ChE 381A: Process Dynamics and Control

End Semester Examination, 2020-21/II

Maximum Marks: 250 **Duration: 3 h**

Instructions

- *There are five questions in all. Answer all questions.*
- *Marks for a question and its subparts are indicated.*
- *Clearly show all steps. No credit for correct answer without showing the steps.*
- *Time units are mins, unless specified otherwise.*
- *Standard PID controller transfer function* $G_c = K_c\left(\frac{\tau_I s+1}{\tau_I s}\right)\left(\frac{\tau_D s+1}{0.1\tau_D s+1}\right)$
- *Use Matlab appropriately for any complex / iterative calculations (e.g. fzero or fsolve). Be sure to clearly state the procedure in your answer script.*
- *This is an open notes / open book examination. You are however not allowed to refer to the internet or social media etc.*

QUESTION I **70 marks**

Consider the SISO process with transfer function $G_p = \frac{e^{-s}}{s}$. A PI controller is used to control the process. **70**

a) Qualitatively sketch the Bode and Nyquist plots for the system assuming τ_I >> 1. 5

b) Obtain an expression in terms of τ_I for the frequency at which the open loop phase exhibits a maximum 5

c) K_C is chosen for a maximum closed loop log modulus of 2 dB. τ_I is chosen such that the open loop phase exhibits a maximum at the maximum closed loop log modulus frequency. Obtain the values of K_C, τ_I and the maximum open loop phase. 30

Hint: Adjust τ_I till L_{CL}^{MAX} frequency becomes the same as frequency at which open loop phase exhibits maximum

d) Obtain K_U and P_U and the corresponding Zeigler-Nichols and Tyreus-Luyben tuning parameters for a PI controller 10

e) For $\tau_I = P_U$, obtain K_C for a gain margin of 2. 10

f) For $\tau_I = P_U$, obtain K_C for a phase margin of 45°. 10

QUESTION II **50 Marks**

Consider the 2x2 multivariable system with **50**

$$\begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = \begin{bmatrix} \dfrac{e^{-2s}}{10s+1} & \dfrac{2e^{-0.5s}}{3s+1} \\ \dfrac{1.5e^{-2s}}{8s+1} & \dfrac{0.5e^{-s}}{5s+1} \end{bmatrix} \begin{bmatrix} u_1 \\ u_2 \end{bmatrix}$$

A decentralized control system is to be designed.

a) Obtain the Niederlinski Index (NI) for the two possible input-output pairings. Based on the NI, what pairing would you recommend. 5

b) Obtain the RGA for the system. Based on the RGA, what pairing would you recommend. 5

For the recommended pairing, the two PI controllers are to be tuned. It is given that tight control of y_1 is more important than y_2. Thus, the y_1 loop is tuned individually to its Zeigler-Nichols settings and all the detuning is taken in the y_2 loop.

c) What is the tuning of the y_1 loop. 10

d) Obtain the tuning of the y_2 controller with τ_I set to the ultimate period (y_1 loop is on) and K_C adjusted for a gain margin of 2. 20

e) Design a 2x2 dynamic decoupler for the system and clearly show the corresponding system block diagram. 10

QUESTION III **30 Marks**

Consider the SISO process transfer function $G_p = 2\frac{-s+1}{(s+1)^2}$

A P controller is used to control the process.

a) Draw a qualitative sketch of the root locus 5

b) What value of K_C gives a closed loop damping coefficient of 0.7071 (i.e. 1/√2). 10

A PD controller is applied to improve the speed of the closed loop dynamic response. A value of τ_D = 1 min is chosen.

c) Draw a qualitative sketch of the root locus. 5

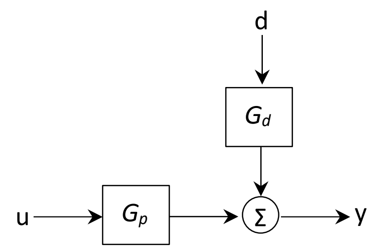
d) What value of K_C gives a closed loop damping coefficient of 0.7071 (i.e. 1/√2). 10

QUESTION IV **40 Marks**

Consider the process system shown in figure with $G_p = \frac{2}{(2s+1)(s+1)^2}$ and $G_d = \frac{-1}{(4s+1)(2s+1)(s+1)}$

a) Fit first order plus dead time models to G_p and G_d. 15+15 = 30

b) Design a feedforward compensator using the models $\hat{G}_p$ and $\hat{G}_d$. Clearly show the corresponding block diagram 10



QUESTION V **60 Marks**

Ethyl acetate (EtOAc) is produced by the esterification reaction between ethyl alcohol (EtOH) and acetic acid (AcOH) in the presence of an acid catalyst. The reaction is reversible, slightly exothermic and liquid phase and may be written as

$$EtOH + AcOH \leftrightarrow EtOAc + H_2O$$

Fresh EtOH and fresh AcOH are fed to a liquid phase boiling esterification reactor. A steam coil heats the reactor to cause the liquid to boil. A rectifier is installed on top of the boiling reactor. The vapor from the reactor flows up the rectifier. The rectifier's function is to prevent AcOH from leaving up the top. The overhead vapor from the rectifier is condensed and a fraction is refluxed back with the rest being withdrawn as distillate. The distillate is further processed in the downstream separation section.

The separation section consists of a liquid-liquid-extractor (LLX) and two distillation columns, namely the recycle column and the product column. The rectifier distillate (EtOAc-EtOH-H_2O) is fed to the bottom of the LLX that uses water as the solvent. The water solvent is fed to the LLX top. The water solvent carries most of the EtOH in the LLX feed down the bottom as the extract.

The LLX extract is distilled in the recycle column with nearly pure water leaving down the bottoms and an alcohol rich distillate leaving up the top, which is recycled back to the reactor. A fraction of the water bottoms from the recycle column is cooled and sent to the LLX as solvent, with the rest being discharged as a wastewater stream from the plant.

The ester rich raffinate from the LLX top is distilled in the product column to recover nearly pure ester down the bottoms as the plant product and a distillate that contains ester and water with some alcohol. This distillate is mixed with the rectifier distillate stream from the reaction section. The mixed stream (rectifier distillate + product column distillate) is cooled and then fed to the LLX. The product column distillate is thus recycled to the LLX.

a) Draw a neat flowsheet clearly showing all the unit operations and material/energy streams as described in the process description above. 10

b) Clearly show all the control valves on the flow sheet. 10

c) What are the control and steady state degrees of freedom for the process. 5

d) What are reasonable specification variables corresponding to the steady state degrees of freedom. 10

e) Draw a plantwide regulatory control system with the fresh acetic acid feed flow as the throughput manipulator. 25