## LAB 1: MODELING OF THE MOTOR SYSTEM

*This lab manual is written such as to allow 4th year students to exercise their engineering judgement and creativity. Design objectives must be met, but how you complete various tasks can vary from one group to another. Hints are offered at various points, instead of step-by-step instructions. This approach is intended to provide a challenging engineering exploration.*

For Lab 1, we focus on the inner-loop in Figure 6, where the motor gear angle is controlled. The loop is duplicated in Figure 7(a); Figure 7(b) shows the later addition of a saturator to limit the motor operating angle range needed when connecting the beam; Figure 7(c) shows the discretized controller acting on the continuous plant.

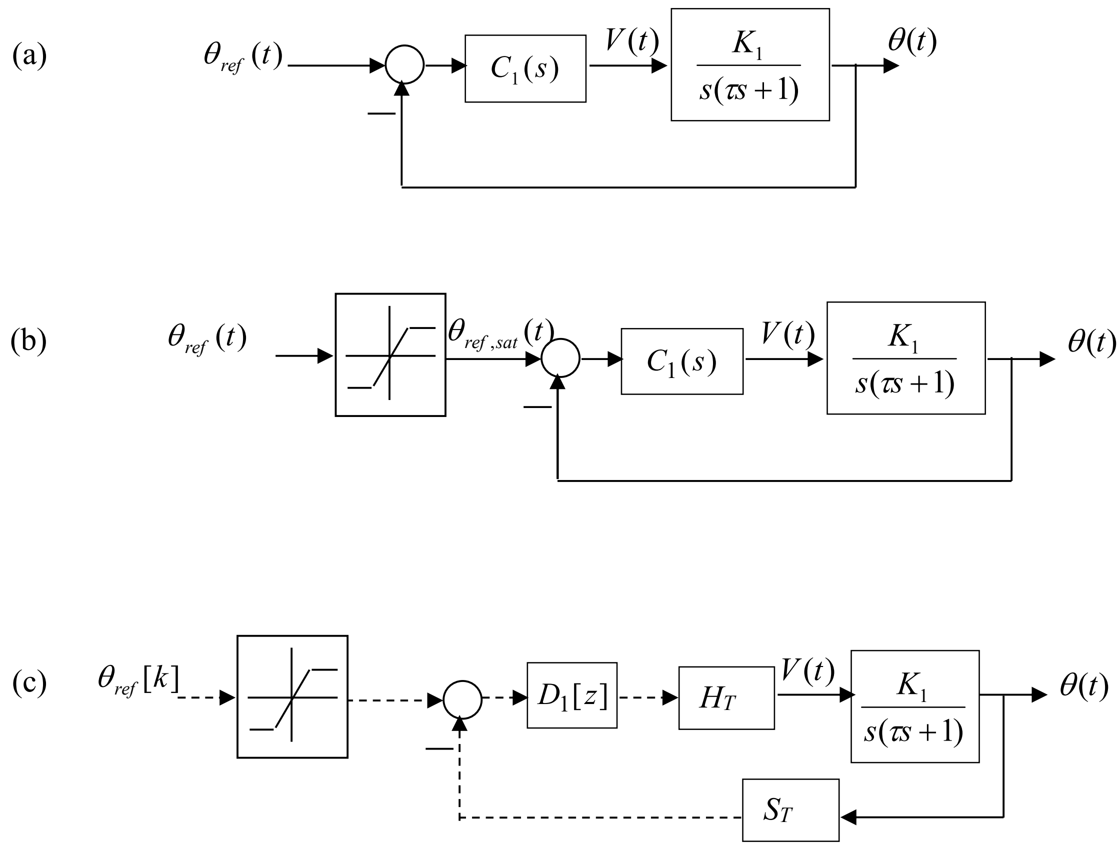



*FIGURE 7:* (a) continuous-time inner loop, (b) continuous-time inner loop with a saturator (c) sampled-data inner loop with a saturator (the dashed arrows represent discrete-time signals, the $S_T$ block represents an ideal sampler, and the $H_T$ block represents an ideal zero-order hold)

> **Warning: Make sure that the beam is not attached to the gear at this point. You need a working controller for the inner-loop to avoid damaging the (surprisingly expensive) ball and beam apparatus!**

(a) Familiarize yourself with the GWiz application. Open **GWiz_3_2.lvproj**; from this project explorer, open **cRIO-9076_RT.vi**. It is strongly suggested that BOTH partners compile the files on their account, and keep a copy of ongoing project work, as a measure of redundancy, and availability of files for submissions and demo.
If you still have questions about the variables used in the formula node, refer to Appendix 3 in this document.

(b) Check out your experimental station. Figure 8 shows a detail of the motor system plant and how to correctly measure the gear angle $\theta$.

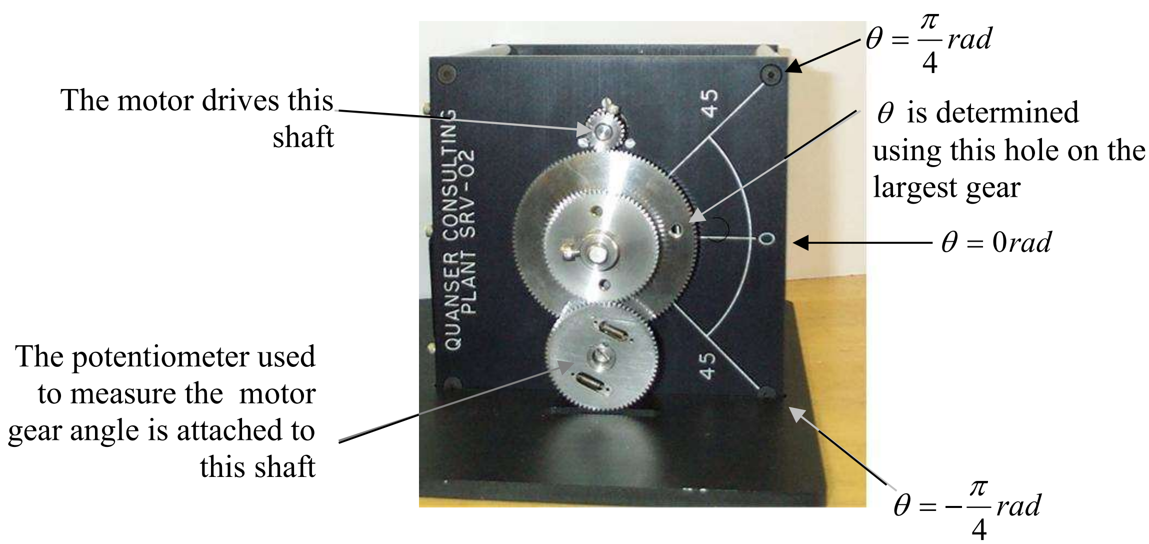



*FIGURE 8:* The motor system plant for Lab 1

(c) The motor gear angle is measured using a potentiometer. It is necessary to convert the potentiometer voltage to the corresponding gear angle in **radians**. This relationship is nonlinear due to an offset, as shown in Figure 9. You should invert this nonlinearity in software (referred to as "sensor scaling" in cRIO-9076_RT.vi), so that the overall system is linear. To implement the gear angle scaling, first experimentally determine the gain and offset for your apparatus. Then, write the necessary code in the formula node of the cRIO-9076_RT.vi file to compute the gear angle in radians.

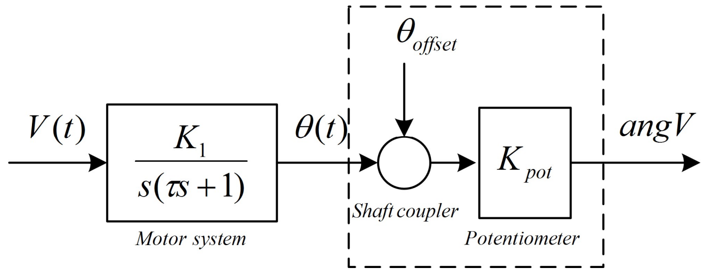



*FIGURE 9:* Nonlinearity introduced by servo-angle potentiometer

(d) Any motor has some amount of static friction, often called "stiction". From a control point of view, stiction is undesirable since it can make fine motor motions very difficult. One strategy to deal with stiction is to (approximately) cancel it out:

- Experimentally determine the motor voltage required to overcome stiction. The following tips may help:
  - Be sure that the "Manual/Auto" toggle switch on the cRIO-9076_RT.vi front panel is set to "**Manual**" so that you can manually adjust the motor voltage.
  - The motor stiction offset should be selected so that, ideally, the dead zone is completely eliminated.
  - Stiction may be nonsymmetrical, so you need to determine the stiction offset for each direction: clockwise and counter-clockwise.

- The term direction, clockwise or counter-clockwise, refers to the direction of rotation of the large gear, viewed from the front.
- A simple stiction compensator is provided in the block diagram of cRIO-9076_RT.vi.

In Lab 1 report, explain briefly how you determined suitable stiction offset values.

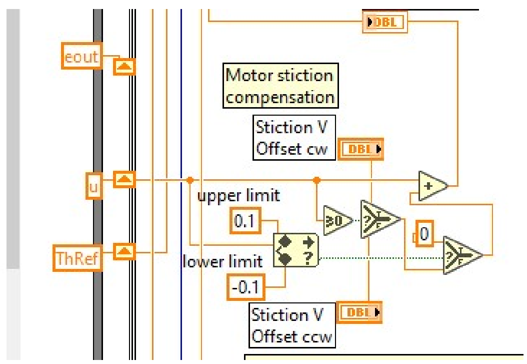
**From now on, it will be assumed that the stiction compensation is implemented in your experimental setup.**

(e) If you are not familiar with DC motor models, consult an undergraduate control textbook to verify that (1) is a standard model.

Using an experimental method, determine the specific values of $K_1$ and $\tau$ for your lab apparatus. Note the following:

- The plant is open-loop unstable, and therefore it is difficult to model the plant directly. Instead, stabilize the plant (how?), and use system identification techniques (e.g., use step response overshoot and time to first-peak to deduce the unknown system parameters, or perhaps a frequency response) to determine a model of the *closed-loop* system. Then use these results to compute $K_1$ and $\tau$. Pay special attention to signs, as some values may be negative.

- Be sure to set the sampling rate appropriately. If you do not explicitly account for the finite sampling rate in your modeling calculations, then set the sampling rate to be sufficiently fast (1,000Hz) when obtaining data. In your report, indicate what sampling rate you used and why.
- With a stable inner-loop, it is a good opportunity to verify that the stiction value you selected in (d) is adequate: the stiction offset should be high enough so that the step response first peak is well rounded with no flat portions, but low enough that the step response settles to its steady-state value with no gear oscillations. Another check is that there should be little or no steady-state error.
- In addition to the cw and ccw Stiction Offsets, the Labview application has two other parameters that affect the behavior of the motor. When exercising the inner loop you may observe oscillations on the motor gear, as it approaches the steady state after the initial overshoot. The oscillations can be reduced by changing the values of the "upper limit" and "lower limit" parameters, which have initial default values of +- 0.1. These parameters can be seen in the snippet of the Block Diagram below:

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- Be sure that you do not saturate the motor voltage by applying more than $\pm 6V$. Include in your report a plot of the motor voltage along with the plot of signals used for system modeling, as evidence that you have avoided saturation.
- Use several sets of data and different system setups, e.g., different controller gains, to increase the probability that your parameter estimates are accurate.

Normally, once the system identification is completed, a different method is employed to run the system identification again. We call this process *validation*. If at the end of the two procedures, your results are similar, you can be confident in the correctness of the parameters you identified.

We are allowing you to skip the validation step, and are providing instead the *nominal* parameter values for this system:

$$abs(K_1) = 1.9 \text{ rad/(Vs)}$$
$$\tau = 0.025\text{s}$$

(f) To help prevent damage to the experimental apparatus when the beam is reconnected to the motor in Lab 2, it is critical that the motor gear angle satisfies $-\frac{\pi}{4}\text{rad} < \theta(t) < \frac{\pi}{4}\text{rad}$ at all times. To help ensure this, prefilter $\theta_{ref}(t)$ using a saturator, as shown in Figure 7(b). In Lab 2/(a) we will design a controller to achieve an overshoot no higher than 5%; when this controller is operating, the condition $-0.7\text{rad} < \theta_{ref,sat}(t) < 0.7\text{rad}$, will ensure $-\frac{\pi}{4}\text{rad} < \theta(t) < \frac{\pi}{4}\text{rad}$.

> **Note:** For simulations, use **Matlab 2021a**, the same as the version available on the lab computers. In later labs, you will be required to submit your Simulink diagram for testing/evaluation, and for this reason, we need a consistent Matlab platform.

Use Simulink to simulate the system in Figure 7(b) to verify that the saturator works as expected. Include in your report the Simulink diagram used and a simulated plot showing the effect of the saturator.

**Warning: Do not attach the ball and beam to the motor at this point.**

Include the saturator in your formula node, and perform an experiment to show that the saturator is functioning as desired. Include the plot in your Lab 1 report.

(g) Draw a block diagram for the inner-loop showing the experimental signals, the variable names used in the formula node, and their units. Be sure to include nonlinear effects, such as offsets and saturation, as well as sensor scaling. Correct signs should also be shown. Indicate which blocks, specifically, are part of the apparatus. Distinguish (colour or line type) between analog and digital signals.

> **Note:** When choosing the platform for creating this diagram, keep in mind that in Lab 2, as the scope of the project expands, you add to this diagram, which will be part of your deliverables again in Lab 2.

(h) Include the code from your Formula Node.

In addition to the General Report Guidelines, attempt, as best as you can, to fit your Lab 1 report within 15 pages from the front page to the end.