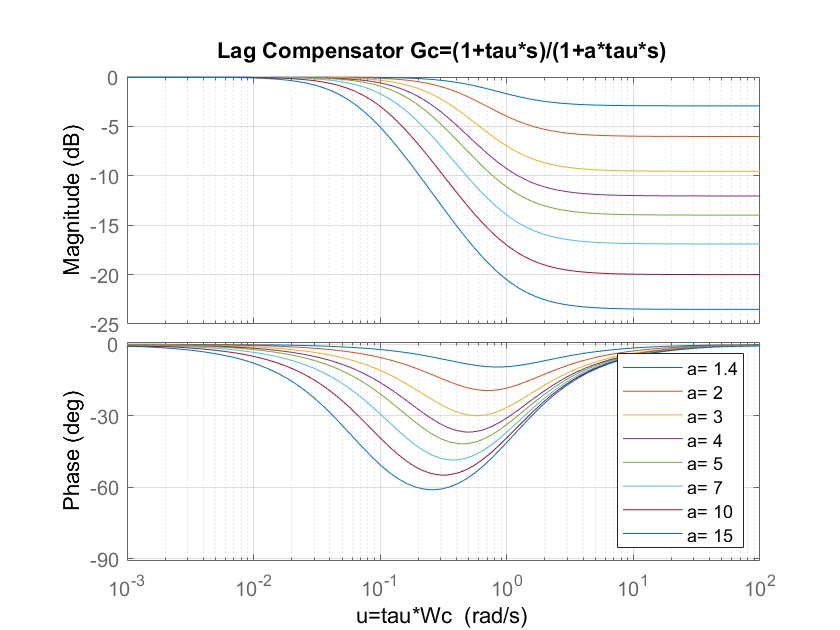
**Lag:** The general transfer function for a lag compensator can be described as:

Where τ is the time constant and a>1.

**Purpose:** The primary purpose of a lag compensator is to improve the steady-state response of the system. This is done by adding a pole and a zero to the system. Since the zero is closer to the origin than the pole, the compensator will have a magnitude less than one for most frequencies, thereby reducing the gain of the system and the steady-state error.

**Placement:** The zero is placed to the left of the pole. The distance between them determines the magnitude of the phase boost, but a lag compensator will not introduce a significant phase lead.

**Drawbacks:** Lag compensators generally degrade the transient response because they tend to reduce the system bandwidth.

****

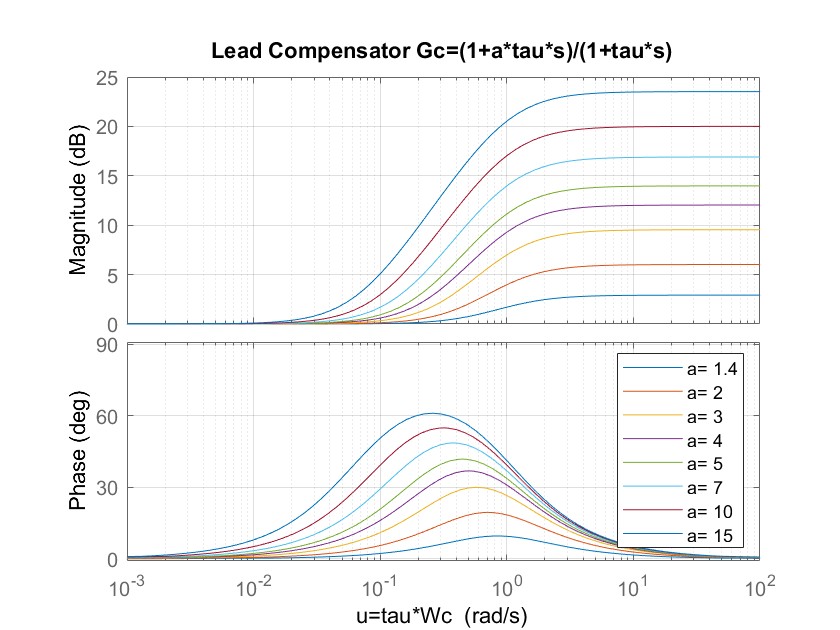
**Lead Compensator:** The general transfer function for a lead compensator can be described as:

Where τ is the time constant and a>1

**Purpose:** The primary purpose of a lead compensator is to improve the transient response of the system. By placing a pole and a zero in the left half plane, it introduces phase lead to the system, which can be used to reshape the root locus or push the closed-loop poles to desired locations.

**Placement:** The zero is placed to the right of the pole, introducing phase lead in the frequency range of interest. The amount of phase lead is determined by the distance between the pole and zero and their proximity to the imaginary axis.

**Drawbacks**: Because of the introduced phase lead, a lead compensator also increases the gain in some frequency range. This can make the steady-state error worse.



**Design Considerations:**

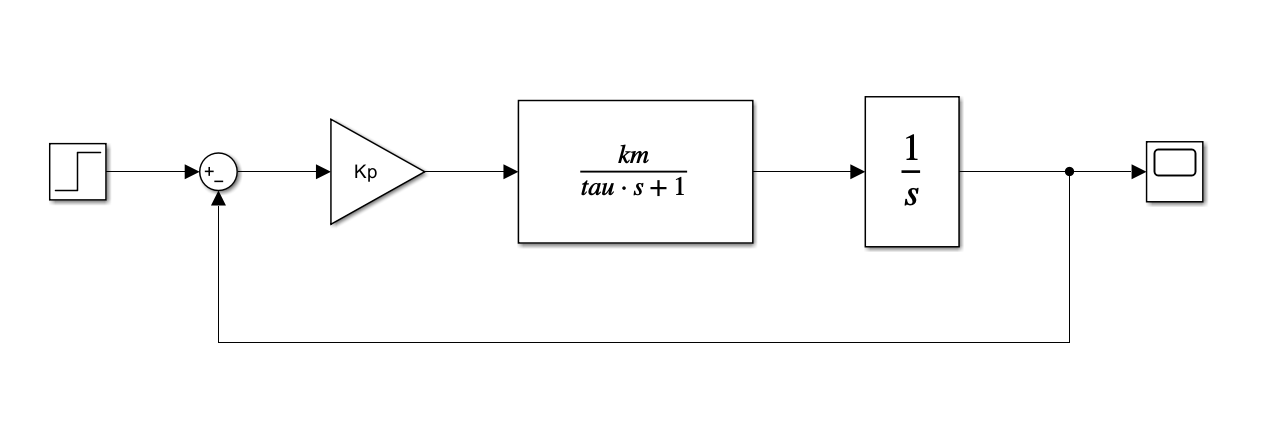
**Lag**: When using a lag compensator, the goal is often to place the pole and zero sufficiently far from the imaginary axis, so they don't affect the transient response. You place the zero so that the magnitude of the system is unchanged at the crossover frequency.

**Lead**: When designing with a lead compensator, the goal is often to add enough phase lead to achieve desired transient characteristics without pushing the gain crossover frequency too high.

In practice, combining both lead and lag compensators can offer an optimal balance between steady-state and transient performance in many systems.

# Pre Lab

## Second order system identification



1. Given the system above, assuming the plant is a DC motor using its first order approximation , write what the blocks represent and the units of the input and output signals.
2. Given the system above, what is the close loop transfer function:
3. Compare the transfer function derived in b. To the standard second order transfer function of the form . Find representations of and as a function of , and *kp*
4. Using Matlab, plot the step response of the following first order system , using the system represented above with gain of *kp*=10.
5. Based on the peak time and over-shoot performance metrices for a standard second order system. Find the values of and .
6. Based on the equations derived in C verify the transfer function of the DC motor in the form of

## PD controller

1. Given the first order approximation of a dc motor, what would be the values of K and (give parametric solution).
2. Using Matlab, plot the step response of the following first order system , Mark the time constant and the steady state gain K.

## Lead-Lag compensator

1. Using Matlab plot the response of the system to various sin inputs, calculate the gain change as a function of frequency. You can use the "lsim” function in Matlab to simulate a system response to an arbitrary input signal in the time domain. Or implement it in Simulink.
2. Calculate the cutoff frequency and plot the system`s sinusoidal response at this frequency.
3. Using the first order approximation Derive an expression to determine based on Hint:

# In Lab

## Coulomb friction

Jfghjgfjfgjfgjghjfghj