CHG 3335 Process Control

Project – 2021: Design of a PID controller

Introduction

As newly hired engineers, your supervisor has made your group responsible for assisting with the start-up of a new reactor. He mentioned that the process is nearing completion and that you need to design a PID controller to control it so that it can operate under the most optimal conditions possible. He asked you to write a report to (1) describe the detailed procedure you used to design the PID controller and (2) show that the closed-loop dynamic behavior of the process meets commonly accepted performance criteria.

The deadline for submitting the report is Monday December 6, 2021. An electronic copy of your report should be submitted through Brightspace. Your supervisor expects a great deal of autonomy from you and that you will use the knowledge acquired during your undergraduate studies. However, he remains available at all times to answer your questions.

Information on the process

The new process comprises a tubular reactor (plug flow reactor) in which it is desired to convert the chemical species A to produce B according to the reaction presented in the following equation.

Reaction: $A \rightarrow B$

Consumption of A: $-r_A = kc_A^n$

Your supervisor thinks that the reaction could be of first order since, according to a series of laboratory tests, the order of the reaction was between 0.8 and 1.2. The kinetic constant was evaluated equal to 1.0 min^{-1}.

The process diagram is given in Figure 1. The tubular reactor operates at constant temperature. The volume of the reactor is 3 m^3. Under normal operating conditions, the average input C_{A0} concentration is 10 mol/m^3 with a flow rate of around 2 m^3/min. The input concentration may vary over time around this value and these variations are considered disturbances. Under these conditions, the concentration at the outlet of the reactor has a concentration of about 2.5 mol/m^3, or a conversion of around 75%. It is normally desired to control the output concentration to 2.5 mol/m^3 but it is possible that this set point may vary according to customer demand. There could therefore be changes in the set point.

You have a single concentration sensor to measure the concentration of chemical species A and it is connected immediately to the outlet of the reactor. It has first order dynamics with a time constant of 0.1 minute. The pneumatic valve for the supply is linear and has a maximum flow rate of 5 m^3/min. This valve reacts like a first order system with a time constant of 0.05 minute.

Your PID controller design should perform well despite the slight changes in input concentration and set point changes that might occur. You have no control over the input concentration. On the other hand, you can manipulate the reactor inlet flow rate and use it as a manipulated variable.

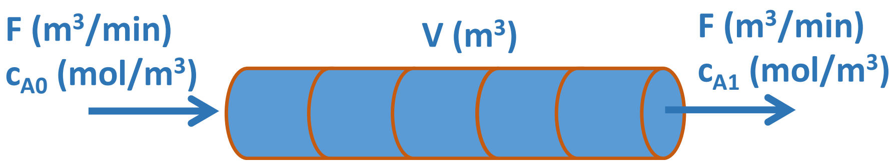

Figure 1 – Schematic of the tubular reactor.

Performance specification

The main goal of this project is to design a PID controller for this process meeting the usual performance criteria. In addition, your supervisor would appreciate having an answer to the following questions:

1. What are the operating limits of this system in terms of the output concentration given the characteristics of the system?
2. How does the reaction order influence the performance of your regulator? Will it be robust enough?
3. How sensitive is the system to the kinetic constant and the reaction order?
4. Are the dynamics of the sensor and actuator adversely affecting the performance of your controller?
5. What is the impact of the measured signal noise on this process?

In addition, your supervisor would like you to solve this problem in the time domain and write a program in VBA to evaluate the performance of your controller. He would like to have a copy of this program to perform some dynamic testing himself. He would like to validate the performance of your controller for two tests:

1. By carrying out the following series of set point changes: (a) operate the process to reach a steady state (c^*_{A1} = 2.5 mol/m^3) for 10 minutes and apply a set point change to 3.5 mol/m^3 for a duration of 10 minutes before changing the set point to 1.5 mol/m^3 for a period of 10 minutes before returning at t = 30 minutes to 2.5 mol/m^3 to end the test at 40 minutes.

2. Carrying out the following series of changes in the input concentration c_{A0} while keeping the set point at c^*_{A1} = 2.5 mol/m^3: (a) operate the process to reach steady state (c_{A0} = 10 mol/m^3) for 10 minutes and apply a change of c_{A0} to 12.0 mol/m^3 for a duration of 10 minutes before changing c_{A0} to 8.0 mol/m^3 for a duration of 10 minutes before returning at t = 30 minutes to 10 mol/m^3 to complete the 40-minute test.

Brief description of the report

The report does not have to be long. There is no point for the length of the report. On the other hand, it must be clear, precise and professional. As suggestions, the report format could contain the following:

- Title page
- Executive summary
- Table of content
- List of figures
- List of tables
- Introduction
- Main sections of the report
    - Description of the system of differential equations.
    - Clear description of the procedure followed to achieve the design of the PID controller and the presentation of the performance of the slave system.
    - Analysis of the various aspects of the system including the robustness of your controller.
- Conclusion
- Annex A - Ethic agreement form and contributions of team members
- Annex B - Any information that is not essential to the essence of the report but considered as support material and data.

Evaluation rubric

Here is the rubric that will be used to evaluate each of the reports.

CHG 3335 Process Control Evaluation of project		Group:	
	Weight	Grade	Mark
Report	**80**		
Executive summary	5		
Table of contents	2		
List of Figures and Tables	2		
Introduction	5		
Design strategy	15		
Data Analysis	15		
VBA program	15		
Analysis of controler robustness	10		
Conclusion	5		
References	1		
Bonus for innovation	5		
Communication	**20**		
Appearance of the report and formatting	10		
Spelling and grammar	5		
Structure and style	5		
Peer Evaluation	**5**		
Final Grade	**105**		

Description	Grade	Percentage
Exceptional	X	100%
Excellent	E	90%
Very good	VG	80%
Good	G	70%
Satisfactory	S	60%
Insufficient	I	50%
Needs significant improvement	N	40%
Poor	P	20%
Missing	M	0%