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Automation Lab

Temperature Control Lab 1
(TCL 1)
Experiment Report

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Contents

1 Introduction

The experiment consists of two main parts: preparation and practical application. Its objectives are to enhance understanding of parameter estimation techniques for linear systems and to gain practical experience by applying model identification methods to independently collected real-world data. Using the Temperature Control Lab, real-world data and the data from step response of the Heater-Sensor system's transfer function will be collected, and two straightforward identification methods—the tangent method and Schwarze's method—will be employed to determine the Heater-Sensor system's transfer function. At the end of the experiment, a comparison will be made between the real-world data and the step response data obtained from the two methods.

2 Model Identification with Aperiodic Test Signals

To ensure the successful execution of the practical component of the experiment, it is imperative that all preparatory tasks are completed in advance.

2.1 Preparation Part

2.1.1 Identification of System Behavior

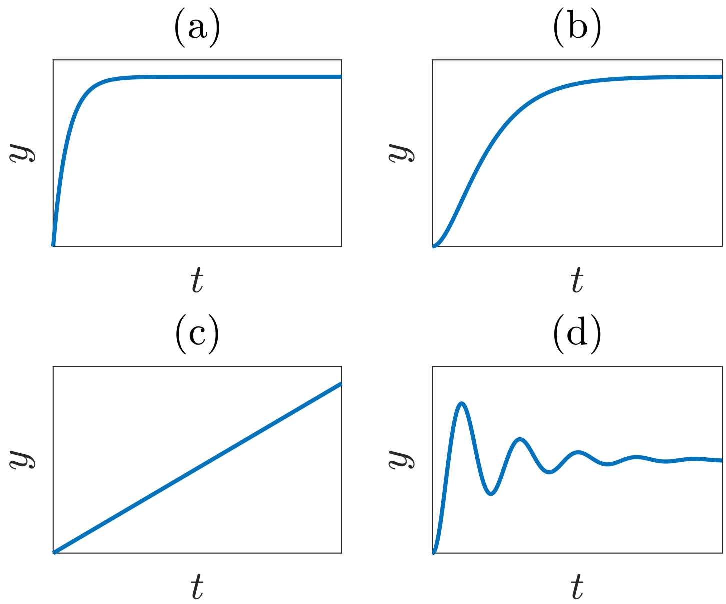

Figure 2.1: Step responses of four basic dynamical systems. [1]

- Step response (a) in the figure 2.1 describes a step response behavior of the PT1 system (First-Order System).
- Step response (b) in the figure 2.1 describes a step response behavior of the PT2 system (Second-Order System without Oscillation).
- Step response (c) in the figure 2.1 describes a step response behavior of the I (Integrator) system.
- Step response (d) in the figure 2.1 describes a step response behavior of the PT2 system (Second-Order System with Oscillation).

2.1.2 Identification Methods

The most commonly used methods for identifying the transfer function of a dynamic system are the **Tangent Method, the Method of Schwarze, and the Least Squares Method**. These techniques are widely recognized for their effectiveness in parameter estimation and system identification, offering distinct approaches suited to various types of system behaviors and input data characteristics.

Applicability, Required Input Signal, Obtaining Specific Parameters of Tangent Method and Method of Schwarze

Table 2.1: Applicability,Required Input Signal, Obtaining Specific Parameters of Tangent Method and Method of Schwarze. [2]

Aspect	**Tangent Method**	**Method of Schwarze**
Applicability	Suitable for systems with smooth, monotonic step responses. Requires measurable delay and rise times.	Effective for systems where percentage-based time points (e.g., 10%, 50%, 90% of final value) are clearly measurable.
Input Signal Required	A unit step input is typically used.	A step input is required.
Parameter Extraction	• Draw the inflection tangent on the step response curve to locate key time parameters: delay time (T_u) and rise time (T_a). • Use the ratio T_a/T_u to identify system order (n) from a reference table. • Determine the system gain (K_S) using: $K_S = \frac{x_e}{x_a}$, where x_a is the amplitude change and x_e is the steady-state input amplitude. • For second-order systems, calculate time constants (T_1, T_2) using derived ratios and reference tables.	• Calculate system gain (K_S) as in the Tangent Method. • Measure time points corresponding to 10%, 50%, and 90% of the final value. • Use the ratio $\mu = t_{90}/t_{10}$ to identify system order (n) from a reference table. • Determine time factors (τ_{10}, τ_{50}, τ_{90}) from parameter tables. • Compute system time constant (T) using: $T = \frac{1}{3}\left(\frac{t_{10}}{\tau_{10}} + \frac{t_{50}}{\tau_{50}} + \frac{t_{90}}{\tau_{90}}\right)$.

2.2 Practical part

2.2.1 Temperature Profile Obtained With Sensor 1

After a pre-heating phase of 5 min using 20% of the maximal power output regarding Heater 1, apply a step input to Heater 1 from 20% to 60% of the maximum power output Heater-Sensor-System.

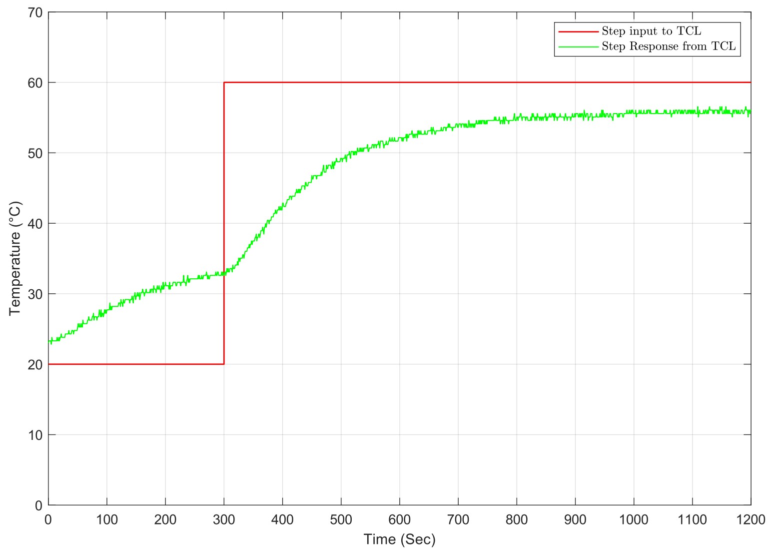

Figure 2.2: Step Input and Step Response of TCL.

The analysis of the step response of the Temperature Control Lab (TCL) indicates that the Heater-Sensor System exhibits the characteristics of a second-order system without oscillatory behavior, commonly referred to as a PT2 system.

2.2.2 Calculation to Determine The Transfer Function

By utilizing the information provided in Handout [2] and the accompanying table, one can easily derive the transfer function corresponding to the step response using MATLAB. The systematic approach outlined in these resources facilitates the formulation of the transfer function, enabling a clear understanding of the system's dynamic behavior in response to a unit step input by both the methods Tangent Method and Method of Schwarze.

Tangent Method

The Tangent Method employs the delay time, Tu, and the rise time Ta, as key parameters to derive the transfer function of a given system. The figure below illustrates the practical application of the Tangent Method to the original step response, highlighting how these time constants are utilized to characterize the system's dynamic behavior and ultimately determine its transfer function.

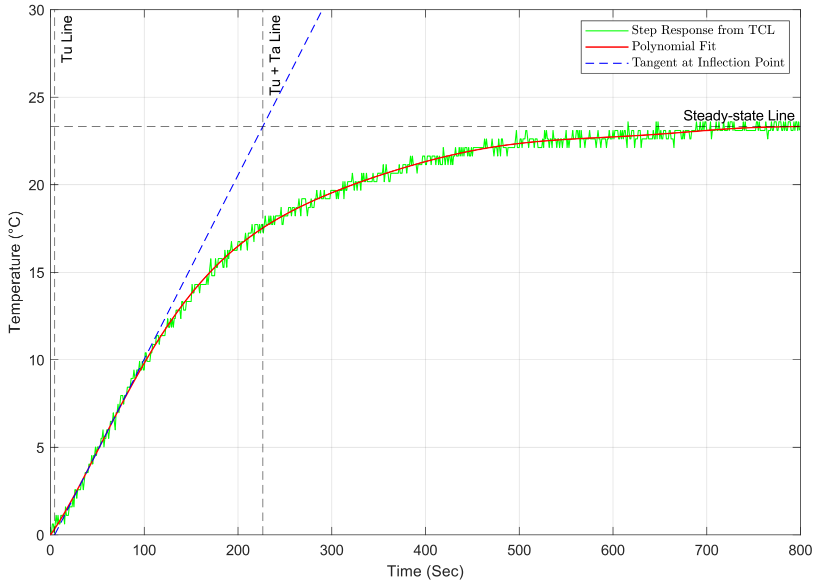

Figure 2.3: Time vs Polynomial Fit of Step Data with Tangent Line.

The system order n can be determine using the ratio $\frac{T_a}{T_u}$. By reading the values from the graph using MATLAB:

$$\frac{T_a}{T_u} \approx 18.28, \quad T_u = 4.4532, \quad T_a = 222.0356,$$

By comparing this ratio with the entries in the Handout [2].

From the comparison, it is verified that the system is of order $n = 2$.

The gain K_S is calculated using the following formula:

$$K_S = \frac{x_a}{x_e} \approx 0.5833, \quad x_a = 23.3304, \quad x_e = 40$$

Time constants T_1 and T_2, and from the ratio $\frac{T_a}{T_u} \approx 49.8596$

With the help of the Handout [2] to get the closest match.

The nearest value for $\frac{T_a}{T_u}$ is found in the row where $\frac{T_2}{T_1} = 9.0$.

For the calculation of T_1 and T_2 using the Handout [2] : $\frac{T_a}{T_1} = 11.84$ (from the Handout [2])

Hence, $T_1 \approx 18.7530$ Since the value of $\frac{T_2}{T_1} = 9$, we can calculate $T_2 = 9 \cdot T_1 \approx 168.7770$

With the values of K_S, T_1 and T_2

There for the transfer function by Tangent Method according to the Handout [2] of the Heater-Sensor System is:

$$G(s) = \frac{0.5833}{(1 + 18.7530s) \cdot (1 + 168.7770s)}$$

Method of Schwarze

The Method of Schwarze derives the transfer function using percentage values from the step response. The figure below illustrates its application to the original step response.

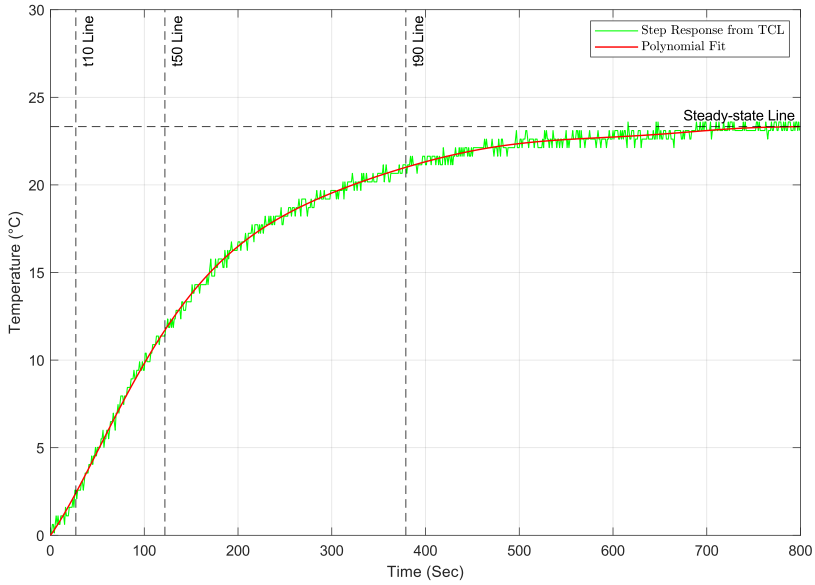

Figure 2.4: Step Response with t10,t50,t90 and Steady State.

Order n of the system is determined with the help of Handout [2] using the ratio $\mu = \frac{t_{10}}{t_{90}}$. Where, $t_{10} = 27.000$, $t_{50} = 122.000$ sec sec and $t_{90} = 379.000$ sec. The $\mu = \frac{t_{10}}{t_{90}} \approx 0.0712$. Hence, the system order is $n = 2$. The gain $K_S = 0.5833$ as same as the Tangent Method. With the data from the step response and from the Handout [2], for $n = 2$, the parameters are: $\tau_{10} = 0.532$; $\tau_{50} = 1.678$; $\tau_{90} = 3.890$. The time constant T should be calculated as $T = \frac{1}{3}\left(\frac{t_{10}}{\tau_{10}} + \frac{t_{50}}{\tau_{50}} + \frac{t_{90}}{\tau_{90}}\right)$ and substituting the values $T = \frac{1}{3} \times 220.887 = 73.629$. Thus, $T \approx 73.629$ seconds.

There for the transfer function by Method of Schwarze according to the Handout [2] of the Heater-Sensor System is:

$$G(s) = \frac{K_S}{(1 + Ts)^2} = \frac{0.5833}{(1 + 73.629s)^2}$$

2.2.3 Simulink Model and Comparison

By replacing the TCL block in the Simulink model with the transfer function derived using the methods described above as represented in the figure 2.5 the step response generated by Tangent Method presented in the figure 2.6 demonstrates a closer alignment to the original step response when compared to the results obtained using the Method of Schwarze.

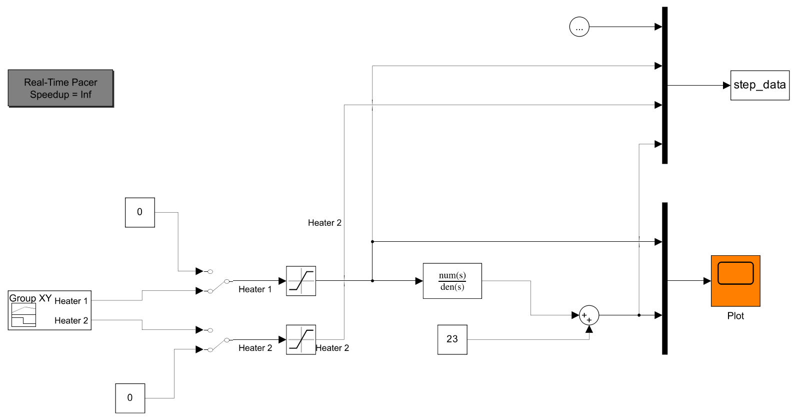

Figure 2.5: Transfer Function Simulation.

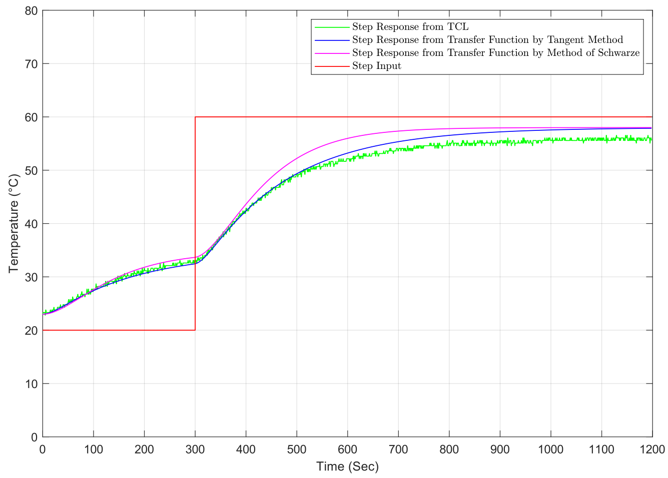

Figure 2.6: Comparison of Step Responses.

2.3 Conclusion

Upon comparing all the step responses from the figure 2.6, it becomes evident that the step response generated using the Tangent Method demonstrates a closer alignment with the data derived from the TCL. This suggests that the transient method provides a more accurate representation of the Heater-Sensor System's dynamic behavior from data derived by the TCL in comparison to the other method considered.

Bibliography

[1] Material TCL 1, 2024. Course: [Automation Lab], University: [Institute for Automation Engineering OVGU].

[2] Handout TCL 1, 2024. Course: [Automation Lab], University: [Institute for Automation Engineering OVGU].