UNIVERSITI SAINS MALAYSIA

First Semester Examination
Academic Session 2007/2008

October/November 2007

EKC 462 – Advanced Control System For Industrial Process
[Sistem Kawalan Lanjutan Untuk Proses Industri]

Duration : 3 hours
[Masa : 3 jam]

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

[Sila pastikan bahawa kertas peperiksaan ini mengandungi ENAM 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 a question either in Bahasa Malaysia or in English.

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

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

Wardle dan Wood (1969) memberikan ungkapan rangkap pindah untuk tingkah laku input-output turus penyulingan seperti di bawah:

$$\begin{bmatrix} y_1(s) \\ y_2(s) \end{bmatrix} = \begin{bmatrix} \dfrac{0.12e^{-6s}}{60s+1} & \dfrac{-0.101e^{-12s}}{(48s+1)(45s+1)} \\ \dfrac{0.094e^{-8s}}{38s+1} & \dfrac{-0.12e^{-8s}}{35s+1} \end{bmatrix} \begin{bmatrix} u_1(s) \\ u_2(s) \end{bmatrix}$$

[a] Draw a block diagram representation of the transfer function matrix.

Lukiskan gambarajah blok yang mewakili ungkapan matrik rangkap pindah tersebut.

[4 marks/markah]

[b] Design an ideal decoupling control scheme using the data provided in the process transfer function matrix. Clearly indicates your assumption and your design criteria for this system.

Rekabentukkan satu skima kawalan unggul bagi sistem kawalan nyahgandingan dengan menggunakan data yang diberikan dalam matrik rangkap pindah proses. Terangkan dengan jelas andaian dan kriteria rekabentuk anda.

[12 marks/markah]

[c] Draw a block diagram representation of the decoupling control scheme indicating the positions of all the transfer function and the additional feedback controllers.

Lukiskan gambarajah blok yang mewakili struktur sistem kawalan nyahgandingan dengan menunjukkan semua rangkap pindah dengan tambahan pengawal suap balik.

[6 marks/markah]

[d] What problem do you foresee in the implementation of this strategy?

Apakah masalah yang anda akan hadapi dengan melaksanakan strategi tersebut?

[3 marks/markah]

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

Apakah yang dimaksudkan dengan ufuk ramalan (M) dan ufuk kawalan (P) dalam skema kawalan ramalan model (MPC)?

[4 marks/markah]

...3/-

[b] Briefly explain the receding horizon approach of MPC control scheme?

Terangkan dengan ringkas kaedah ufuk menyurut dalam skema kawalan MPC?

[4 marks/markah]

[c] Considered the following diagram representation nonlinear model predictive control strategy.

Pertimbangkan gambarajah berikut yang mewakili strategi kawalan ramalan model tak lelurus.

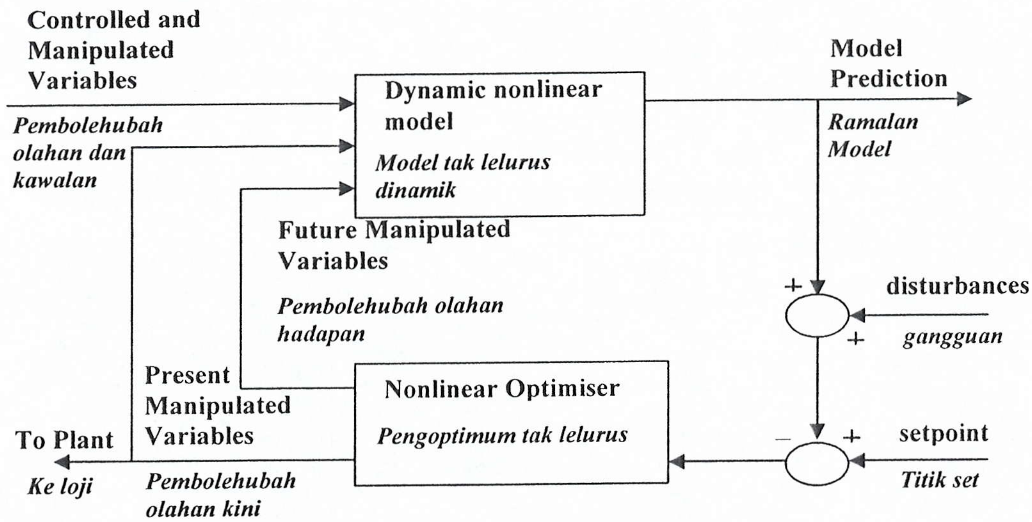

Figure Q. 2[c]: Model Predictive Control (MPC) strategy
Rajah S. 2[c]: Strategi model kawalan ramalan (MPC)

[i] Briefly discuss the key features of this control strategy.

Terangkan dengan ringkas ciri-ciri utama strategi kawalan ini.

[4 marks/markah]

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

Takrifkan semua ungkapan, tuliskan fungsi kos atau fungsi objektif pengawal lazim yang digunakan dalam hukum kawalan ramalan model.

[8 marks/markah]

[iii] Supposed that a mechanistic model was to be used as a dynamic nonlinear model, discuss the advantages and disadvantages of using a detail mechanistic model within the model predictive control (MPC) strategy.

Jika model mekanistik akan digunakan sebagai model tak lelurus dinamik bincangkan apakah kekurangan dan kelebihan menggunakan model mekanistik terperinci dalam strategi kawalan ramalan model (MPC).

[5 marks/markah]

3. [a] Runger and Pignatiello (1991) consider a plastics injection molding process for a part that has a critical width dimension with a historical mean of 100 and a historical standard deviation of 8. Periodically, clogs form in one of the feeder lines, causing the mean width to change. As a result, the operator periodically takes random samples of size four and the data are shown in Table Q. 3.[a].

Runger dan Pignatiello (1991) telah mempertimbangkan proses pengacuan suntikan plastik bagi bahagian yang mempunyai dimensi lebar genting dengan sejarah purata 100 dan sisihan piawai 8. Secara berkala, sekatan terbentuk di salah satu talian suapan, yang menyebabkan perubahan lebar purata berubah. Akibatnya, operator akan mengambil sampel bersaiz empat secara rawak dan berkala seperti ditunjukkan di Jadual S.3.[a].

Table Q.3.[a] : Random samples for plastic width dimension
Jadual S.3.[a] : Sampel rawak untuk dimensi lebar plastik

Group *Kumpulan*	Sample 1 *Sampel 1*	Sample 2 *Sampel 2*	Sample 3 *Sampel 3*	Sample 4 *Sampel 4*
1	93.77	105.09	106.18	103.21
2	97.66	103.55	90.57	105.08
3	95.57	102.25	100.98	101.17
4	103.95	100.41	101.21	100.18
5	105.74	90.16	103.63	102.04
6	105.53	112.05	112.33	119.15
7	109.74	106.41	112.75	106.95
8	105.91	115.40	95.55	101.33

Calculate the appropriate control limits and plot the control chart ($\overline{X}$-chart). Comment on your result.

Kirakan had kawalan wajar yang sepatutnya dan plotkan carta kawalan (carta $\overline{X}$). Komen keputusan anda.

[13 marks/markah]

[b] For an Internal Model Control (IMC), show that setting $g_{p+} = e^{-\theta s}$ leads to a Smith predictor controller structure when $g_p = \tilde{g}_p$ for a first order plus time delay (FOPTD) process.

Bagi Kawalan Model Dalam (IMC), tunjukkan bahawa dengan mengambil $g_{p+} = e^{-\theta s}$ untuk proses tertib pertama dengan masa lengah (FOPTD) akan membawa kepada struktur Pengawal Pemampas Smith apabila $g_p = \tilde{g}_p$.

[12 marks/markah]

4. [a] Briefly explain the following:

Terangkan secara ringkas perkara-perkara berikut:

[i] Simple factorization

Pemfaktoran mudah

[ii] All pass factorization

Pemfaktoran semua lulus

[iii] Open loop controller

Pengawal gelung terbuka

[iv] Semiproper and strictly proper transfer function

Rangkap pindah separuh wajar dan tegas wajar

[v] Model Based Controller

Pengawal Berasaskan Model

[5 marks/markah]

[b] Design an IMC controller for each of the following process model using simple factorization. Keep you final answer in s domain.

Rekabentukkan pengawal IMC bagi setiap proses berikut dengan menggunakan pemfaktoran mudah. Kekalkan jawapan akhir anda dalam domain s.

[i] $$\frac{s^2+2.5s+1}{s^4+6.5s^3+15s^2+14s+4}$$

[ii] $$\frac{s^2-s-2}{s^4+6.5s^3+15s^2+14s+4}$$

[iii] $$\frac{10(s-1)e^{-s}}{s^2+s-2}$$

[iv] $$\frac{d^2y}{dt^2}+4\frac{dy}{dt}+3y=u-\frac{du}{dt}$$

[20 marks/markah]

5. [a] Briefly explain what self-tuning controller is and why is it needed in chemical process control?

Terangkan secara ringkas apakah pengawal talaan-diri dan mengapa ia diperlukan dalam kawalan proses kimia?

[3 marks/markah]

[b] Describe what the Smith Predictor and inferential control are.

Nyatakan apakah pemampas Smith dan pengawal taabir.

[6 marks/markah]

[c] Consider the closed-loop response for IMC when model is not perfect. Show that there is no offset for a set point change for the following model and process transfer functions:

Pertimbangkan sambutan gelung tertutup bagi IMC bila model tidak sempurna. Tunjukkan bahawa tiada ofset untuk perubahan titik set bagi model proses dan rangkap pindah proses berikut:

Process model $\tilde{g}_p(s) = \dfrac{1}{10s+1}$

Process $g_p(s) = \dfrac{0.75(-s+1)}{(2s+1)(8s+1)}$

[16 marks/markah]

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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 $t\ge 0$ only.