UNIVERSITI SAINS MALAYSIA

Second Semester Examination
2015/2016 Academic Session

June 2016

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

Duration : 3 hours
[Masa : 3 jam]

Please ensure that this examination paper contains SEVEN printed pages and ONE printed 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.]

Instruction: Answer **ALL** questions.

*[**Arahan:** Jawab **SEMUA** soalan.]*

In the event of any discrepancies, the English version shall be used.

[Sekiranya terdapat sebarang percanggahan pada soalan peperiksaan, versi Bahasa Inggeris hendaklah diguna pakai].

Answer ALL questions.

1. [a] Explain the following:

   [i] Nonlinear Control

   [ii] Adaptive Control

   [iii] Model Based Control

   [iv] Inferential Control

[12 marks]

   [b] Describe what the Smith Predictor is. Draw its block diagram and derive the closed-loop set point transfer function. Assume the model is perfect.

[6 marks]

   [c] Shinskey has proposed a delay-time compensator of the form:

$$G_c(s) = K_c\left(\frac{1+\tau_I s}{1+\tau_I s - e^{-\theta s}}\right)$$ for a first order plus time delay (FOPTD) process,

with $K_c = 1/K_p$ and $\tau_I = \tau$.

Derive the closed-loop transfer function and show that the time delay is eliminated from characteristic equation. Will the closed-loop response exhibit overshoot?

[7 marks]

2. [a] Design an internal model control (IMC) for each of the following process model using all pass factorization. Keep the final answer in *s* domain.

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

[12 marks]

Jawab SEMUA soalan.

1. [a] *Terangkan perkara-perkara yang berikut:*

   [i] *Kawalan Tak Lelurus*

   [ii] *Kawalan Suai*

   [iii] *Kawalan Berasaskan Model*

   [iv] *Kawalan Taabir*

[12 markah]

[b] *Terangkan apakah Peramal Smith. Lukiskan gambarajah bloknya dan terbitkan rangkap pindah set titik gelung tertutup. Anggapkan model adalah sempurna.*

[6 markah]

[c] *Shinskey mencadangkan satu pemampas masa-lengah dalam bentuk:*

$G_c(s) = K_c\left(\dfrac{1+\tau_I s}{1+\tau_I s - e^{-\theta s}}\right)$ *bagi proses tertib pertama dengan masa lengah (FOPTD), dengan* $K_c = 1/K_p$ *dan* $\tau_I = \tau$.

Terbitkan rangkap pindah gelung tertutup dan tunjukkan bahawa masa lengah dikeluarkan daripada persamaan ciri. Adakah sambutan gelung tertutup akan menunjukkan ciri terlajak?

[7 markah]

2. [a] *Rekabentukkan Kawalan Model Dalam (IMC) bagi setiap proses berikut dengan menggunakan pemfaktoran semua lulus. Kekalkan jawapan akhir dalam domain* s.

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

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

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

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

[12 markah]

[b] Using the IMC design method to design two controllers for the FOPTD process based on the time-delay approximations below:

[i] Padé approximation:

$$e^{-\theta s} \cong \frac{1 - \frac{\theta}{2}s}{1 + \frac{\theta}{2}s}$$

[ii] First-order Taylor series approximation:

$$e^{-\theta s} \cong 1 - \theta s$$

[13 marks]

3. A process has the following transfer function description:

$$\begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = \begin{bmatrix} \dfrac{12.8e^{-s}}{16.7s+1} & \dfrac{-18.9e^{-3s}}{21.0s+1} & \dfrac{3.8e^{-8.1s}}{14.9s+1} \\ \dfrac{6.6e^{-7s}}{10.9s+1} & \dfrac{-19.4e^{-3s}}{14.4s+1} & \dfrac{4.9e^{-3.4s}}{13.2s+1} \end{bmatrix} \begin{bmatrix} u_1 \\ u_2 \\ u_3 \end{bmatrix}$$

Figure Q.3: Transfer function for multiple input multiple output (MIMO) system.

[a] Draw an open loop block diagram representation of the transfer function matrix shown in Figure Q.3 and calculate the relative gain array (RGA) for that MIMO system if $s = 1$.

[5 marks]

[b] Draw a complete block diagram proposing the structure of a decoupling control system. Clearly state the function of each block.

[8 marks]

[c] Design an ideal decoupling control scheme using the data provided in the process transfer function matrix shown in Figure Q.3. Clearly indicates your design criteria.

[8 marks]

[d] Explains how the decoupling control system may be simplified based upon practical consideration. What are the consequences of any simplification made?

[4 marks]

[b] *Gunakan kaedah rekabentuk IMC untuk merekabentuk dua pengawal bagi proses FOPTD berdasarkan anggaran masa lengah berikut:*

[i] *Anggaran Padé :*

$$e^{-\theta s} \cong \frac{1 - \frac{\theta}{2}s}{1 + \frac{\theta}{2}s}$$

[ii] *Anggaran siri Taylor tertib pertama:*

$$e^{-\theta s} \cong 1 - \theta s$$

[13 markah]

3. *Suatu proses mempunyai rangkap pindah seperti berikut:*

$$\begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = \begin{bmatrix} \frac{12.8e^{-s}}{16.7s+1} & \frac{-18.9e^{-3s}}{21.0s+1} & \frac{3.8e^{-8.1s}}{14.9s+1} \\ \frac{6.6e^{-7s}}{10.9s+1} & \frac{-19.4e^{-3s}}{14.4s+1} & \frac{4.9e^{-3.4s}}{13.2s+1} \end{bmatrix} \begin{bmatrix} u_1 \\ u_2 \\ u_3 \end{bmatrix}$$

Gambarajah S.3: Rangkap pindah untuk sistem masukkan berbilang keluaran berbilang (MIMO)

[a] *Lukiskan gambarajah blok gelung terbuka yang mewakili matrik rangkap pindah yang ditunjukkan dalam gambarajah S.3 dan kirakan tatasusunan gandaan relatif (RGA) bagi sistem MIMO tersebut sekiranya* s=*1.*

[5 markah]

[b] *Lukiskan gambarajah blok lengkap yang mencadangkan struktur sistem kawalan nyahgandingan. Sila nyatakan dengan jelas fungsi setiap blok.*

[8 markah]

[c] *Rekabentukkan satu skima kawalan unggul bagi sistem kawalan nyahgandingan dengan menggunakan data yang diberikan dalam Gambarajah S.3. Terangkan dengan jelas kriteria rekabentuk anda.*

[8 markah]

[d] *Tunjukkan bagaimana sistem kawalan nyahgandingan boleh dipermudahkan berdasarkan pertimbangan secara praktikal. Apakah akibat permudahan tersebut?*

[4 markah]

4. [a] Outline the philosophy of model predictive control (MPC) calculation and explain the concept of a receeding horizon.

[6 marks]

[b] Consider the shown in Figure Q.4.[b] model predictive control strategy.

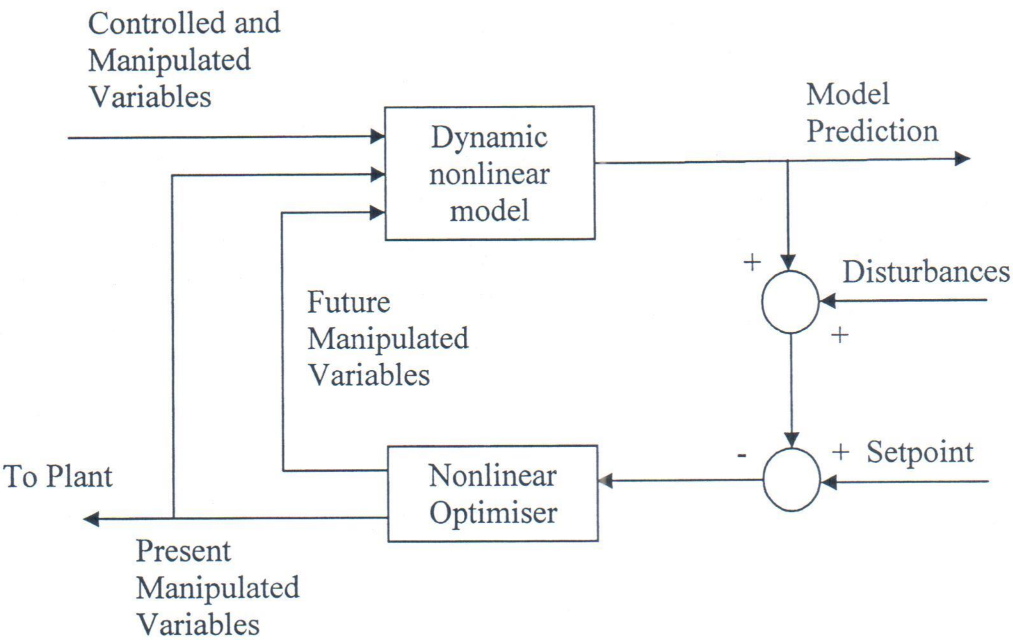


Figure Q.4.[b]: MPC strategy

[i] Discuss the key features of this control strategy.

[6 marks]

[ii] Defining all terms, write down a typical controller cost function used in MPC laws.

[6 marks]

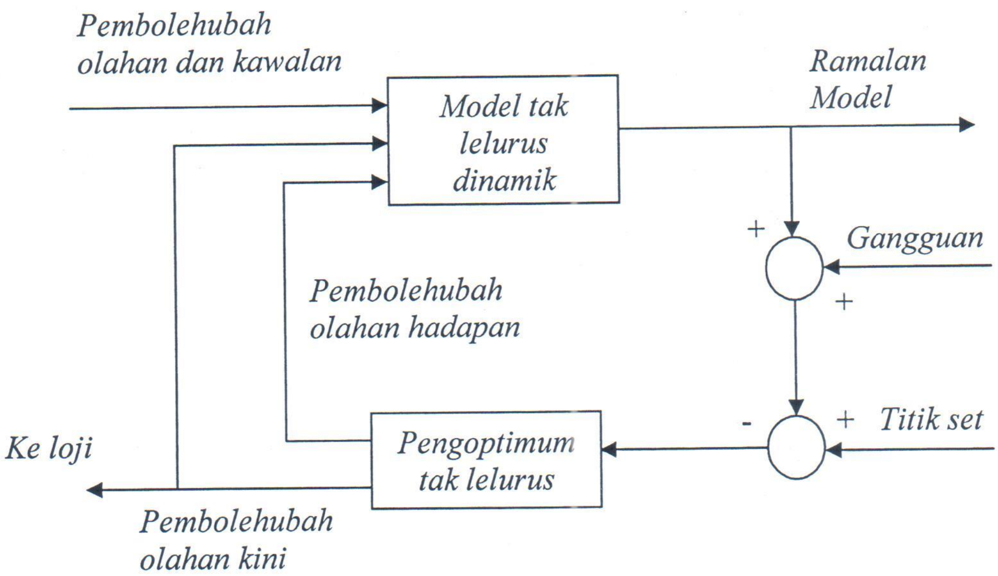
[c] Your company hired a consultant to judge whether a distillation column in your plant would benefit from the Model Based Predictive Control (MBPC) strategy. As you know that the existing distillation column is very old and sometimes take longer time to produce the on specification product if a new feed composition is fed to the column. The consultant claims that the benefits would be significant and recommended that your company goes ahead with MBPC. In addition to that, they also willing to install the system for your company. As a process control engineer, determine any consideration would you require in the report by the consultant to judge the soundness of the claims.

[7 marks]

4. [a] *Rangkakan falsafah pengiraan kawalan ramalan model (MPC) dan terangkan konsep ufuk surut.*

[6 markah]

[b] *Pertimbangan strategi kawalan ramalan model yang ditunjukkan dalam Gambarajah S.4.[b].*



Gambarajah S.4.[b]: Strategi MPC

[i] *Bincangkan dengan ringkas ciri-ciri utama strategi kawalan tersebut.*

[6 markah]

[ii] *Takrifkan semua ungkapan, tuliskan fungsi kos pengawal lazim yang digunakan dalam hukum.*

[6 markah]

[c] *Syarikat anda telah mengupah seorang perunding untuk mengadili sama ada turus penyulingan di kilang anda akan mendapat manfaat daripada strategi Kawalan Model Berasaskan Ramalan (MPBC). Seperti yang anda tahu turus penyulingan yang sedia ada adalah sangat lama dan kadangkala ia mengambil masa yang agak panjang untuk menghasilkan spesifikasi produk yang diperlukan jika komposisi baru disuapkan ke dalam turus penyulingan tersebut. Perunding tersebut mendakwa bahawa syarikat anda akan mendapat manfaat yang banyak dan mencadangkan supaya anda meneruskan pelaksanaan MPBC. Di samping itu, dia juga bersedia untuk memasang sistem tersebut untuk syarikat anda. Sebagai jurutera kawalan proses, apakah pertimbangan yang anda kehendaki dalam laporan yang disediakan oleh perunding tersebut untuk menilai kekukuhan dakwaannya?*

[7 markah]

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Appendix

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.