Name:__________________

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Total:____

UNIVERSITY OF TORONTO

FACULTY OF APPLIED SCIENCE AND ENGINEERING

FINAL EXAMINATION, APRIL 2001

CHE322S – PROCESS DYNAMICS AND CONTROL

Examiner – W.R. Cluett

Closed Book

All work to be marked must appear on front of page. Use back of page for rough work only.

1. (15 marks)

(a) Define the regulation control problem.

(b) Define the servo control problem.

(c) Describe several reasons why automatic control might be beneficial in the chemical or mineral processing industries.

(d) Consider the following statement:

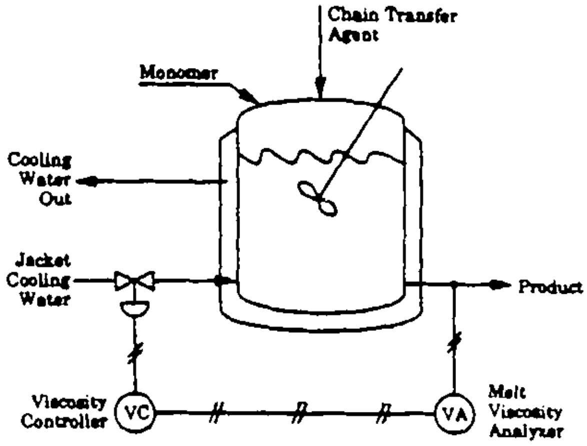
"Process control strategies, like feedback and feedforward, do not actually remove process variability, they simply transfer variability from important variables (controlled output variables) to less important variables (manipulated input variables).

Do you agree or disagree with this statement? Give some justification for your argument using your experience in the laboratory associated with this course in which you studied the control of a stirred-tank heater process as an example.

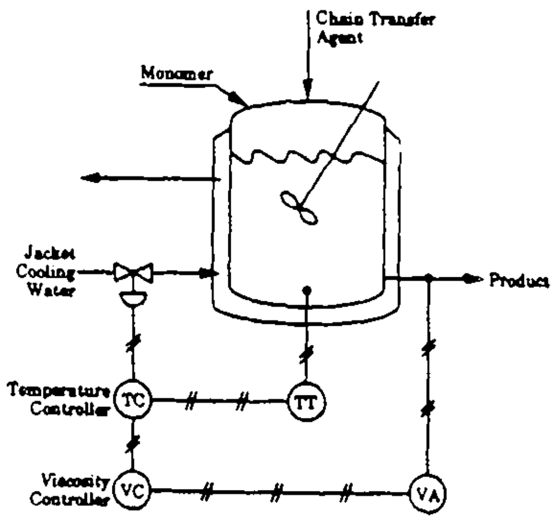
2. (15 marks)

The primary control objective for a certain industrial reactor is to control the quality of the produced polymer product as measured by its melt viscosity. The two feed streams shown are monomer and chain transfer agent that react exothermically to produce the polymer product. The key manipulated variable is the control valve on the jacket cooling water flowrate, which affects the reactor temperature, which in turn affects the product melt viscosity.

(a) Consider two disturbances that affect this process: cooling water supply temperature and cooling water supply pressure. Describe how the basic feedback strategy for controlling the product viscosity shown below will work to counteract the effect of these two disturbances, considering the effect of each disturbance separately.



(b) Consider the cascade control strategy shown below that has inserted a temperature controller between the viscosity controller and the jacket cooling water valve. Describe why this control strategy should be able to improve upon the performance of the basic strategy in part (a).



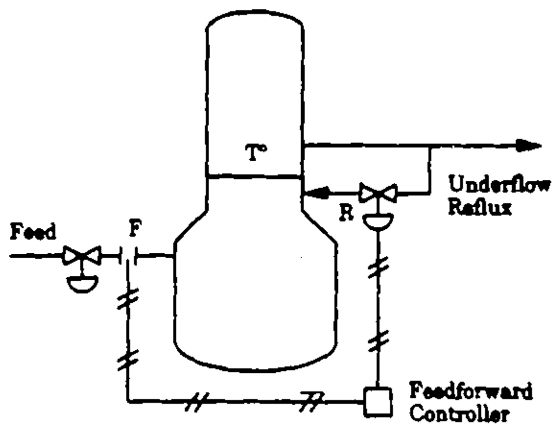
(c) Describe a step-by-step experimental procedure for designing the cascade control strategy shown in part (b). Be very specific about the process variables you make changes to and the process variables you measure.

3. (30 marks)

The temperature at a critical point in a fractionator (separator) unit (T) is to be controlled as indicated in the diagram below using a feedforward controller that manipulates the reflux flowate (R) on the basis of feed flowrate measurements (F) (the feed valve is **not** available for manipulation). The following transfer function models have been obtained for the effect of changes in R and F on T :

$$T'(s) = \frac{20e^{-14s}}{36s+1} F'(s)$$

$$T'(s) = \frac{-4e^{-4s}}{6s+1} R'(s)$$



(a) Design a gain-only feedforward controller to provide offset-free performance in the critical temperature (T) in the presence of step disturbances in feed flowrate (F).

(b) Draw a block diagram representation of the fractionator along with the feedforward controller designed in part (a) showing all variables and related transfer functions.

(c) Develop the overall transfer function for this feedforward controlled system that relates changes in the feed flowrate ($\boldsymbol{F}$) to changes in the critical temperature ($\boldsymbol{T}$).

(d) Is this controlled system stable for all values of the feedforward controller gain? Give some justification for your answer.

(e) Consider a unit step disturbance in the feed flowrate. How would your feedforward controller adjust the reflux flowrate?

(f) Consider again a unit step disturbance in the feed flowrate. However, this time assume that the process operator is manually doing the necessary feedforward control actions by watching a readout of the measured feed flowrate. How would you go about helping the operator figure out how to change the reflux flowate in order to achieve perfect control?

(g) Assume that you change the control configuration to implement instead a feedback controller that measures the critical temperature directly and manipulates the reflux flowrate. Discuss the inherent performance limitations and advantages of this feedback strategy in comparison to a feedforward control strategy in the presence of step disturbances in feed flowrate.

4. (20 marks)

An approximate model has been identified for an industrial process:

$$\begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = \begin{bmatrix} \dfrac{0.8}{3s+1} & 0 \\ \dfrac{0.55}{4s+1} & \dfrac{-.01}{3.5s+1} \end{bmatrix} \begin{bmatrix} m_1 \\ m_2 \end{bmatrix}$$

(a) Does this model show any evidence of interactions between the process variables? If so, which output variable is expected to be more susceptible to the effect of interactions and why?

(b) Calculate the RGA for this process. What does this suggest in terms of input/output pairing?

Note: $\lambda_{11} = \dfrac{1}{1 - \dfrac{K_{12}K_{21}}{K_{11}K_{22}}}$

(c) Assuming a $y_1 - m_1 / y_2 - m_2$ pairing, the objective is to design two single-loop feedback PI controllers for this process. Beginning with the y_1 controller, design a PI controller that will give a first order closed-loop response to a step change in $y_{1,sp}$ with a time constant of 3 and zero offset.

(d) Draw a block diagram for this system that shows the process interconnected with just the y_1 controller using the given process transfer functions and the controller transfer function designed in part (c).

(e) With just the y_1 controller connected to the process, what would be the effect on y_2 if a unit step change in $y_{1,sp}$ was introduced? (Hint: derive the transfer function relating $y_{1,sp}$ to y_2 from your block diagram in part (d).)

5. (10 marks)

Consider a first order process with input-output characteristics that have been approximated by the following transfer function model:

$$G_{p,model}(s) = \frac{5}{10s+1}$$

This model is to be used for feedback controller design purposes. The objective is to design a feedback controller for this process that will yield the following closed-loop transfer function:

$$\frac{y}{y_{sp}} = \frac{1}{\tau_{cl}s+1}$$

Suppose that the true process is nonlinear, and that the true input-output characteristics can be represented by:

$$G_{p,true}(s) = \frac{K}{10s+1}$$

where K varies depending on the steady-state around which the process is operating.

(a) Design the feedback controller that will yield the desired closed-loop transfer function when applied to the process model given by $G_{p,model}(s)$.

(b) Derive the true closed-loop transfer function relating y_{sp} to y , by using the feedback controller designed in part (a) and the true process description given by $G_{p,true}(s)$. Using this result, determine whether the feedback controller will provide offset-free servo control performance when applied to the true process.

(c) Show that when the feedback controller designed in part (a) is implemented on the true process, the overall closed-loop system will always be stable for all values of $\tau_{cl} > 0$ provided the true process gain K remains positive.

6. (10 marks)

An unstable first order process, with transfer function:

$$\frac{2}{s-4}$$

is to be controlled using a proportional (P) controller.

(a) How would this process respond to a unit step input change without any feedback control action?

Note: the inverse Laplace transform of $\dfrac{K}{s(\tau s+1)}$ is $K(1-e^{-t/\tau})$.

(b) The P-controller has now been installed around this unstable process. The engineer responsible for selecting the 'right' controller gain (K_c) believes that the best choice is a small value for K_c because this person recalls from a process control course taken as an undergraduate student that a large value for the feedback controller gain K_c will likely produce oscillatory, and possibly even unstable closed-loop behaviour. However, this person has turned to you for advice. What range of values for K_c would you suggest to ensure a stable, non-oscillatory closed-loop response?

(c) Choose a specific value for K_c that produces a stable, non-oscillatory closed-loop response. Sketch the response of the process output to a unit step change in the setpoint value, showing as much detail as possible (shape of the response, approximate time to reach steady-state, any offset from the setpoint value, etc.).