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Bachelor in Electronic Engineering

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This version of this report only contains the sections done by Richard Jimenez

Workload in Report:
- **First Order System Section:** Bhavesh
- **Second Order System Section:** Richard Jimenez
- **PID Section:** Bhavesh & Richard Jimenez

[Text Edition: Richard Jimenez]

2023

1 Introduction by Richard Jimenez

This report presents a comprehensive analysis of a series of experiments conducted on first-order systems, second-order systems, and the application of PID (Proportional-Integral-Derivative) control. These experiments were carried out during two separate sessions in June and July of 2023 at a laboratory at the HSHL (Hochschule Hamm-Lippstadt). The successful completion of these experiments was the result of a highly collaborative team effort, with both team-members actively working together to tackle each task. In our experiments, we focused on working together and making sure everyone understood each experiment as well. In the next sections, we will explain each of the six sub-experiments in more detail. We will also share what we discovered, analyzed, and learned from these experiments, giving us a better understanding of how the control systems behave and perform.

It is worth noting that the photos/images of the oscilloscope screen were taken during the lab sessions. These images can be either photographs or screenshots captured from the Rohde & Schwarz RTB2004 oscilloscope using the USB saving functionality.

2 First Order System by Bhavesh

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Note: This version of this report only contains the sections done by Richard Jimenez

3 Second Order System by Richard Jimenez

In this section, the second-order system circuit will be analyzed in three different configurations: (1) overdamped, (2) critically damped, and (3) underdamped, as depicted in Figure 1. These configurations exhibit distinct outputs on the oscilloscope depending on the component values. They were also compared to the results obtained from the Simulink simulation conducted in the previous pre-report. The observations of the second-order systems highlight the concept of feedback control, indicating that these systems offer the advantage of adjusting both transient and steady-state performance. By analyzing and designing a control system, it becomes essential to define and measure its performance. Control system performance is typically evaluated based on two aspects: the transient response, which gradually diminishes over time, and the steady-state response, which persists after initiating an input signal [1].

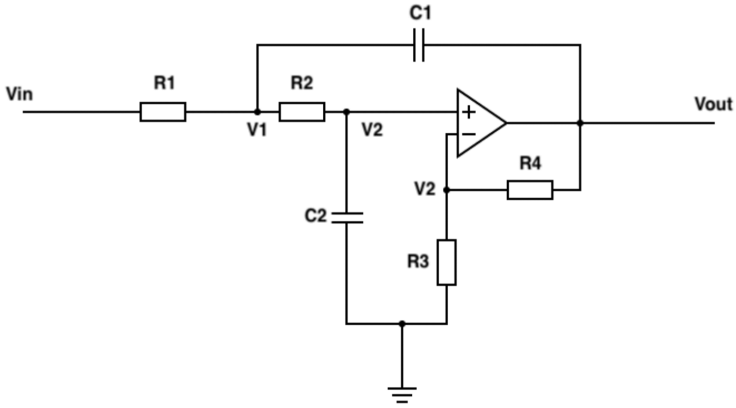

Figure 1: Circuit to be analyzed No.2. Source: Second Order Circuit, composed of one operational amplifier, two capacitors, and four resistors. Adapted from Instructions Control Engineering by Prof. Dr.-Ing. da Costa and Mrs. Faezeh.

3.1 Overdamped System by Richard Jimenez

In an overdamped system, the damping is strong enough to prevent oscillations, resulting in a slower response compared to a critically damped or underdamped system. For an overdamped system, ζ must be greater than 1, which can be expressed as following:

$$1 < \frac{R_2}{2\sqrt{R_1 R_2}} \tag{1}$$

The components required to construct the circuit for this experiment are presented in the following table, by having the configuration shown in Figure 1. This experiment aims to investigate the behaviour of an overdamped system and analyze the effects of varying the resistance values on the system's response.

Components	**Value**
R1	100 Ω
R2	1 kΩ
R3	2.2 kΩ
R4	2.2 kΩ
C1	1 μF
C2	1 μF

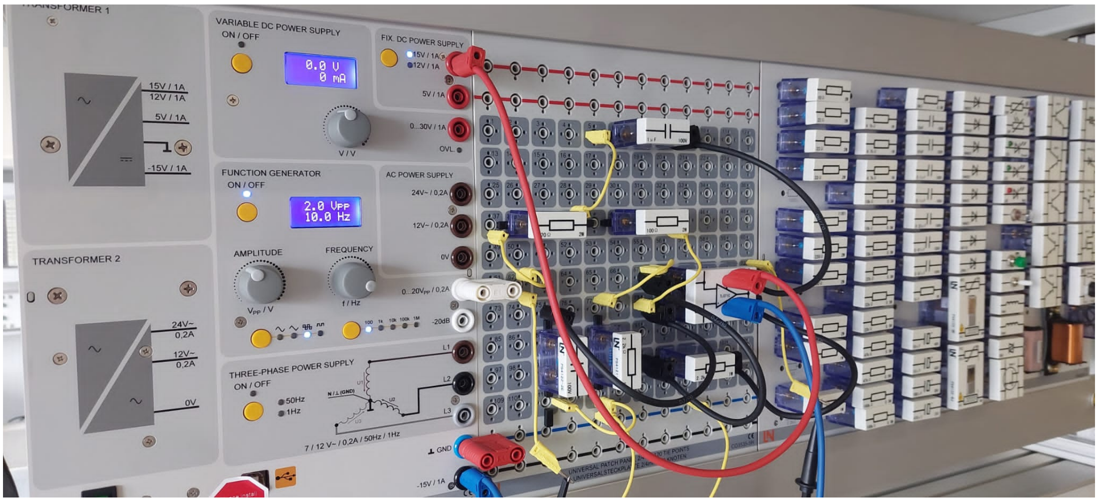

Figure 2: Assembled circuit for the overdamped system. Source: Own Creation

As shown in the Figure 3 the output plot on the oscilloscope of an overdamped second-order circuit, with a peak maximum of 164.5mV and a minimum of -235.5mV, shows a characteristic response indicative of an overdamped system. The waveform appears as a smooth curve with no oscillations. The curve rises from the minimum value to the peak maximum, exhibiting a slower rise time compared to a critically damped or underdamped system. Once it reaches the peak maximum, the curve gradually decays back down to the minimum value, again with a slower decay rate.

Figure 3: Oscilloscope Rohde & Schwarz RTB2004: Screenshot (USB) - Overdamped System. Source: Own Creation.

3.2 Critically damped System by Richard Jimenez

A critically damped second-order system is a type of dynamic system that achieves the fastest possible response without any overshoot or oscillations. It occurs when the damping factor of the system is set to a specific critical value. The response of a critically damped system is characterized by a rapid approach to the desired steady-state value without any oscillatory behavior. For a critically damped system, ζ must be equal to 1, which can be expressed as:

$$1 = \frac{R_2}{2\sqrt{R_1 R_2}} \tag{2}$$

The table presented below provides the components needed to construct the circuit for this experiment, which follows the configuration illustrated in Figure 1. For this specific experiment, the objective of this experiment is to examine the characteristics of overdamped and critically damped systems, as well as analyze how the responses of these systems are influenced by varying resistance values:

Components	Value
R1	33 Ω
R2	100Ω
R3	2.2 kΩ
R4	2.2 kΩ
C1	1 μF
C2	1 μF

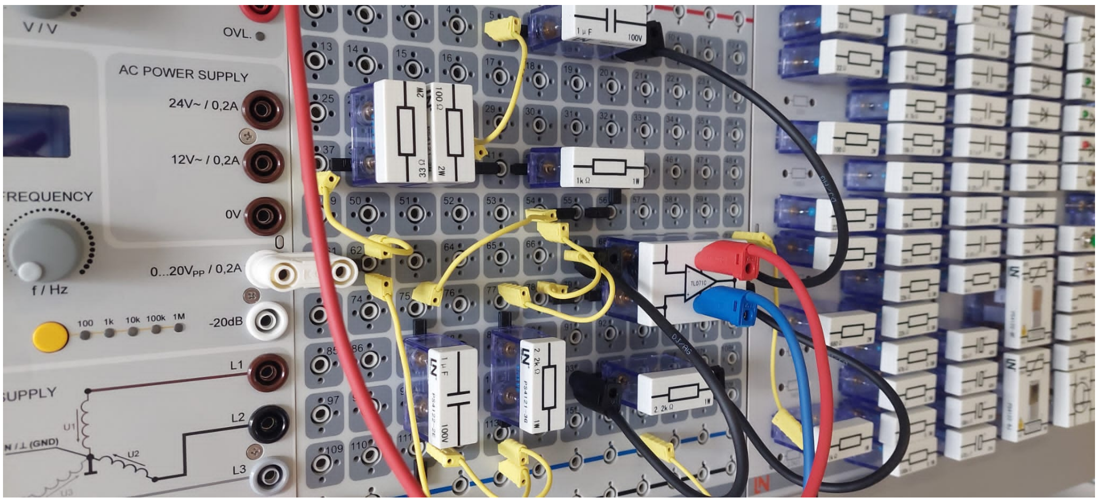

Figure 4: Assembled circuit for the critically damped system. Source: Own Creation.

In a critically damped circuit, the damping factor is precisely equal to the critical damping value, resulting in the fastest possible response without oscillation. This leads to a rapid rise and fall time with minimal overshoot. On the oscilloscope plot, the waveform exhibits a sharp and quick rise from the minimum value to the peak maximum. The rise time is notably faster compared to an underdamped system, allowing the output to reach its peak quickly. As shown in the Figure 4 the output plot on an oscilloscope of a critically damped second-order circuit, with a peak maximum of 191mV and a minimum of -289.5mV, reveals a response characteristic of a critically damped system.

Figure 5: Oscilloscope Rohde & Schwarz RTB2004: Screenshot (USB) - Critically damped System. Source: Own Creation.

3.3 Underdamped System by Richard Jimenez

An underdamped second-order system is a type of dynamic system that exhibits oscillations in its response. It occurs when the damping factor of the system is relatively low. The response of an underdamped system includes overshoot, where the system briefly exceeds the desired steady-state value, followed by oscillations before settling down. For an underdamped system ζ must be smaller than 1, that is shown in the following expression:

$$1 > \frac{R_2}{2\sqrt{R_1 R_2}} \tag{3}$$

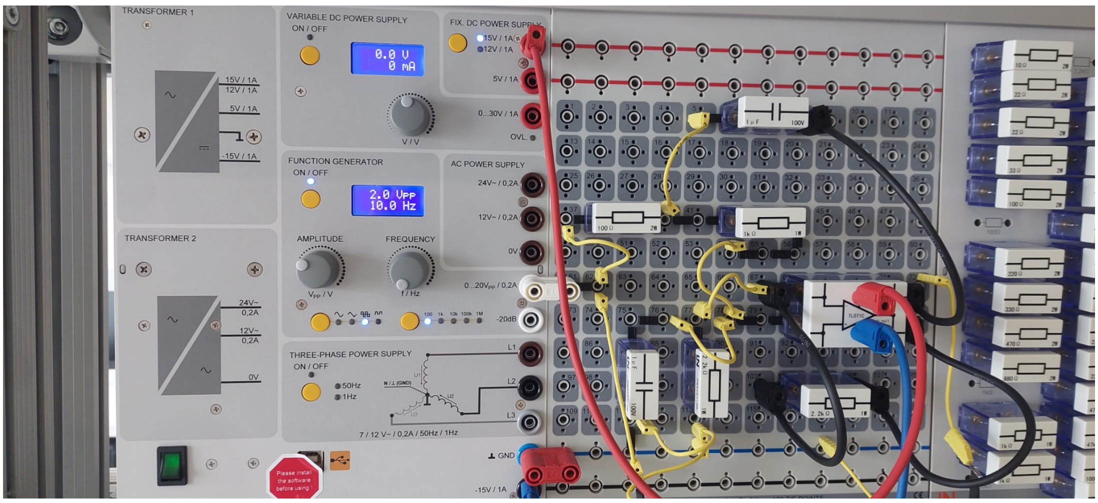

Figure 6: Assembled circuit for the underdamped system. Source: Own Creation.

In this underdamped circuit, the damping factor is less than the critical damping value, leading to a response that exhibits oscillatory behavior. In order to achieve this behaviour in the system, the following components were used based on the circuit configuration of Figure 1:

Components	Value
R1	470 Ω
R2	100Ω
R3	2.2 kΩ
R4	2.2 kΩ
C1	1 μF
C2	1 μF

On the oscilloscope plot, the waveform displays oscillations that occur between the peak maximum and the minimum values. These oscillations exhibit a decaying amplitude as time progresses. As shown in the Figure 7, the output plot on an oscilloscope of an underdamped second-order circuit, with a peak maximum of -345mV and a minimum of -648mV, reveals a response characterized by oscillations.

Figure 7: Oscilloscope Rohde & Schwarz RTB2004: Screenshot (USB) - Underdamped System. Source: Own Creation.

4 PID by Bhavesh - & Richard Jimenez

In this section, the PID controller is observed and discussed in terms of its three control actions: proportional control, integral control, and derivative control.

4.1 PID – Proportional Controller by Bhavesh

4.2 PID – Integral Controller by Bhavesh

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Note: This version of this report only contains the sections done by Richard Jimenez

4.3 PID – Derivative Controller by Richard Jimenez

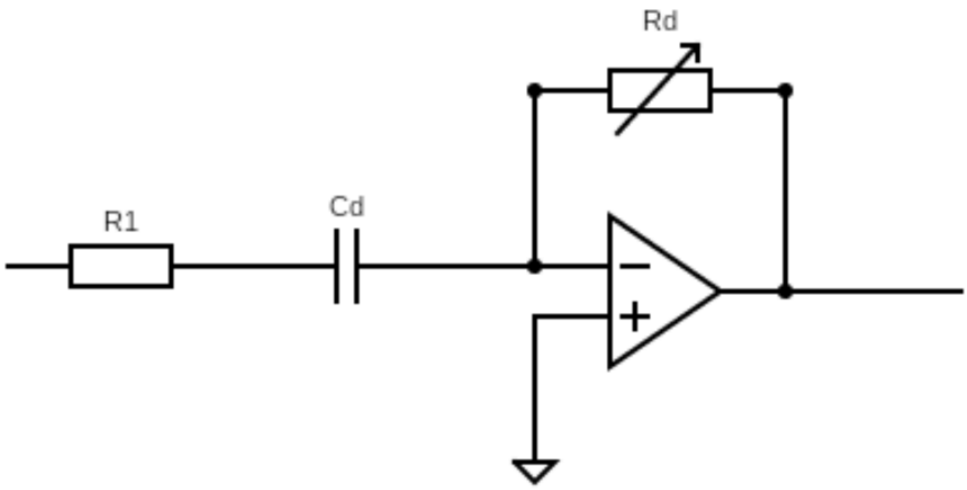

Figure 8: Derivative Controller Circuit. Source: Adapted from Instructions Control Engineering by Prof. Dr.-Ing. da Costa and Mrs. Faezeh.

The derivative controller, while analysing the behaviour of the PID (Proportional-Integral-Derivative) control, is a component that utilizes the rate of change of the error signal to influence the control output. According to Wilkie [2], the derivative control representation in the time domain is defined by the following equation:

$$u_c(t) = K\frac{de}{dt} \tag{4}$$

It calculates the derivative of the error with respect to time and multiplies it by a tuning parameter known as the derivative gain. The derivative action provides a damping effect and helps to improve the system's response by predicting future behavior based on the current rate of error change. In this sense the following system, as shown in Figure 9, was assembled in the lab to analyse this specific derivative controller.

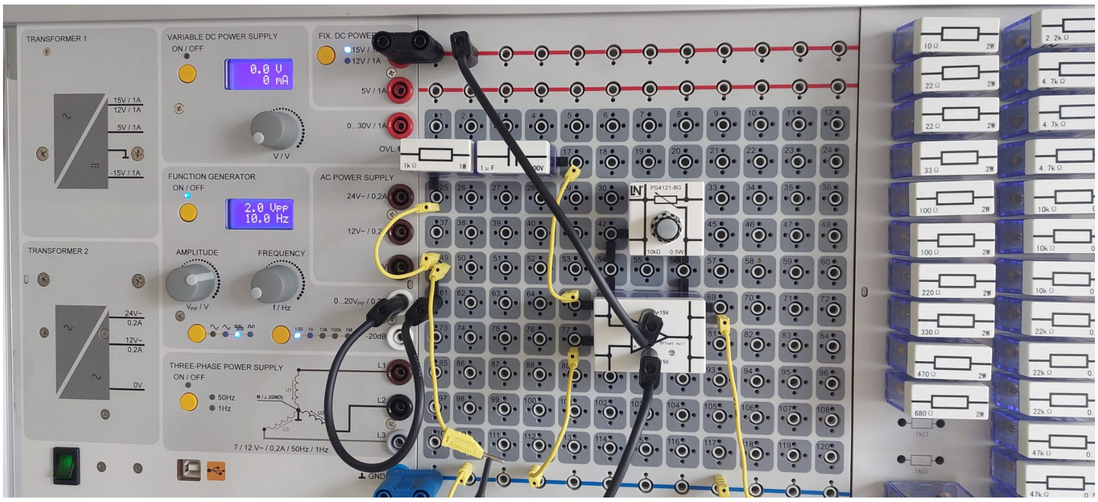

Figure 9: Assembled circuit for the derivative controller. Source: Own Creation.

In this derivative control PID system, the derivative term enhances the system's response to changes in the input signal. It provides a damping effect that helps mitigate overshoot and stabilize the output. Based on Figure 8, the following component values were chosen to achieve the derivative control configuration:

Components	**Value**
Operational Amplifier	-
Potentiometer	10kΩ
R1	1kΩ
C_d	1μF

As shown in the Figure 10, the output plot on an oscilloscope of a derivative control Proportional-Integral-Derivative (PID) system, with a peak maximum of 13.868V and a minimum of -13.233V, exhibits a response influenced by the derivative control component. On the oscilloscope plot, the waveform displays a response with a relatively fast rise time, as the derivative term enhances the system's ability to respond quickly to changes in the input.

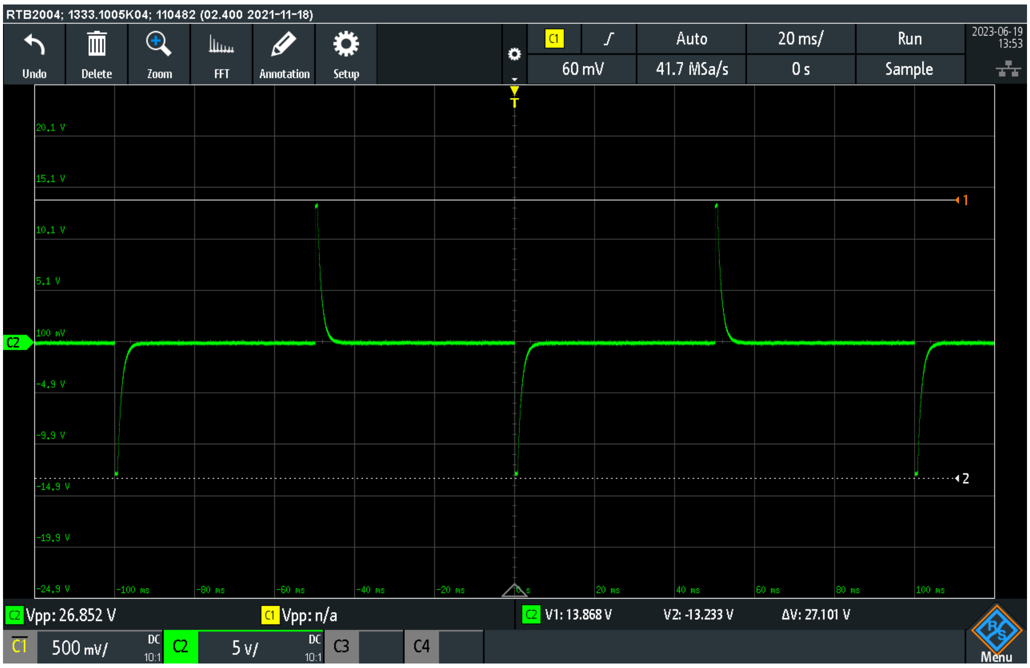

Figure 10: Oscilloscope Rohde & Schwarz RTB2004: Screenshot (USB) - Derivative Controller. Source: Own Creation.

References

[1] R.C. Dorf and R.H. Bishop. *Modern Control Systems*. Pearson, 2011.

[2] J. Wilkie, M.A. Johnson, and R. Katebi. *Control Engineering*. Bloomsbury Publishing, 2017.