# ME 360 Introduction to Control Systems: Lab 1

## Basic Identification, Time Response Measurement, and P-Control

## 1. Introduction

**Setup and Background:** A detailed description of the system we will work with is provided in the complementary handout titled "Lab Background Information". Please go through and read the description now. This handout lays out some steps you need to follow while performing the labs, and clarifies some more involved parts of the background information. **Note:** The lab relies on Simulink and the Matlab Real Time Workshop to interface with the hardware. Make sure to go through the MATLAB/Simulink Tutorial presented in the beginning of the term and posted on LEARN. If you have further MATLAB/Simulink questions, please contact the TAs and/or the instructor in advance.

**Report Submission (due 5:00 pm, one week after your lab date (due Feb 13-17):** Each lab group is required to submit a single project report for Lab 1 one week after the completion of Lab 1, in the format of a technical report (max. 10 pages with cover page). The report has to be prepared collectively by the members of that group. Communication with other groups is not allowed! Specifically, your report should address all of the questions included in this lab instruction document.

**Synopsis and Motivation:** In Lab 1, you will become familiar with the basic principles of control engineering. You will also become acquainted with the experimental setup that will be used in all the three labs: *Quanser* linear motion cart with incremental encoder feedback (IP02 model), shown in Figure 1.

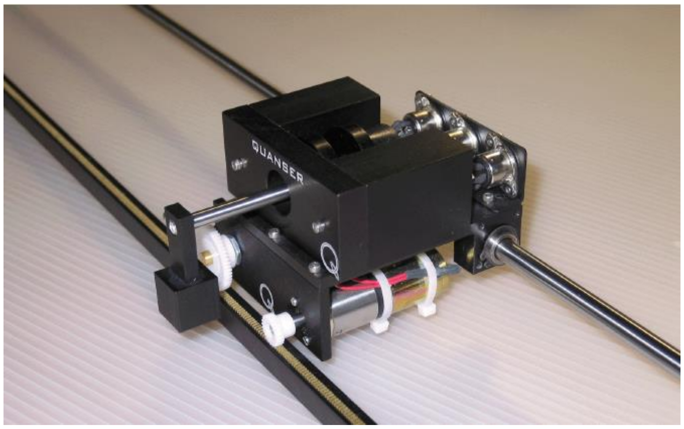


**Figure 1:** Linear cart setup.

Control engineering practice typically consists of two main tasks:

1) Identifying a model for the system to be controlled
2) Designing and/or tuning an appropriate controller

In many cases, the above tasks are executed iteratively, one after another until the desired performance, stability, and robustness characteristics are achieved. Lab 1 is designed to give a flavor of these tasks, which are frequently used in real-life controller design for applications such as robots, CNC machine tools, disk drives, or autopilot systems. The necessary real-time code has been prepared for the students. This will be explained in context in this manual. It is the students' responsibility to conduct the experiments and save their own data after each test.

In Lab 1, to get an accurate model of the DC motor and disk in the cart setup of Figure 1, you will identify the corresponding system parameters. If you experiment with the system parameters in the pre-lab, you may notice that the inertia and friction components of the dynamics have much larger effect than the armature inductance and resistance. This is because the inductance of the armature is relatively small, and therefore the bandwidth of the electric motor is much greater than that of the inertial dynamics. The result is that we can ignore the faster electric motor dynamics ($L_a \approx 0$) when identifying the system, and work with a simplified system model. Note that we are also ignoring the effects of external disturbances in the identification of the motor parameters.

## 2. Pre-Lab

The pre-lab is intended to familiarize you with the use of Simulink block diagrams for simulation of the lab apparatus. These should be thought of a preparatory exercise for each of the labs and will be verified at the start of the lab but not marked. Much of the content will be useful in generating the actual lab reports. Before you arrive at the lab, make sure to have done each of the following:

1) Read the lab background information, which provides a detailed description of the lab hardware.
2) Read these notes, which give instructions for performing the labs.
3) Have a look at the “Introduction to Matlab-Simulink” document under the “Lab Material” folder on LEARN.
4) Build a model of the set-up hardware in Simulink: You can compose this Simulink model by rebuilding Figure 3 of the “Lab Background Information” document (ME360_Lab_Background.pdf in “Labs” folder on LEARN) with model parameters defined in Table 1 of that document, selecting corresponding blocks from the Simulink library browser and setting their parameters, and connecting these blocks similarly to Figure 3 connections.

## 3. Getting Started

1) Create a copy of the folder “ME_360_W23” located on the desktop. Rename the folder with your Lab group number.
2) Open up the Simulink file “cart_trial_simple.slx”.
3) Create the Simulink model based on the instructions given in the Lab document.
4) Once the Simulink model is finalized, go to the “Hardware” tab. Make sure the runtime is set to 8 seconds. Then, click “Monitor and Tune” to run.
5) Ensure the data was recorded by checking for it in the Matlab workspace. <u>Save the data with a separate name each time, as Simulink will overwrite the data recorded during previous runs</u>.
6) For analysis, it is recommended not to use the first few seconds of the result – transient effects may decrease the quality of the readings.

## 4. In Lab Instructions

### 4.1. Parameter Identification through Step Response Measurement

The velocity response of most servo-drive systems can be represented by the following first order model, as derived in class:

$$V(s) = \frac{K_v}{\tau_v s + 1} U(s), \quad for \quad U(s) = \mathcal{L}\{u(t)\}, V(s) = \mathcal{L}\{v(t)\} \tag{1}$$

where $\boldsymbol{U(s)}$ is the Laplace transform of the input voltage signal $\boldsymbol{u(t)}$ [V], $\boldsymbol{V(s)}$ is the Laplace transform of the axis velocity output $\boldsymbol{v(t)}$ [mm/sec], $\boldsymbol{K_v}$ [(mm/sec)/V] is the velocity gain and $\boldsymbol{\tau_v}$ [sec] is the time constant. When a unit step voltage input is applied, the following response would be observed in the ideal case:

$$v(t) = K_v\left(1 - e^{(-t/\tau_v)}\right) \tag{2}$$

A plot of the ideal response (2) is shown in Figure 2.

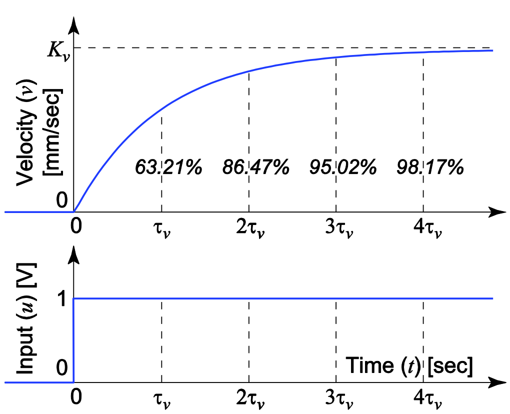

**Figure 2:** First order system response to a unit step input with zero initial conditions.

**4-1a.** Measure the velocity response of the drive system by applying a square wave input with ±1.5 [V] amplitude and 1 Hz frequency. Compose the Simulink file in Figure 3 to run this experiment. To obtain the measured velocity, the position measurements from the encoder on the cart are numerically differentiated with respect to time. After data collection, save the contents of the "scope" block to the MATLAB workspace, following instructions to be provided by the TAs. **You may not copy and paste this figure directly into your report. You must save the measured data arrays into a file which you will work with. Each group is responsible for saving their data after each experiment.** *Hint: It is a good idea to check the correctness of the data files by retrieving and plotting them using another MATLAB script after clearing the workspace.*

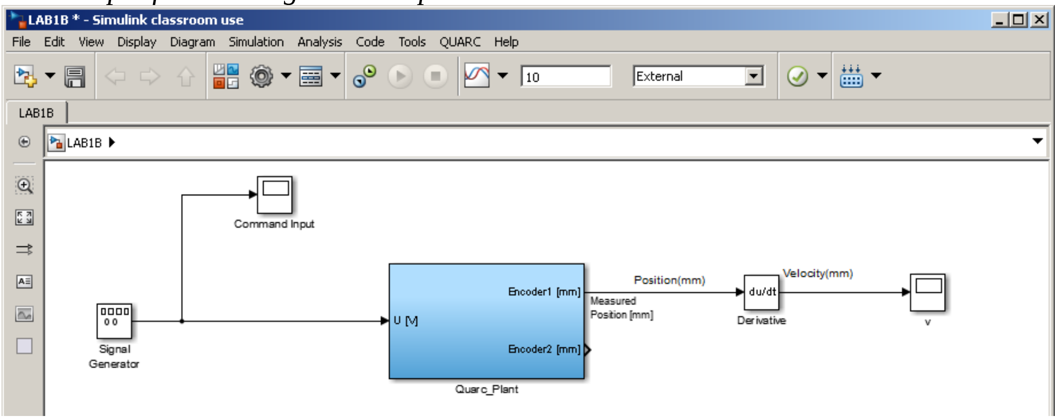


**Figure 3:** Simulink file for measuring velocity step response.

**4-1b.** Using the measured data, determine the values of the velocity gain $K_v$ and the time constant $\tau_v$. (**Please, read Section 2 of "Lab Background Information" document about identifying time constant ($\tau_v$) and velocity constant ($K_v$) for first order system response. Take notes of your derivations to use in report writing later.**

**More detailed help is given in "ME360_Lab1BackgroundAssist" document on Learn.**

**4-1c.** Construct a Simulink model of the system (1), using identified gain ($K_v$) and time constant ($\tau_v$) parameters. Simulate the theoretical velocity response using this Simulink model, applying the input signal profile ($u$) you had captured during the experiment.

## 4.2 Proportional (P) Position Control

You will now implement your first servo-controller experimentally! A block diagram depicting the proportional (P) position control is shown in Figure 4, where $\boldsymbol{x_r}$ [mm] is the commanded position and $\boldsymbol{x}$ [mm] is the actual cart position. $\boldsymbol{e} = \boldsymbol{x_r} - \boldsymbol{x}$ [mm] is the position error, commonly referred to as "tracking error". $\boldsymbol{K_p}$ [V/(mm/sec)] is the proportional feedback gain which generates the control voltage signal $\boldsymbol{u}$ [V] applied to the amplifier's input based on how large the position error is. In reality, there is also an equivalent disturbance $\boldsymbol{d}$ [V] which originates from the friction in the cart mechanism. The friction disturbance opposes the cart motion; hence it has a negative sign. The effect of the disturbance on the servo performance will be studied in later labs. The cart's position $\boldsymbol{x(t)}$**,** which is integral of the velocity $\boldsymbol{v(t)}$, is measured and fed back into the control loop.

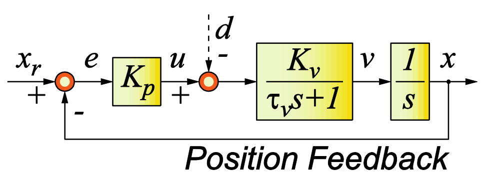


**Figure 4:** Proportional (P-type) position control.

Construct a Simulink model of your P –Control system based on Figure 5, and run it to verify the structure and the output. Once you are satisfied with your simulation you can try it out on the experimental setup.

**4-2a.** Implement the P position controller using the Simulink model in Figure 5. As position command, apply a ±5.0 [mm] square wave with 0.5 Hz frequency. Try out the values **0.15**, **0.25**, **0.5** [V/mm] for $K_p$**.** Capture the response from the "scope" block in each case. Save your data after each experiment, rather than copying the MATLAB plots.

**⇨ Never use negative values for $K_p$, to avoid the control system becoming unstable and the cart crashing to one end! To avoid damages to the drive mechanism, do not try out gains that exceed 0.6 [V/mm], and for high feedback gains, do not run the setup for longer than 10 seconds at a time!**

**⇨ Do not saturate the control signal! The voltage sent to the motor should never exceed ±5V, otherwise nonlinear effects are introduced, which will corrupt your experimental data, and system response.**

**⇨ Save your data after each step. Before leaving, verify with the Lab TA that what you have saved is correct.**

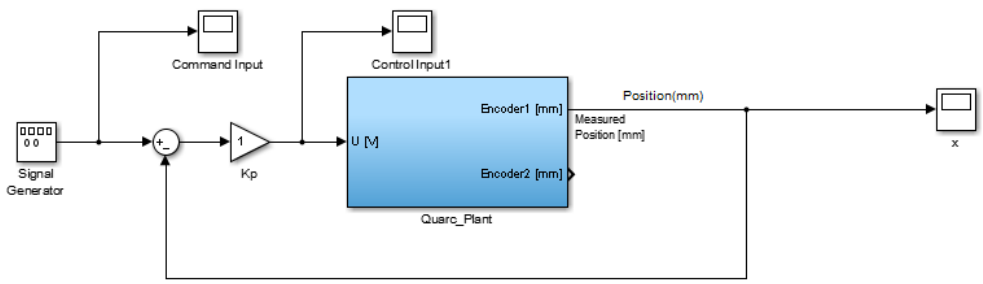


**Figure 5:** Simulink model for proportional position control.

## 5) Post-Lab instructions

**For Parameter Identification through Step Response Measurement**

**5-1a.** In your Lab 1 report, provide a plot showing the velocity step response you obtained in Part 4-1a. Clearly explain how you obtained/identified the values plant parameters $K_v$ and $\tau_v$ in Part 4-1b.

**5-1b.** Provide plots of the measured and simulated step responses overlaid on top of each other (i.e. $v_{meas}$ (from Part 4-1a) and $v_{ave}$ (from Part 4-1c) vs. time $t$). Comment on the similarities and/or discrepancies between the two, reflecting your engineering judgment. Also plot the input profile ($u$ vs. $t$) underneath the velocity response graph. The time axes should be identical. You may ask the TAs to explain the details of how these plots should look like.

**For Proportional (P-type) Position Control:**

**5-2a.** The P-controlled closed loop system can be represented with an equivalent 2nd order model, as shown in Figure 6. In the simplified model, $\omega_n$ [rad/sec] represents natural frequency and $\zeta$ represents damping ratio of the closed-loop poles. Derive the expressions for $\omega_n$ and$\zeta$, and compute their values for $K_p = 0.15, 0.25$ and 0.5 [V/mm].

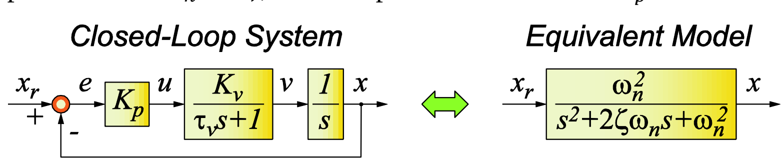


**Figure 6:** Equivalent 2nd order model for P-controlled servo system.

**5-2b.** Plot the closed-loop position step response for different values of $K_p$ (i.e. 0.15, 0.25, and 0.5 [V/mm]) in the format shown in Figure 7. As the proportional gain is varied, comment how the rise time, overshoot, steady state error, and control signal in the step response change. *Refer to control theory from your textbook (or additional references) in coming up with appropriate explanations that account for your experimental observations*.

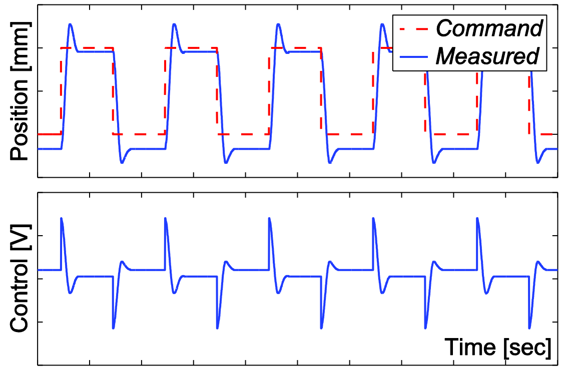


**Figure 7:** Sample step response for P-control.

**5-2c.** Include a plot in your report showing your experimental P-Control closed loop system output overplayed with the simulated one, and accompanied by a subplot showing actual control signal and simulated control signal. You may ask the TAs to show/explain the details of how these plot should look like.