UNIVERSITI SAINS MALAYSIA

Second Semester Examination
Academic Session 2007/2008

April 2008

EKC 361 – Dynamic & Process Control
[Dinamik & Kawalan Proses]

Duration : 3 hours
[Masa : 3 jam]

Please check that this examination paper consists of TWELVE pages of printed material and FOUR pages of Appendix before you begin the examination.

[Sila pastikan bahawa kertas peperiksaan ini mengandungi DUABELAS muka surat yang bercetak dan EMPAT muka surat Lampiran sebelum anda memulakan peperiksaan ini.]

Instructions: Answer **FOUR** (4) questions. Answer **TWO** (2) questions from Section A. Answer **TWO** (2) questions from Section B.

*[**Arahan**: Jawab **EMPAT** (4) soalan. Jawab **DUA** (2) soalan dari Bahagian A. Jawab **DUA** (2) soalan dari Bahagian B.]*

You may answer your questions either in Bahasa Malaysia or in English.

[Anda dibenarkan menjawab soalan sama ada dalam Bahasa Malaysia atau Bahasa Inggeris.]

Section A : Answer any TWO questions.
Bahagian A : Jawab mana-mana DUA soalan.

1. [a] Consider the mixer shown in Figure Q.1. [a]. As a process control engineer, you have been asked to propose a feedback control scheme for this mixer by controlling the outlet concentration.

Rujuk pencampur seperti yang ditunjukkan di dalam Rajah S.1.[a]. Sebagai jurutera kawalan proses anda telah diarahkan untuk mencadangkan satu skema kawalan suapbalik bagi pencampur dengan mengawal kepekatan keluaran pencampur tersebut. Cadangan anda mesti mengandungi.

[i] Draw the block diagram representing the process.
Lukiskan gambarajah blok yang mewakili proses tersebut.

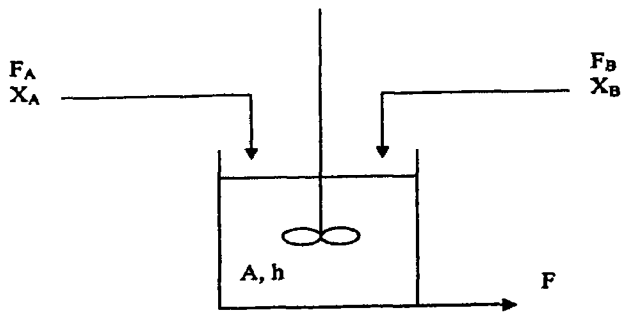
[4 marks/markah]

[ii] List all the assumptions that have been made.
Senaraikan segala andaian yang telah dibuat

[2 marks/markah]

[iii] Up-date the mixer's system schematic (including control loop, the control valve and all possible sensors) based on the control scheme in [i]. **Please attach Appendix A as part of your answer.**
Kemaskinikan gambarajah pencampur (termasuk gelung kawalan, injap kawalan dan juga semua pengesan yang mungkin) berdasarkan skema kawalan di [i]. ***Sila kepilkan Lampiran A bersama buku jawapan anda sebagai sebahagian daripada jawapan anda.***

[4 marks/markah]



Nomenclature:
Tatanama:

F = Flowrate (mol/s)
Kadar aliran (mol/s)
X = Species mole fraction
Pecahan mol spesies
A = Tank cross-sectional Area
Luas keratan rentas tangki
h = Liquid height (m)
Tinggi cecair (m)

Figure Q. 1. [a] : Mixer system
Rajah S. 1. [a] : Sistem pencampur

[b] [i] The open loop unit step response for a heat exchanger system is shown in Figure Q.1.[b] [i]:

Sambutan langkah seunit gelung terbuka bagi sistem penukar haba adalah ditunjukkan Rajah S.1.[b][i]:

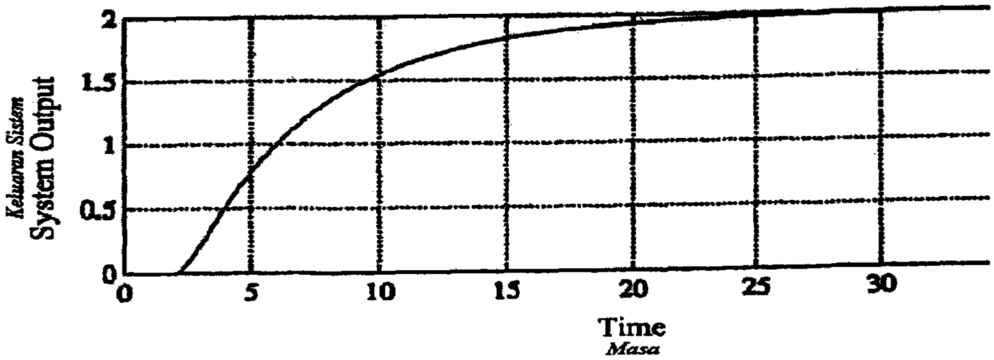


Figure Q.1. [b] [i] : Heat Exchanger process response
Rajah S.1. [b] [i] : Sambutan bagi proses penukar haba

Estimate the effective dead time, time constant and gain for the process reaction curve tuning method. **Please attach Appendix B as part of your answer**

Anggarkan masa lengah berkesan, pemalar masa dan gandaan berdasarkan kaedah penalaan lengkungan tindakbalas proses. ***Sila kepilkan Lampiran B bersama buku jawapan anda sebagai sebahagian daripada jawapan anda***

[6 marks/markah]

[ii] The current proportional controller was found to give undesirable offset. You are required to install a PI controller. Design the PI controller by determining the values of the appropriate controller parameters based on the information in [i].

Pada masa ini, pengawal kadaran didapati memberikan sisihan yang tidak dikehendaki. Anda dikehendaki memasang sebuah pengawal PI. Rekabentukkan satu pengawal PI dengan menentukan nilai-nilai parameter pengawal yang sepatutnya berdasarkan maklumat di [i].

[6 marks/markah]

[iii] What are the advantages of the controller tuning method used in [ii] above?

Apakah kelebihan-kelebihan kaedah penalaan kawalan di atas [ii]?

[3 marks/markah]

2. The temperature in an exothermic reactor is controlled by varying the coolant flow into the reactor jacket.

Suhu dalam sebuah reaktor eksotermik dikawal dengan mengubah kadar aliran penyejuk ke dalam jaket reaktor.

[a] Discuss, why would such a scheme be used?

Bincangkan kenapa skema berikut digunakan?

[2 marks/markah]

[b] Draw the schematic diagram showing the reactor and the jacket together with the closed loop temperature control scheme. You must show in your figure the feed to the reactor, concentration in the feed, coolant flow in and out, concentration and temperature in the reactor.

Lukiskan gambarajah skema menunjukkan reaktor dan jaket bersama skema kawalan suhu gelung tertutup. Anda mesti tunjukkan di dalam rajah suapan ke reaktor, kepekatan dalam suapan, aliran pendingin masuk dan keluar, kepekatan dalam reaktor dan juga suhu reaktor.

[6 marks/markah]

[c] Scenario 1: Variation in coolant temperature feed is occurred. How would you modify the temperature control scheme and draw a new block and new schematic diagram after the modification? Give the advantages of your new control scheme.

Senario 1: Perubahan suhu suapan pendingin berlaku. Bagaimanakah anda akan mengubah skema kawalan suhu gelung tertutup dan lukis gambarajah blok yang baru selepas perubahan tersebut. Berikan kelebihan-kelebihan skema kawalan baru anda

[8 marks/markah]

[d] Scenario 2: Variation in feed flow to the reactor has occurred. Due to the 'tight' control of the outlet concentration which is related to the reactor temperature, suggest a new temperature control scheme and draw a new block and schematic diagram after modification. Give the advantages of your new control scheme.

Senario 2: Perubahan aliran suapan didapati berlaku. Disebabkan oleh kawalan ketat kepekatan keluaran yang mempunyai kaitan dengan suhu reaktor; apakah cadangan anda bagi skema kawalan suhu yang baru dan lukiskan gambarajah blok dan skema selepas pengubahsuaian tersebut. Berikan kelebihan-kelebihan skema kawalan baru anda.

[9 marks/markah]

3. Consider the distillation column shown in Figure Q.3.

Pertimbangkan turus penyulingan yang ditunjukkan di Rajah S.3.

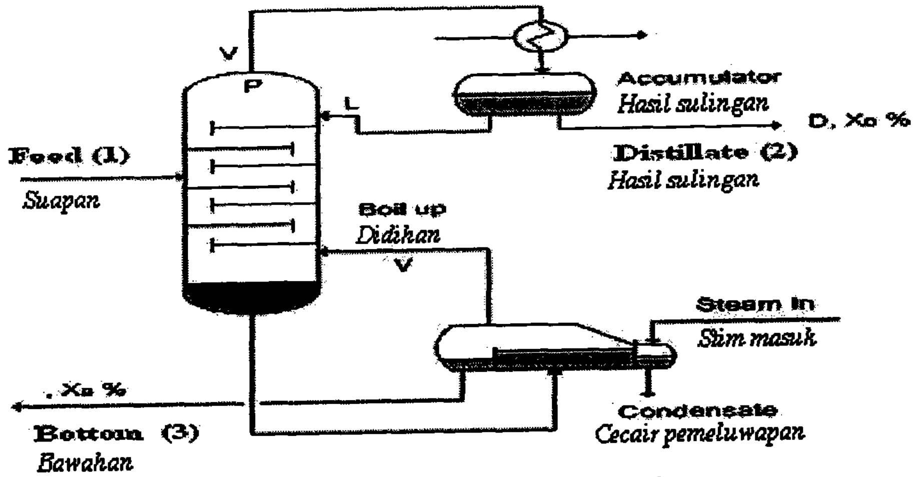


Figure Q.3. : Schematic of a distillation column

Rajah S.3. : Skema turus penyulingan

Stream (1), the feed stream, has a fowrates F(kg/hr) and the weight fraction of the more volatile component (MVC) is x_f. Stream (2), the top product, has a flowrate of D (kg/hr) and the weight fraction of the MVC is x_D, while the bottom stream (3), the bottom product, has a flowrate, B (kg/hr) with a MVC weight fraction of x_B. Suppose the following transfer function model has been identified;

Aliran (1), aliran suapan mempunyai kadar aliran, F(kg/jam) dan pecahan berat komponen yang lebih meruap (MVC) x_F. Aliran (2), hasil atas, mempunyai kadar aliran, D (kg/jam) dan pecahan komponen berat MVC, X_D, sementara aliran bawahan (3), hasil bawahan mempunyai kadar aliran, B (kg/jam) dengan pecahan jisim MVC X_B. Andaikan model rangkap pindah yang berikut telah dikenalpasti;

$$\frac{X_D(s)}{D(s)} = \frac{k_p e^{-10s}}{100s+1}$$

$$\frac{X_D(s)}{F(s)} = \frac{k_L e^{-20s}}{50s+1}$$

Where, the process gain, k_p and k_L vary with process operating point due to the nonlinear nature of the process. The controlled variable is $X_D(s)$, the manipulated variable is D(s) and the F(s) may be considered as a measured disturbance variable.

Di mana gandaan proses k_p dan k_L berubah mengikut titik operasi disebabkan oleh sifat tak linear proses. Pembolehubah kawalan ialah $X_D(s)$, pembolehubah olahan ialah D(s) dan F(s) boleh dianggap sebagai pembolehubah gangguan terukur.

[a] Draw a block diagram representation of a feedback control system that may be used to regulate $X_D(s)$.

Lukiskan gambarajah blok yang mewakili sistem kawalan suapbalik yang boleh digunakan untuk mengatur $X_D(s)$.

[3 marks/markah]

[b] Use the block diagram in [a] to derive a closed loop transfer function model describing how $X_D(s)$ responds to set point changed.

Gunakan gambarajah blok [a] untuk menerbitkan model rangkap pindah gelung tertutup yang menghuraikan bagaiman $X_D(s)$ bertindak bila titik set berubah.

[4 marks/markah]

[c] Set the closed loop transfer function equal to a first order plus dead-time transfer function with a gain of 1, a time constant of 50 minutes, and a time delay of 10 minutes. Determine the setting of a Proportional-Integral (PI) controller. State all assumptions that you make.

Setkan rangkap pindah gelung tertutup menyamai rangkap pindah tertib pertama dan masa lengahan dengan gandaan 1, pemalar masa 50 minit, dan lengahan masa 10 minit. Tentukan 'setting' untuk pangawal Kadaran-Kamiran (PI). Nyatakan semua andaian yang digunakan.

[12 marks/markah]

[d] Through block diagram analysis, derive the structure of the feedforward control element and show that it eliminates the impact of the process disturbance, F(s) of the process output, $X_D(s)$.

Melalui analisis gambarajah blok, terbitkan struktur kawalan suapdepan dan tunjukkan ia melenyapkan kesan gangguan proses , F(s) terhadap keluaran proses, $X_D(s)$.

[6 marks/markah]

Section B : Answer any TWO questions.
Bahagian B : Jawab mana-mana DUA soalan.

4. [a] Obtain the solution Y(t), as a deviation from its initial steady-state condition y(0), of the following differential equations. Use the method of Laplace transforms and partial fractions expansion. The forcing function is the unit step function, x(t) = u(t)

Dapatkan penyelesaian Y(t), dalam bentuk penyisihan dari keadaan keseimbangan awalnya y(0), bagi persamaan-persamaan kebezaan berikut. Gunakan kaedah Jelmaan Laplace dan pengembangan pecahan separa. Fungsi memaksa adalah fungsi unit tukar langkah, x(t) = u(t)

[i] $$\frac{dy}{dt} + 2y = 5x + 3$$

[ii] $$9\frac{d^2y}{dt^2} + 12\frac{dy}{dt} + 4y = 8x - 4$$

Repeat problem a [ii] above using forcing function, $x(t) = e^{-t/3}$

Ulangi soalan a [ii] di atas dengan menggunakan fungsi memaksa, $x(t) = e^{-t/3}$

[9 marks/markah]

[b] Two constant-volume stirred tanks, connected in series (see Figure Q.4.[b]), are fed by a single stream with constant volumetric flow rate, q. The feed composition, c_i (mass/volume of a catalyst species), can vary with time. Density is constant.

Dua tangki teraduk berisipadu malar dihubungkan secara bersiri (lihat Rajah S.4.[b]), disuapkan dengan satu alur dengan kadar aliran isipadu malar,q. Komposisi suapan, c_i *(jisim/isipadu spesis mangkin), boleh berubah dengan masa. Ketumpatan adalah malar.*

[i] Develop a dynamic model for this process that can be used to calculate the concentrations of catalyst exiting Tank 1 (c_1) and Tank 2 (c_2).

Binakan satu model dinamik bagi proses ini yang boleh digunakan untuk mengira kepekatan mangkin pada keluaran tangki 1 (c_1) *dan tangki 2* (c_2).

[ii] Make a degrees of freedom analysis for your model, indicating input(s), output(s), parameters, and so on.

Lakukan analisis darjah kebebasan bagi model anda, nyatakan masukan, keluaran, parameter dan sebagainya.

...7/-

[iii] Suppose a recycle stream is used to return some multiple of the inlet flow rate (rq) from the exit stream of the second tank back to the first stirred tank (see Figure Q.4.[b][iii])? Repeat parts [i] and [ii].

Sekiranya alur kitar semula digunakan untuk mengembalikan sebahagian kadar aliran masuk berbilang (rq) daripada alur keluar tangki kedua ke tangki teraduk pertama (lihat Rajah S.4.[b][iii])? Ulangi bahagian-bahagian [i] dan [ii].

[iv] For r →∞, what can you say about the model for this process? Does it simplify in some way? Hint: Take a new look at the physical system and don't just try to manipulate your mathematical model.

Bagi r → ∞, apakah yang anda boleh katakan terhadap model bagi proses ini? Adakah ia dapat diringkaskan? Petunjuk: Ambil gambaran baru pada keadaan fizikal sistem tersebut dan jangan hanya cuba mengubah model matematik anda.

[16 marks/markah]

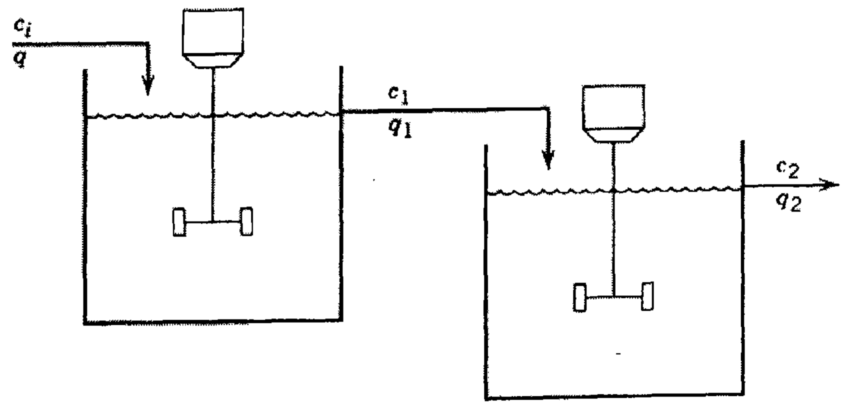


Figure Q.4.[b]
Rajah S.4.[b]

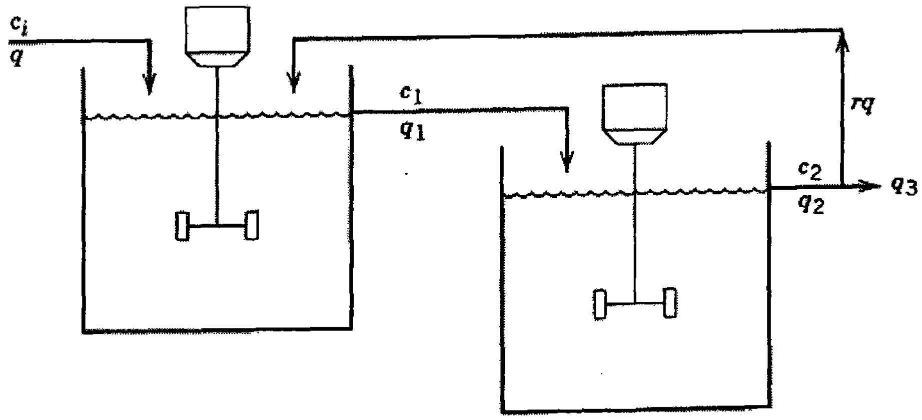


Figure Q.4.[b][iii]
Rajah S.4.[b][iii]

5. [a] Figure Q.5. [a] shows the schematic of a compressor suction pressure control loop. A mass balance on the suction volume results in the following approximate linear model for the suction pressure:

Rajah S.5.[a] menunjukkan skema bagi gelung kawalan bagi tekanan sedutan pemampat. Imbangan jisim terhadap isipadu sedutan menghasilkan model linear hampir bagi tekanan sedutan seperti berikut:

$$P(s) = \frac{0.5}{7.5s+1}[F_i(s) - F_c(s)] \text{ psi}$$

where $F_i(s)$ and $F_c(s)$ are, respectively, the inlet and compressor flows, kscf/min (1kscf = 1000 ft^3 at standard condition of 1 atm and 60°F), and the time constant is in seconds. The response of the compressor flow to the controller output (%CO) signal, M(s) is

Di mana $F_i(s)$ dan $F_c(s)$ adalah, masing-masing aliran masukan dan pemampat, kscf/min (1kscf = 1000 kaki^3 pada keadaan piawai 1 atm dan 60°F), dan pemalar masa dalam saat. Sambutan bagi aliran pemampat ke keluaran pengawal (%CO), M(s), ialah

$$F_c(s) = \frac{0.36}{2.5s+1} M(s)$$

The pressure transmitter has a range of 0 to 20 psig and can be presented by a first-order lag with a time constant of 1.2s. Draw the block diagram for the loop and write the closed-loop transfer function and the characteristic equation. Must the controller be direct-acting or reverse-acting?

Penghantar tekanan mempunyai julat 0 hingga 20 psig dan boleh diwakili oleh sistem tertib pertama dengan masa lengah dan pemalar masa 1.2s. Lukiskan gambarajah blok bagi gelung tersebut dan tuliskan rangkap pindah gelung tertutup dan persamaan cirinya. Adakah pengawal tersebut bertindak-terus atau bertindak-balikan?

[9 marks/markah]

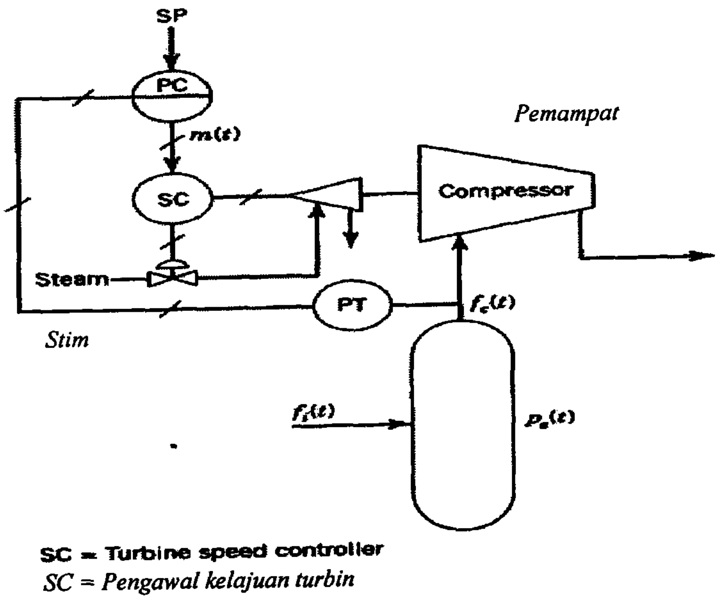


Figure Q.5.[a] : Compressor pressure control

Rajah S.5.[a] : Kawalan tekanan pemampat

[b] A process control system contains the following transfer functions:
Satu sistem kawalan proses mempunyai rangkap-rangkap pindah berikut:

$$G_p(s) = \frac{2e^{-1.5s}}{(60s+1)(5s+1)}$$

$$G_v(s) = \frac{0.5e^{-0.3s}}{(3s+1)}$$

$$G_m(s) = \frac{3e^{-0.2s}}{(2s+1)}$$

$$G_c(s) = K_c$$

[i] Show how $G_{OL}(s)$ can be approximated by FOPTD model;
Tunjukkan bagaimana $G_{OL}(s)$ boleh dianggarkan sebagai model FOPTD;

$$G_p G_v G_m G_c = G_{OL}(s) \approx \frac{Ke^{-\theta s}}{\tau s + 1}$$

Find K, τ, and θ for the open-loop process transfer function.
Carikan K, τ, dan θ bagi rangkap pindah gelung tertutup tersebut.

[ii] Use Routh stability methods and your FOPTD model to find the range of K_c values that will yield a stable closed-loop system.
Gunakan kaedah kestabilan Routh dan model FOPTD anda untuk mencari julat nilai K_c yang menghasilkan sistem gelung tertutup yang stabil.

[10 marks/markah]

[c] Figure Q.5.[c] shows the response of six different processes to a step change in input. Give an indication of the form(s) of possible transfer function(s) for each process.
Rajah S.5.[b] menunjukkan sambutan enam proses berbeza terhadap seunit tukar langah pada masukan. Nyatakan bentuk kemungkinan rangkap pindah bagi setiap proses.

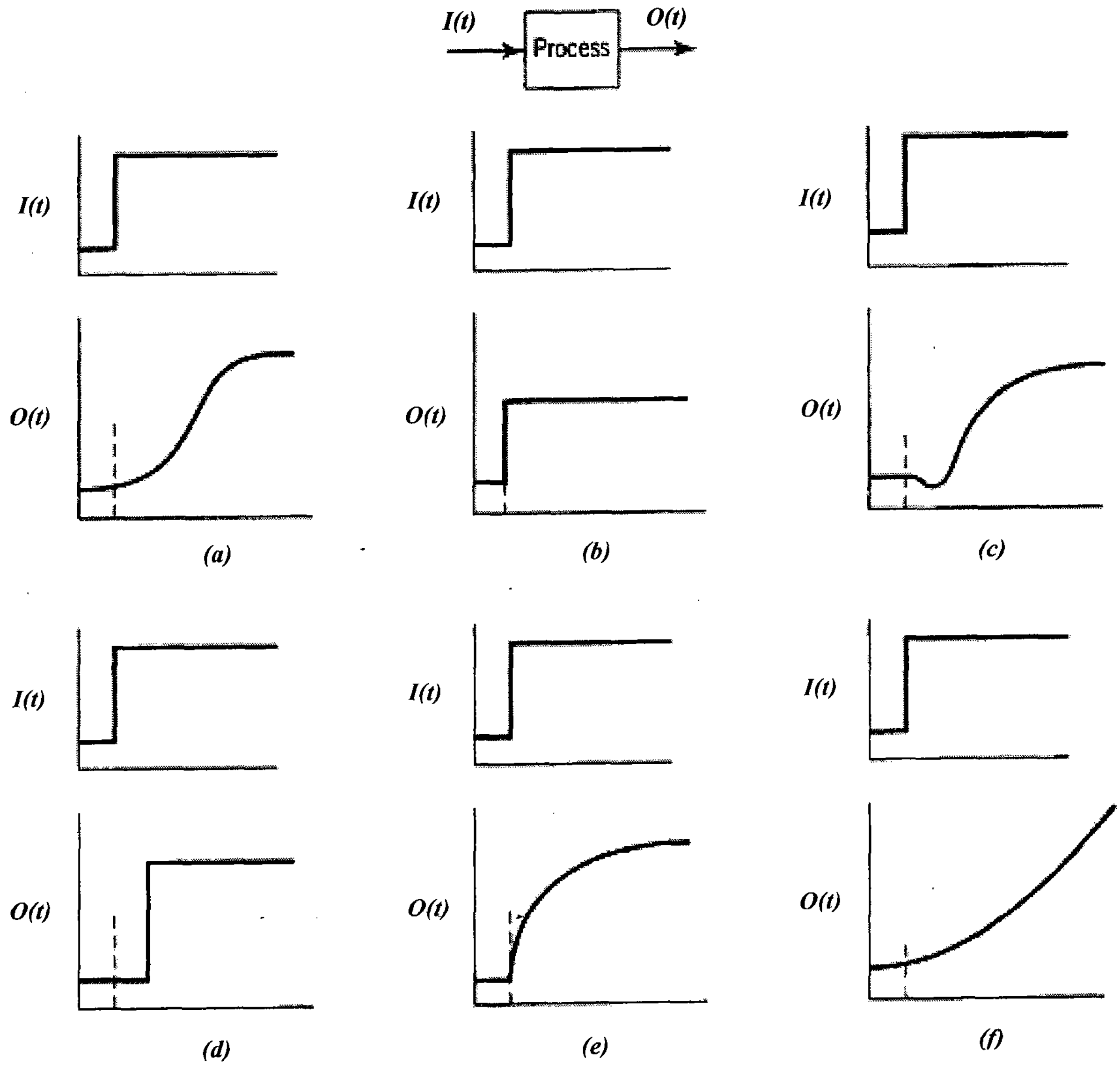


Figure Q.5.[c] : The response of six different processes to a step change in input.
Rajah S.5.[c] : Sambutan enam proses berbeza terhadap seunit tukar langah pada masukan.

[6 marks/markah]

6. [a] Draw the block diagram representing the following transfer functions. In each case, do not do any algebraic manipulations to simplify the transfer functions, but use the rules of block diagram algebra to simplify the diagram if possible.

Lukiskan gambarajah blok yang mewakili rangkap-rangkap pindah berikut. Dalam setiap kes, jangan lakukan sebarang manipulasi algebra untuk memudahkan rangkap pindah tersebut, sebaliknya gunakan peraturan algebra bagi gambarajah blok untuk meringkaskan gambarajah tersebut jika boleh.

$$Y(s) = \frac{K_1}{(\tau_1 s + 1)} X(s) + \frac{K_2}{(\tau_2 s + 1)} X(s)$$

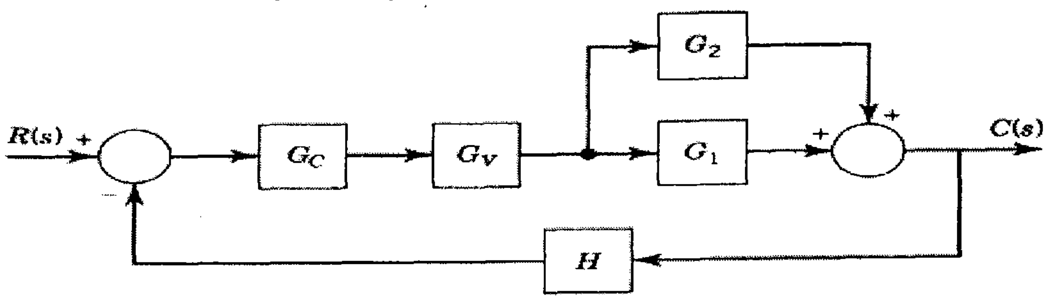
$$Y(s) = \frac{1}{(\tau s + 1)}[K_1 F_1(s) - K_2 F_2(s)]$$

$$Y_1(s) = G_1(s)X(s) + G_3(s)Y_2(s) \;\; ; \;\; Y_2(s) = G_2(s)Y_1(s)$$

[6 marks/markah]

[b] [i] Determine the transfer function C(s)/R(s) for the systems shown in Figure Q.6. [b] [i].

Tentukan rangkap pindah C(s)/R(s) bagi sistem yang ditunjukkan dalam Rajah S.6. [b] [i].



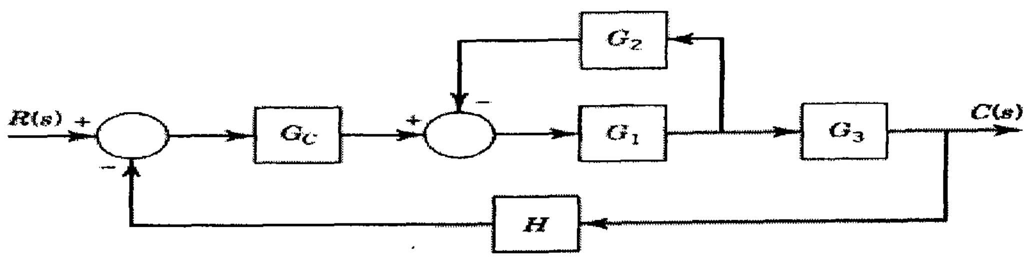


Figure Q.6. [b] [i]
Rajah S.6. [b] [i]

[ii] Determine the transfer function C(s)/L(s) for the system shown in Figure Q.6. [b] [ii].

Tentukan rangkap pindah C(s)/L(s) bagi sistem yang ditunjukkan dalam Rajah S.6. [b] [ii].

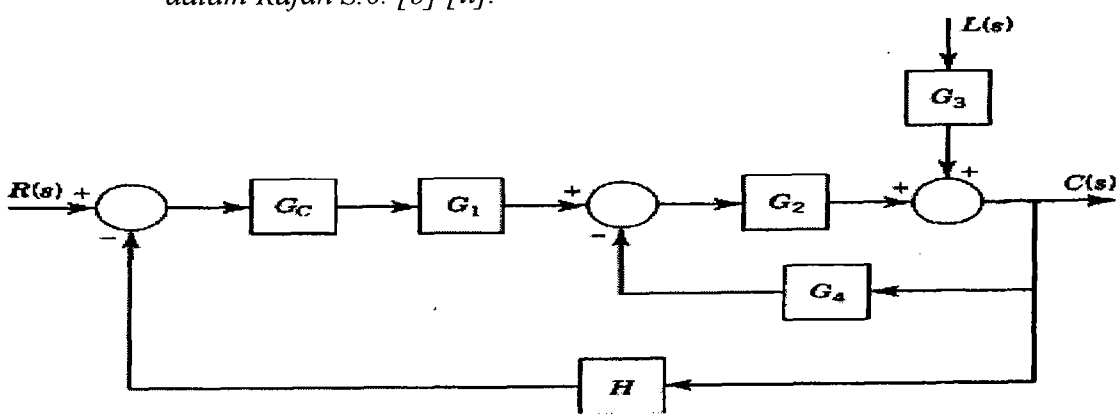


Figure Q.6. [b] [ii]
Rajah S.6. [b] [ii]

[9 marks/markah]

[c] An electrically heated process is known to exhibit second-order dynamics with the following parameter values: K = 3°C/kW, τ = 3 min, ζ = 0.7. If the process initially is at steady state at 70°C with heater input of 20kW and the heater input is suddenly changed to 26 kW and held there:

Satu proses pemanas elektrik menunjukkan dinamik tertib kedua dengan nilai-nilai parameter berikut: K = 3°C/kW, τ = 3 min, ζ = 0.7. Jika proses pada awalnya berada pada keadaan keseimbangan pada 70°C dengan masukan pemanas 20kW dan pemanas tersebut secara tiba-tiba berubah dan kekal pada 26 kW:

[i] What will be the expression for the process temperature as function of time?

Apakah ungkapan bagi suhu proses terhadap fungsi masa?

[ii] What will be the maximum temperature that one observes? When will it occur?

Apakah suhu maksimum yang akan diperhatikan? Bilakah ia akan berlaku?

[10 marks/markah]

Given that the step response of the second order process is:

Diberi sambutan langkah bagi proses tertib kedua ialah:

Overdamped:
Teredam lebih:

$$y(t) = KM\left(1 - \frac{\tau_1 e^{-t/\tau_1} - \tau_2 e^{-t/\tau_2}}{\tau_1 - \tau_2}\right)$$

Critically damped:
Teredam kritikal:

$$y(t) = KM\left[1 - \left(1 + \frac{t}{\tau}\right)e^{-t/\tau}\right]$$

Underdamped:
Kurang Redam:

$$y(t) = KM\left\{1 - e^{-\zeta t/\tau}\left[\cos\left(\frac{\sqrt{1-\zeta^2}}{\tau}t\right) + \frac{\zeta}{\sqrt{1-\zeta^2}}\sin\left(\frac{\sqrt{1-\zeta^2}}{\tau}t\right)\right]\right\}$$

- ooo O ooo -

Appendix
Lampiran

Table Laplace Transforms for Various Time-Domain Functions[a]

$f(t)$	$F(s)$
1. $\delta(t)$ (unit impulse)	1
2. $S(t)$ (unit step)	$\frac{1}{s}$
3. t (ramp)	$\frac{1}{s^2}$
4. t^{n-1}	$\frac{(n-1)!}{s^n}$
5. e^{-bt}	$\frac{1}{s+b}$
6. $\frac{1}{\tau}e^{-t/\tau}$	$\frac{1}{\tau s+1}$
7. $\frac{t^{n-1}e^{-bt}}{(n-1)!}$ $(n>0)$	$\frac{1}{(s+b)^n}$
8. $\frac{1}{\tau^n(n-1)!}t^{n-1}e^{-t/\tau}$	$\frac{1}{(\tau s+1)^n}$
9. $\frac{1}{b_1-b_2}(e^{-b_2 t}-e^{-b_1 t})$	$\frac{1}{(s+b_1)(s+b_2)}$
10. $\frac{1}{\tau_1-\tau_2}(e^{-t/\tau_1}-e^{-t/\tau_2})$	$\frac{1}{(\tau_1 s+1)(\tau_2 s+1)}$
11. $\frac{b_3-b_1}{b_2-b_1}e^{-b_1 t}+\frac{b_3-b_2}{b_1-b_2}e^{-b_2 t}$	$\frac{s+b_3}{(s+b_1)(s+b_2)}$
12. $\frac{1}{\tau_1}\frac{\tau_1-\tau_3}{\tau_1-\tau_2}e^{-t/\tau_1}+\frac{1}{\tau_2}\frac{\tau_2-\tau_3}{\tau_2-\tau_1}e^{-t/\tau_2}$	$\frac{\tau_3 s+1}{(\tau_1 s+1)(\tau_2 s+1)}$
13. $1-e^{-t/\tau}$	$\frac{1}{s(\tau s+1)}$
14. $\sin \omega t$	$\frac{\omega}{s^2+\omega^2}$
15. $\cos \omega t$	$\frac{s}{s^2+\omega^2}$
16. $\sin(\omega t+\phi)$	$\frac{\omega\cos\phi+s\sin\phi}{s^2+\omega^2}$
17. $e^{-bt}\sin \omega t$ (b, ω real)	$\frac{\omega}{(s+b)^2+\omega^2}$
18. $e^{-bt}\cos \omega t$ (b, ω real)	$\frac{s+b}{(s+b)^2+\omega^2}$
19. $\frac{1}{\tau\sqrt{1-\zeta^2}}e^{-\zeta t/\tau}\sin(\sqrt{1-\zeta^2}\,t/\tau)$ $(0 \le \lvert\zeta\rvert < 1)$	$\frac{1}{\tau^2 s^2+2\zeta\tau s+1}$
20. $1+\frac{1}{\tau_2-\tau_1}(\tau_1 e^{-t/\tau_1}-\tau_2 e^{-t/\tau_2})$ $(\tau_1 \ne \tau_2)$	$\frac{1}{s(\tau_1 s+1)(\tau_2 s+1)}$
21. $1-\frac{1}{\sqrt{1-\zeta^2}}e^{-\zeta t/\tau}\sin[\sqrt{1-\zeta^2}\,t/\tau+\psi]$, $\psi=\tan^{-1}\frac{\sqrt{1-\zeta^2}}{\zeta}$, $(0 \le \lvert\zeta\rvert < 1)$	$\frac{1}{s(\tau^2 s^2+2\zeta\tau s+1)}$
22. $1-e^{-\zeta t/\tau}[\cos(\sqrt{1-\zeta^2}\,t/\tau)+\frac{\zeta}{\sqrt{1-\zeta^2}}\sin(\sqrt{1-\zeta^2}\,t/\tau)]$ $(0 \le \lvert\zeta\rvert < 1)$	$\frac{1}{s(\tau^2 s^2+2\zeta\tau s+1)}$
23. $1+\frac{\tau_3-\tau_1}{\tau_1-\tau_2}e^{-t/\tau_1}+\frac{\tau_3-\tau_2}{\tau_2-\tau_1}e^{-t/\tau_2}$ $(\tau_1 \ne \tau_2)$	$\frac{\tau_3 s+1}{s(\tau_1 s+1)(\tau_2 s+1)}$
24. $\frac{df}{dt}$	$sF(s)-f(0)$
25. $\frac{d^n f}{dt^n}$	$s^nF(s)-s^{n-1}f(0)-s^{n-2}f^{(1)}(0)-\cdots-sf^{(n-2)}(0)-f^{(n-1)}(0)$
26. $f(t-t_0)S(t-t_0)$	$e^{-t_0 s}F(s)$

[a]Note that $f(t)$ and $F(s)$ are defined for $t \ge 0$ only.

Cohen-Coon Settings

1. For a proportional controller, use:

$$K_c = \frac{1}{K}\frac{\tau}{t_d}\left(1+\frac{t_d}{3\tau}\right)$$

2. For a PI controller, use:

$$K_c = \frac{1}{K}\frac{\tau}{t_d}\left(0.9+\frac{t_d}{12\tau}\right) \qquad \tau_I = t_d\frac{30+3t_d/\tau}{9+20t_d/\tau}$$

3. For a PID controller, use:

$$K_c = \frac{1}{K}\frac{\tau}{t_d}\left(\frac{4}{3}+\frac{t_d}{4\tau}\right) \qquad \tau_I = t_d\frac{32+6t_d/\tau}{13+8t_d/\tau} \qquad \tau_D = t_d\frac{4}{11+2t_d/\tau}$$

Controller Transfer Functions

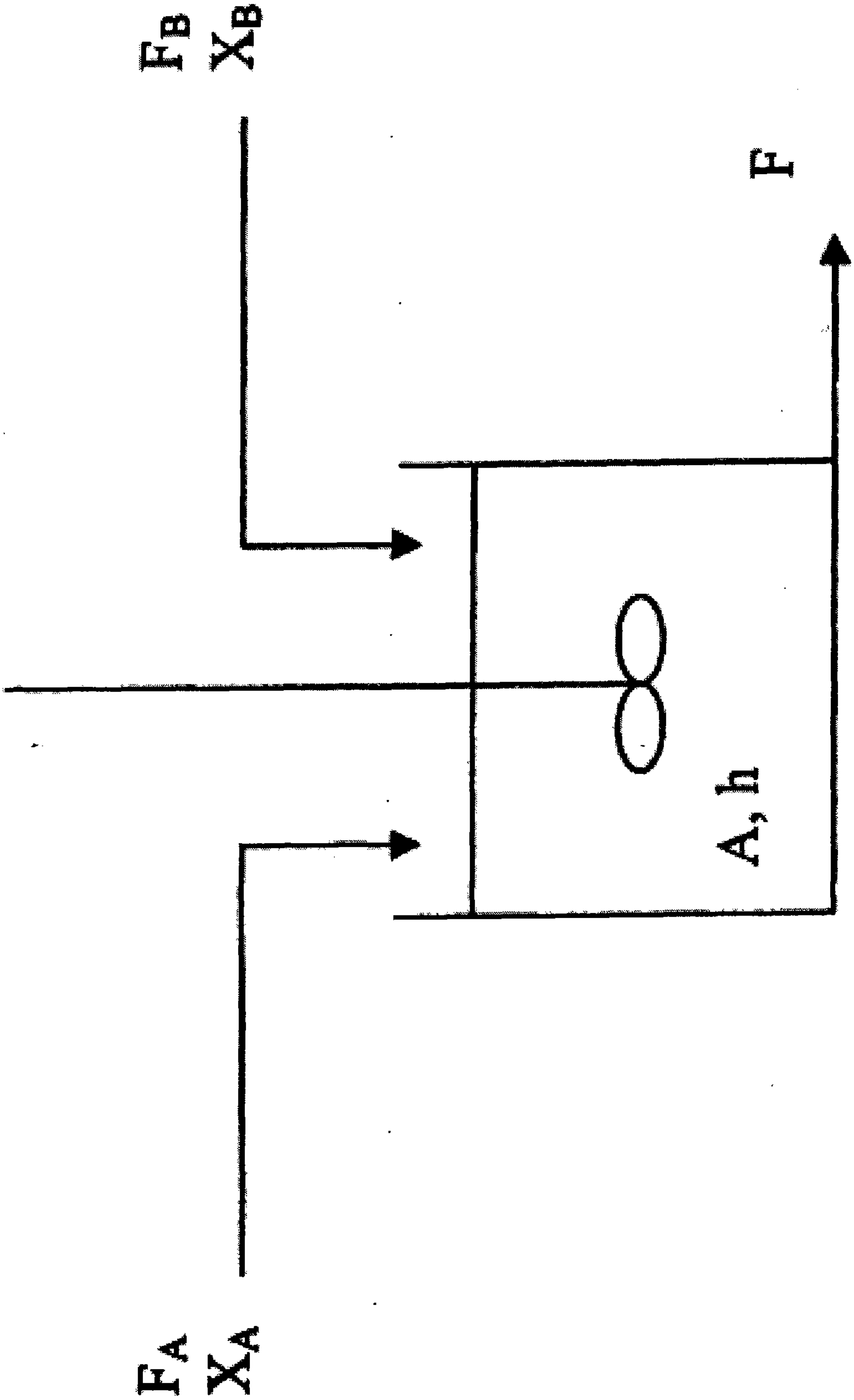
1. Proportional controller (P): $G_c(s) = K_c$

2. Proportional-Integral controller (PI): $G_c(s) = K_c\left(1+\frac{1}{\tau_I s}\right)$

3. Proportional-Integral-Derivative contróller (PID): $G_c(s) = K_c\left(1+\frac{1}{\tau_I s}+\tau_D s\right)$

Appendix A

Lampiran A



Appendix B
Lampiran B