UNIVERSITI SAINS MALAYSIA

Second Semester Examination
Academic Session 2008/2009

April/May 2009

EKC 462 – Advanced Control System for Industrial Processes
[Sistem Kawalan Lanjutan untuk Proses Industri]

Duration : 3 hours
[Masa : 3 jam]

Please check that this examination paper consists of SEVEN pages of printed material and ONE page of Appendix before you begin the examination.

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

Instructions: Answer any **FOUR** (4) questions.

*[**Arahan**: Jawab mana-mana **EMPAT** (4) soalan.]*

You may answer the question either in Bahasa Malaysia or in English.

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

Answer any <u>FOUR</u> questions.
Jawab mana-mana <u>EMPAT</u> soalan.

1. Wardle and Wood (1969) gave the following transfer function matrix for the input-output behaviour of a distillation column

1. Wardle dan Wood (1969) telah memberi matrik fungsi pemindahan bagi sifat masukan-keluaran bagi sebuah turus penyulingan

$$\begin{bmatrix} CV_1(s) \\ CV_2(s) \end{bmatrix} = \begin{bmatrix} \dfrac{0.12e^{-6s}}{60s+1} & \dfrac{-0.101e^{-12s}}{(48s+1)(45s+1)} \\ \dfrac{0.094e^{-8s}}{38s+1} & \dfrac{-0.12e^{-8s}}{35s+1} \end{bmatrix} \begin{bmatrix} MV_1(s) \\ MV_2(s) \end{bmatrix}$$

[a] Calculate the relative gain of the loop and hence calculate the relative gain array.

[a] Kirakan gandaan relatif bagi gelung dan kirakan juga tatasusunan gandaan relatif.

[4 marks/markah]

[b] Using the relative gain array, make comments on the selection of control loop pairing for two single loop controllers.

[b] Dengan menggunakan tatasusunan gandaan relatif, berikan komen pada pemilihan pasangan gelung kawalan bagi dua pengawal gelung tunggal.

[4 marks/markah]

[c] To assess system sensitivity, the engineer considers:

[i] a change in mv1(s) of magnitude 1 with mv2(s) held constant

[ii] a change in mv2(s) of magnitude 1 with mv1(s) held constant

What are the effective gains that correspond to this input direction?

[c] Untuk menilai kepekaan sistem, jurutera harus mempertimbangkan:

[i] perubahan magnitud 1 pada mv1(s) dengan mv2(s) ditetapkan malar

[ii] perubahan magnitut 1 pada mv2(s) dengan mv1(s) ditetapkan malar

Apakah gandaan berkesan yang sepadan bagi arah masukan tersebut?

[8 marks/markah]

[d] If the ratio of the two effective gains is the condition number of the plant, what is significance of the two effective gains? Please confirm your answer.

[d] Jika nisbah bagi dua gandaan berkesan adalah syarat bagi nombor keadaan sesebuah loji, apakah kepentingan dua gandaan berkesan tersebut? Sila sahkan jawapan anda.

[5 marks/markah]

[e] Using the value obtained for the condition number in [d] make comments about the sensitivity of the plant and the feasibility for applying a decoupling control law.

[e] Dengan menggunakan nilai yang diperolehi untuk nombor keadaan pada [d] berikan komen mengenai kepekaan loji dan kesesuaian penggunaan hukum kawalan tak berpasangan.

[4 marks/markah]

2. [a] What is it meant by prediction horizon (M) and control horizon (P) in model based predictive control (MPC) schemes?

2. [a] Apakah yang dimaksudkan dengan ramalan ufuk (M) dan kawalan ufuk (P) di dalam model berasaskan skim kawalan ramalan (MPC)?

[4 marks/markah]

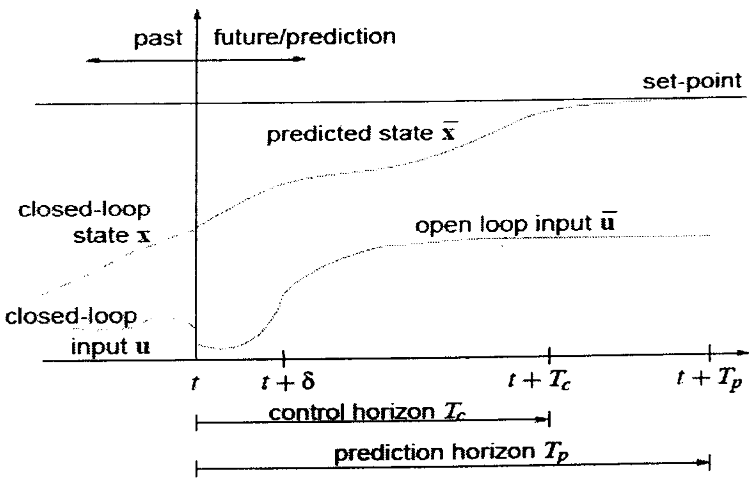

Figure Q.2. [b] : Principle of model predictive control.
Rajah S.2. [b] : Prinsip model kawalan ramalan.

[b] Briefly explain about the principal of MPC control schemes based on the Figure Q.2. [b]?

[b] Terangkan secara ringkas prinsip bagi Skim Kawalan MPC berdasarkan Rajah S.2. [b]?

[4 marks/markah]

[c] Consider the following diagram representing conventional and nonlinear model predictive control strategy

[c] Pertimbangkan gambarajah berikut yang mewakili strategi lazim dan model kawalan ramalan yang tak linear

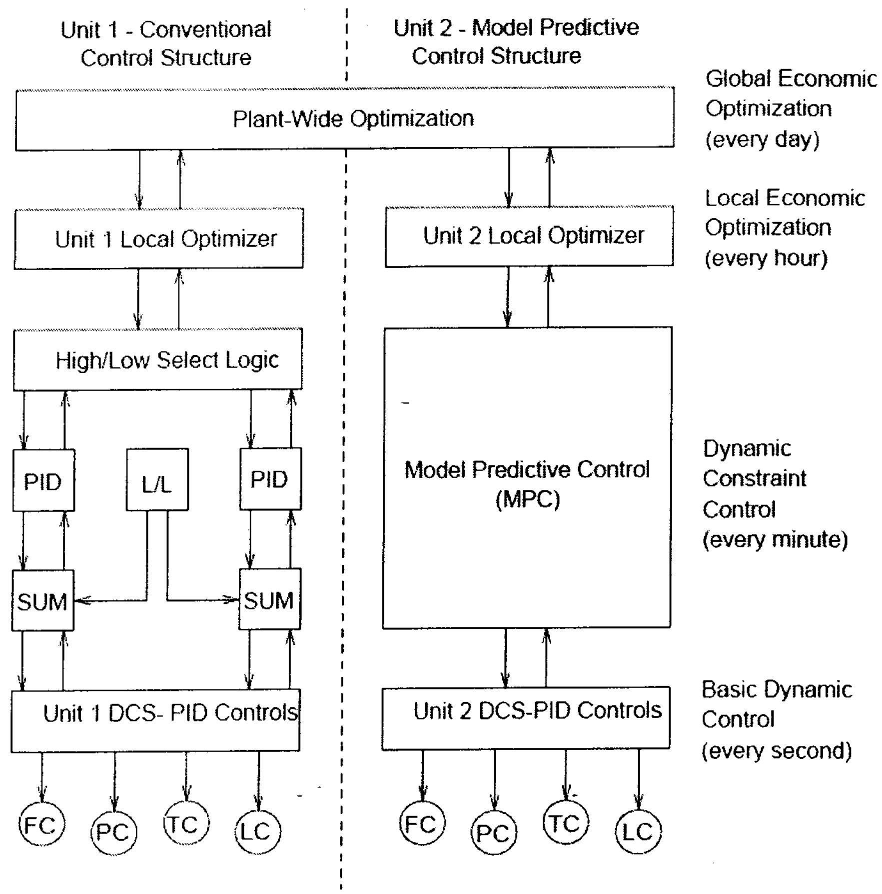

Figure Q.2. [c]. Hierarchy of control system functions in a typical processing plant. Conventional structure is shown at the left; MPC structure is shown at the right.

Rajah S.2. [c]. Hierarki bagi fungsi sistem kawalan dalam loji pemprosesan. Struktur lazim ditunjukkan pada sebelah kiri; struktur MPC ditunjukkan pada sebelah kanan.

[i] Briefly discuss the key features of MPC as compared to conventional control strategy based on the Figure Q.2.[c].

[i] Bincangkan secara ringkas sifat-sifat MPC berbanding dengan strategi kawalan lazim berdasarkan Rajah S.2.[c].

[4 marks/markah]

[ii] Defining all terms and write down a typical controller cost function used in model predictive control laws.

[ii] Takrifkan semua terma dan tuliskan ciri menyeluruh bagi fungsi pengawal kos yang digunakan dalam hukum kawalan ramalan.

[8 marks/markah]

[iii] One of the general objectives of an MPC controller is to prevent violation of input and output constraints. Briefly explain how to support this statement.

[iii] Salah satu daripada objektif umum bagi sebuah pengawal MPC ialah untuk mencegah pelanggaran kekangan bagi masukan dan keluaran. Jelaskan bagaimana untuk menyokong kenyataan ini

[5 marks/markah]

3. [a] Design a model predictive control (MPC) strategy for the process

$$[Gp(s)] = \left[\frac{e^{-6s}}{10s+1}\right], \quad Gv = Gm = 1$$

Select a values of N based on 95% completion of the step response and $\Delta t = 2$. Obtain the controller gain Kc with the following design parameters.

Control Horizon M = 1, Prediction Horizon, P = 10, Output weight $Q = I$, and Input Weight $R = 0$.

3. [a] Rekabentukkan sebuah strategi model kawalan ramalan (MPC) bagi proses

$$[Gp(s)] = \left[\frac{e^{-6s}}{10s+1}\right], \quad Gv = Gm = 1$$

Pilih nilai N berdasarkan kepada 95% siap kepada langkah respon dan $\Delta t = 2$. Dapatkan gandaan pengawal Kc dengan parameter-parameter rekabentuk berikut.

Pengawal Ufuk M = 1, Ramalan Ufuk, P = 10, Berat Keluaran $Q = I$, dan Berat Masukan $R = 0$.

[12 marks/markah]

[b] A process has the following input-output model:

$$\tilde{g}_p(s) = \frac{-2(3s+1)}{(-4s+1)(5s+1)}$$

Design the IMC-based PID controller (perhaps PI cascaded with a lead-lag filter) for this process.

[b] Satu proses mempunyai model keluaran-masukan seperti berikut:

$$\tilde{g}_p(s) = \frac{-2(3s+1)}{(-4s+1)(5s+1)}$$

Rekabentukkan pengawal IMC-asas PID (mungkin PI dengan satu penapis mendulu-mengekor) bagi proses ini.

[13 marks/markah]

4. [a] Explain the following:

[i] Smith Predictor
[ii] Inferential Control
[iii] Adaptive Control

4. [a] Terangkan perkara-perkara yang berikut:

[i] Pemampas Smith
[ii] Pengawal Taabir
[iii] Pengawal Suai

[12 marks/markah]

[b] Consider the following isothermal chemical reactor (Figure Q.4.[b]), where the dilution rate (feed flow rate per unit volume of reactor) is manipulated to achieve a desired concentration of product.

[b] Pertimbangkan reaktor kimia isoterma berikut (Rajah S.4b), di mana kadar pencairan (kadar aliran masuk per unit isipadu reaktor) diolah untuk mencapai kepekatan produk yang dikehendaki.

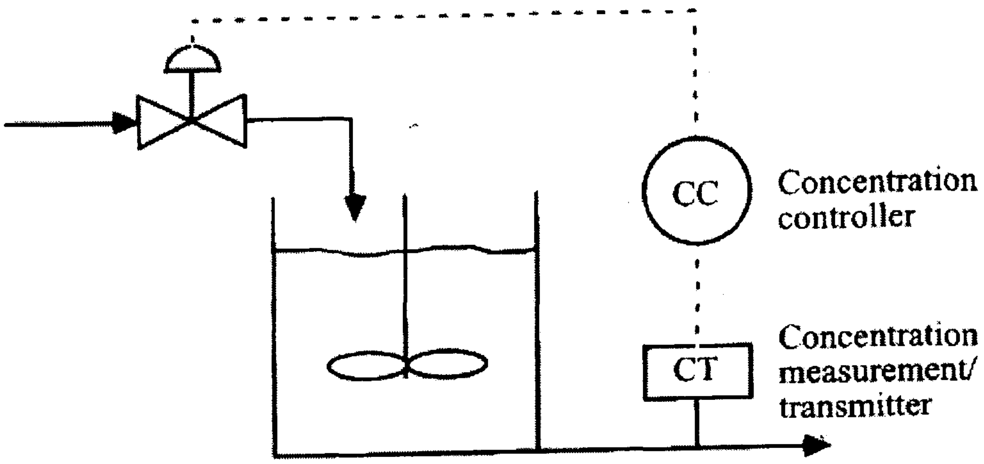

Figure Q.4. [b] : Chemical Reactor
Rajah S.4[b]: Reaktor Kimia

The process model is:

$$\tilde{g}_p(s) = \frac{0.5848(-0.3549s+1)\,e^{-0.5s}}{0.1858s^2+0.8627s+1}$$

Design an IMC for this process using all-pass factorization technique.

Model bagi proses tersebut ialah:

$$\tilde{g}_p(s) = \frac{0.5848(-0.3549s+1)\,e^{-0.5s}}{0.1858s^2+0.8627s+1}$$

Rekabentukkan pengawal IMC bagi proses ini dengan menggunakan teknik pemfaktoran semua lulus.

[13 marks/markah]

5. [a] Figure Q.5.[a] shows the proposed automatic control schemes for a reactor where an exothermic reaction A + B → C takes place. Do the following:

[i] Identify the control schemes proposed.
[ii] Justify the needs of such control schemes in the reactor.

5. [a] Rajah S.5.[a] menunjukkan cadangan skema-skema pengawal automatik bagi satu reaktor yang mana tindakbalas eksotermik A + B → C berlaku. Laksanakan perkara-perkara berikut:

[i] Kenalpasti skema-skema pengawal yang dicadangkan.
[ii] Jelaskan mengapa skema-skema pengawal itu diperlukan bagi reaktor tersebut.

[12 marks/markah]

[b] A process including sensor and control valve can be modelled by a fourth-order transfer function:

$$g_0(s) = \frac{5}{(1.2s+1)(0.08s+1)(s+1)(0.008s+1)}$$

[i] Derive an approximate FOPTD model using Skogestad's half rule
[ii] Design PID controller using IMC-Based PID procedure for the process.

[b] Satu proses termasuk penderia dan injap kawalan boleh diungkapkan sebagai rangkap pindah tertib keempat seperti berikut:

$$g_0(s) = \frac{5}{(1.2s+1)(0.08s+1)(s+1)(0.008s+1)}$$

[i] Terbitkan satu anggaran model FOPTD menggunakan peraturan separuh Skogestad
[ii] Rekabentukkan pengawal PID menggunakan kaedah IMC-asas PID bagi proses tersebut.

[13 marks/markah]

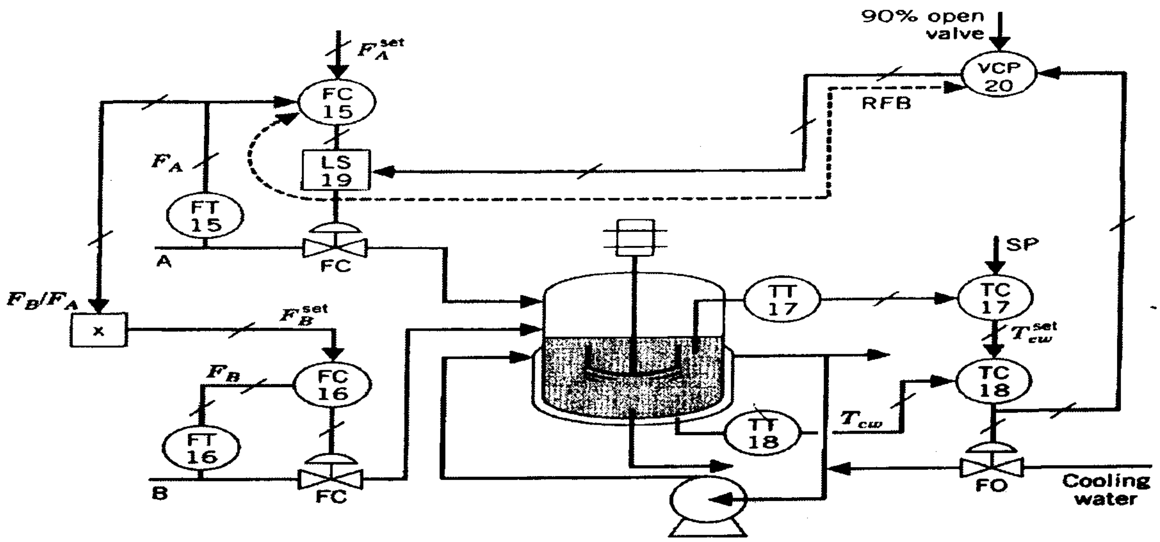

Figure Q.5.[a]: Proposed automatic control scheme for the reactor
Rajah S.5.[a]: Cadangan skema pengawal automatik bagi satu reaktor

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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. $\frac{1}{b_1-b_2}(e^{-b_2t}-e^{-b_1t})$		$\frac{1}{(s+b_1)(s+b_2)}$
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. $\frac{b_3-b_1}{b_2-b_1}e^{-b_1t}+\frac{b_3-b_2}{b_1-b_2}e^{-b_2t}$		$\frac{s+b_3}{(s+b_1)(s+b_2)}$
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. $\frac{1}{\tau\sqrt{1-\zeta^2}}e^{-\zeta t/\tau}\sin(\sqrt{1-\zeta^2}\,t/\tau)$ $(0\le\lvert\zeta\rvert<1)$		$\frac{1}{\tau^2s^2+2\zeta\tau s+1}$
20. $1+\frac{1}{\tau_2-\tau_1}(\tau_1e^{-t/\tau_1}-\tau_2e^{-t/\tau_2})$ $(\tau_1\ne\tau_2)$		$\frac{1}{s(\tau_1 s+1)(\tau_2 s+1)}$
21. $1-\frac{1}{\sqrt{1-\zeta^2}}e^{-\zeta t/\tau}\sin[\sqrt{1-\zeta^2}\,t/\tau+\psi]$ $\psi=\tan^{-1}\frac{\sqrt{1-\zeta^2}}{\zeta}$, $(0\le\lvert\zeta\rvert<1)$		$\frac{1}{s(\tau^2s^2+2\zeta\tau s+1)}$
22. $1-e^{-\zeta t/\tau}[\cos(\sqrt{1-\zeta^2}\,t/\tau)+\frac{\zeta}{\sqrt{1-\zeta^2}}\sin(\sqrt{1-\zeta^2}\,t/\tau)]$ $(0\le\lvert\zeta\rvert<1)$		$\frac{1}{s(\tau^2s^2+2\zeta\tau s+1)}$
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. $\frac{d^nf}{dt^n}$		$s^nF(s)-s^{n-1}f(0)-s^{n-2}f^{(1)}(0)-\cdots-sf^{(n-2)}(0)-f^{(n-1)}(0)$
26. $f(t-t_0)S(t-t_0)$		$e^{-t_0s}F(s)$

[a]Note that $f(t)$ and $F(s)$ are defined for $t\ge0$ only.