University of Applied Sciences and Arts Northwestern Switzerland
School of Engineering

Fundamentals of Control Engineering (rtGL)

Lab Exercises

Bachelor Systems Engineering (4Seng)

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Chapter 1

PID Control – Motor

In the following, the lab exercise "‘PID Control – Motor"’ will be described. The purpose and learning objectives will be named, the laboratory setup will be explained, and the tasks to be accomplished will be given.

1.1 Purpose

Tuning a PID controller according to well-proven rules is part of the fundamental knowledge of an engineer. The purpose of this laboratory exercise is to apply the knowledge acquired during the course concerning PID controller selection and tuning to a real-life plant. The speed of an electrical motor is to be controlled. The laboratory setup is representative of many technical applications, e.g.

- speed control of conveyor belts
- speed control of linear drives
- speed control of spindle drives

Many technical applications require constant-speed movements that are independent of the load (e.g. force or torque). The actuator most frequently used in order to achieve such tasks is the electrical motor. In particular in applications where not only constant-speed movements are relevant but where defined acceleration and brakes phases are required, direct-current (DC) motors are typically employed.

1.2 Learning objectives

The following learning objectives shall be reached in this laboratory exercise:

- You are capable of determining the characteristic quantities of a plant based on both step response and oscillation method.
- You are capable of selecting suitable parameters for PID controllers based on the Ziegler-Nichols and Chien-Hrones-Reswick methods.
- You are capable of optimizing the controller parameters manually in closed loop.

1.3 Fundamentals

It is important to know the purpose and the limits of PID tuning rules. These aspects will be discussed in the following.

1.3.1 Tuning rules for PID controllers

Investigating the step response of a plant yields the required information in order to select and tune a controller. Furthermore, certain tuning rules are based on the oscillation method. The application of both the step response and oscillation method is described in the course material. The tuning rules according to Ziegler-Nichols (oscillation method) and Chien-Hrones-Reswick (step response method) are used for PID controller tuning.

1.3.2 Manual optimization of PID controllers

Tuning rules typically yield suitable starting values for a controller. However, manual optimization of a controller is often more essential to tuning a controller than selecting controller parameters precise to the 5th decimal place based on a tuning rule. Optimal controller parameters are frequently determined by unexpected properties of the plant or by subconscious criteria. Therefore, it is highly important to know the influence of changes to the different controller parameters on the closed-loop behavior. Systematic investigation of the control loop according to this description is the base for gaining this experience.

Unfortunately, there is no mature theory on optimization of controller parameters. Modern methods for tuning PID controllers also identify certain characteristic quantities, usually based on the open-loop behavior, that form the basis for selecting suitable controller parameters.

1.4 Description of the laboratory setup

Both hardware and software part of the laboratory setup will be described in the following.

1.4.1 Hardware

This laboratory setup consists of three main components:

- Plant
- Controller
- PC with the user interface running under Matlab

The plant itself consists of the following elements:

- Motor: The motor used in the setup is a universally usable DC motor. The brushed DC motor is excited using permanent magnets.
- Tachometer: The speed sensor which is physically connected to the motor is a tachometer generator. It yields a voltage signal that is proportional to the motor speed.

The controller consists of an Arduino UNO microcontroller along with a motor shield (Adafruit Motor Shield v2.3) and a voltage divider circuit. The motor shield is based on an H bridge and is capable of delivering the required current (as opposed to the Arduino UNO board itself). The voltage divider is required in order to transform the tachometer signal into a signal compatible with the analog input.

Microcontroller and PC are connected with a USB cable and communicate across the serial port.

Additionally, the laboratory setup includes a circuit that allows to simulate an external disturbance (e.g. a sudden increase of the load driven by the motor) by changing the position of a switch.

During the exercise, instructions on how to connect plant and controller will be given.

1.4.2 Software

The code running on the Arduino UNO consists of the following functions:

- reading of the sensor value from the analog input

- computation of the actuator value based on a PID controller, including all auxiliary function from the course
- writing of the actuator value to the motor shield

The user interface running under Matlab has the following functionality:

- reading of different values (e.g. sensor value, tracking error) from the serial port
- displaying different values as trends with the possibility to zoom and to export data
- writing of different parameters (e.g. PID controller parameters, sampling time) to the serial port

All required code will be distributed during the exercise.

1.5 Tasks

The tasks to be accomplished in this laboratory exercise include proper planning of the exercise, determination of the plant parameters, control design and optimization, simulation, and documentation of the results in a laboratory report.

1.5.1 Planning

Proper planning of the laboratory exercise is crucial and should be finished before starting the actual experiments. The following tasks are part of this planning phase:

- Make sure that you possess all required theoretical knowledge and that you have all written documents that may be helpful ready.
- Get acquainted with the experiment setup. Study all elements and try to understand how they work together.
- Plan your work, i.e. make a list of the tasks to be completed and allocate the available time to these tasks.
- Plan your report, i.e. generate a template in which you can directly paste your results. Make sure that you have collected all required information at the end of the exercise.

1.5.2 Plant parameters

The following tasks are required for identifying the plant parameters, which are required in the control design part:

1. Record the characteristic curve of the plant for the entire range of possible system inputs and discuss its properties. Choose the range of inputs economically, but take care not to overlook any relevant phenomena.
2. Choose an operating point for which you design the controller and justify your choice.
3. Carry out a step experiment and determine the plant parameters gain K_{S}, delay time T_{u}, and compensation time T_{g}.
4. Carry out an oscillation experiment and determine the plant parameters critical gain $K_{\mathrm{P,crit}}$ and critical period τ_{crit}.

1.5.3 Control design and optimization

Control design and optimization consists of the following tasks:

- Before you set the controller to automatic mode for the first time, indicate which controller type you would use based on the information obtained with step response method and name your reasons.
- In the following, **always discuss the performance of the controllers and the influence of the controller parameters in each step and provide figures.**
- Design controllers according to the tuning rules and perform a parameter sensitivity analysis as follows:
  1. **P controller** (**either** Ziegler-Nichols **or** Chien-Hrones-Reswick):
     Vary the controller gain K_P as follows:
     - $K_\mathrm{P} = K_\mathrm{P,rule}$ according to tuning rule
     - $K_\mathrm{P} = 0.2 \cdot K_\mathrm{P,rule}$
     - $K_\mathrm{P} = 4 \cdot K_\mathrm{P,rule}$
  2. **PI controller** (**either** Ziegler-Nichols **or** Chien-Hrones-Reswick):
     Vary the integral time T_i as follows:
     - $K_\mathrm{P} = K_\mathrm{P,rule}$ and $T_\mathrm{i} = T_\mathrm{i,rule}$ according to tuning rule
     - $K_\mathrm{P} = K_\mathrm{P,rule}$ and $T_\mathrm{i} = 0.2 \cdot T_\mathrm{i,rule}$
     - $K_\mathrm{P} = K_\mathrm{P,rule}$ and $T_\mathrm{i} = 4 \cdot T_\mathrm{i,rule}$
  3. **PID controller** (**both** Ziegler-Nichols **and** Chien-Hrones-Reswick):
     - $K_\mathrm{P} = K_\mathrm{P,rule}$, $T_\mathrm{i} = T_\mathrm{i,rule}$, and $T_\mathrm{d} = T_\mathrm{d,rule}$ according to tuning rule
- Select the best PID controller that you have obtained so far and optimize its parameters such that the closed-loop settling time is as short as possible and such that no significant overshoot (≤ 5 %) can be observed.
- Use this controller and try it for different reference values, in particular at values far from the operating point that you selected.
- Use this controller and investigate its disturbance rejection capabilities by using the switch in the laboratory setup.

1.5.4 Simulation

The simulation should comprise the following aspects:

- Remark: This exercise does not require any laboratory equipment and can hence be done after the laboratory hours.
- Generate a simulation model of the plant in Matlab/Simulink. Use a series connection of a dead time element and a first-order lag element (PT_1) or optionally a series connection of two or three first-order lag elements. Adjust the parameters such that the simulated step response matches the recorded step response as closely as possible.
- Document the plant model and parameters and provide a block diagram. Compare the two step responses and discuss the differences.
- Implement a PID controller in your Matlab/Simulink model. Use the controller parameters of the best controller that you found during your experiments. Compare the tracking behavior between simulation and experiment and discuss the differences. Do not forget to consider the effect of the auxiliary functions of the PID controller.

1.5.5 Report

The report should have the following content:

- Introduction with summary of the exercise (e.g. objectives, tasks)
- Description of the control loop including a block diagram with three to five blocks
- Characteristic curve and operating point
- Plant identification, i.e. step response and oscillation methods
- Controller tuning and closed-loop behavior
- Simulation and comparison with experiment
- Analyses, comments, and conclusions (also in the course of the report, not only at the end)

The report should be concise and address a reader familiar with the fundamentals of control engineering. It follows the usual guidelines for technical reports and is correct in terms of grammar and orthography (the required level of grammar and orthography is higher if you choose to write it in German language, of course). All figures should be meaningful and all results and conclusions can be reproduced.