UNIVERSITI SAINS MALAYSIA

Second Semester Examination
Academic Session 2006/2007

April 2007

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

Duration : 3 hours
[Masa : 3 jam]

Please ensure that this examination paper contains THIRTEEN printed pages and TWO printed pages of Appendix before you begin the examination.

[Sila pastikan bahawa kertas peperiksaan ini mengandungi TIGA BELAS muka surat yang bercetak dan DUA muka surat Lampiran sebelum anda memulakan peperiksaan ini.]

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

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

[PELAJAR DIBENARKAN MENJAWAB SEMUA SOALAN DALAM BAHASA INGGERIS ATAU BAHASA MALAYSIA ATAU KOMBINASI KEDUA-DUANYA.]

<u>Section A</u> : Answer any <u>TWO</u> questions.
<u>Bahagian A</u> : Jawab mana-mana <u>DUA</u> soalan.

1. [a] Briefly describe or define the following terms: -

[i] First order process

[ii] Second order process

[iii] Open – loop system

[iv] Closed – loop system

[v] Interacting and noninteracting process

[vi] Control variable, manipulated variable and disturbance

[6 marks]

[b] What are the strengths and weaknesses of feedback control system?

[4 marks]

[c] Ahmad, supervisor of the process control group of the Ideal Gas Company, has installed a 8 X 12 X 1.5 meter swimming pool in his backyard. The pool contains level and temperature sensors used with feedback controllers to maintain the pool level and temperature at desired values. Ahmad is satisfied with level control system, but he feels that the addition of one or more feedforward controllers could help maintain the pool temperature more nearly constant. As a new member of the process control group, you have been selected to check Ahmad's mathematical analysis and given your advice. The following information may or may not be pertinent to your analysis:-

- Ahmad is particular about cleanliness and thus has a high-capacity pump at continually recirculates the water through an activated charcoal filter.

- The pool is equipped with a natural gas-fired heater that adds heat to the pool at a rate Q (t) that is directly proportional to the output signal from the controller p (t).

- There is a leak in the pool, which Ahmad has determined is constant equal to F (volumetric flow rate). The liquid-level control system adds water from the city supply system to maintain the level in the pool exactly at the specified level. The temperature of the water in the city system is Tw a variable.

- A significant amount of heat is lost by conduction to the surrounding ground which has a constant, year-round temperature T_G. Experimental tests by Ahmad showed that essentially all the temperature drop between the pool and the ground occurred across the homogeneous layer of gravel that surrounded his pool. The gravel thickness is Δx and the overall thermal conductivity is K_G.

- The main challenge to Ahmad's modelling ability was the heat loss term accounting for convection, conduction, radiation and evaporation to the atmosphere. He determined that the heat loses per unit area of open water could be represented by:

$$\text{losses} = U\,(T_p - T_a)$$

where T_p = temperature of pool
T_a = temperature of the area, a variable
U = overall heat transfer coefficient

Ahmad's detailed model included radiation losses and heat generation due to added chemicals, but he determined that these terms were negligible.

[i] Draw a schematic diagram for the pool and all control equipment. Show all inputs and outputs, including all disturbance variables.

[ii] What additional variable (s) would have to be measured to add feedforward control to the existing pool temperature feedback controller?

[iii] Write a steady-state energy balance. How can you determine which of the disturbance variables you listed in part [i] are most/least likely to be important?

[iv] What recommendations concerning the prospects of adding feedforward control would you make to Ahmad?

[10 marks]

[d] A temperature control system for a distillation column is shown in Figure Q.1:

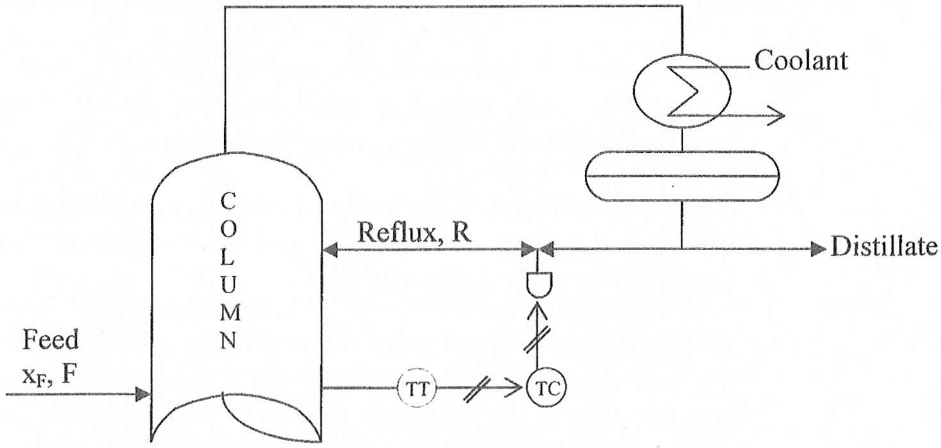


Figure Q.1: Temperature control system for a distillation column.

The temperature T of a tray near the top of the column is controlled by adjusting the reflux flow rate R. Draw a block diagram for this feedback control system. You may assume that both feed flow rate F and feed composition x_F are disturbance variables. All of the instrumentation, including the controller, is pneumatic.

[5 marks]

1. [a] *Terangkan atau takrifkan secara ringkas sebutan-sebutan berikut: -*

[i] *Proses tertib pertama*

[ii] *Proses tertib kedua*

[iii] *Sistem gelung terbuka*

[iv] *Sistem gelung tertutup*

[v] *Proses saling tindak dan proses tidak saling tindak*

[vi] *Pembolehubah kawalan, pembolehubah pengolah dan gangguan*

[6 markah]

[b] *Apakah kekuatan-kekuatan dan kelemahan-kelemahan sistem kawalan suap balik?*

[4 markah]

[c] *Ahmad, penyelia kumpulan kawalan proses bagi Syarikat Ideal Gas, telah membina satu kolam renang berukuran 8 X 12 X 1.5 meter di belakang rumahnya. Kolam tersebut mempunyai penderia aras dan suhu yang digunakan dengan pengawal suap balik untuk mengekalkan aras dan suhu kolam pada nilai-nilai yang diingini. Ahmad berpuas hati dengan sistem kawalan aras tetapi dia merasakan dengan menambah satu atau lebih pengawal suap depan dapat membantu mengekalkan suhu kolam lebih hampir kepada nilai malar. Sebagai seorang ahli baru bagi kumpulan kawalan proses, anda telah dipilih untuk memeriksa analisis matematik yang dibuat oleh Ahmad dan seterusnya memberikan nasihat-nasihat anda. Maklumat berikut mungkin atau tidak berkaitan dengan analisa anda:-*

- *Ahmad sangat mementingkan kebersihan dan oleh itu sebuah pam berkapasiti tinggi dipasang untuk memastikan air dapat berkitar secara berterusan melalui penapis arang teraktif.*

- *Kolam itu dilengkapi dengan pemanas gas asli yang membekalkan haba kepada kolam pada kadar Q (t) dan ia berkeadaan terus dengan isyarat keluaran daripada pengawal p (t).*

- *Terdapat satu kebocoran di dalam kolam, dan Ahmad telah menetapkan nilainya bersamaan F (kadar aliran isipadu). Sistem kawalan aras air menambahkan air daripada sistem bekalan bandar untuk mengekalkan aras pada kolam sama seperti yang diingini. Suhu air dari sistem bandar ialah Tw merupakan satu pembolehubah.*

- *Sejumlah haba hilang ke tanah persekitaran melalui konduksi pada kadar malar dan suhu sepanjang tahun adalah* T_G. *Ujikaji-ujikaji yang dijalankan oleh Ahmad menunjukkan penurunan suhu antara kolam dan tanah berlaku sepanjang lapisan homogen batu kerikil di sekitar kolamnya. Ketebalan lapisan batu kerikil ialah* Δx *dan keberaliran haba keseluruhan ialah* K_G.

- *Cabaran utama bagi keupayaan model yang dibina oleh Ahmad ialah terma kehilangan haba ke persekitaran disebabkan oleh sinaran dan penyejatan. Ia telah menentukan yang kehilangan haba per unit luas bagi air pada ruangan terbuka boleh diwakili oleh:*

$$kehilangan = U\,(T_p - T_a)$$

di mana T_p = *suhu kolam*
T_a = *suhu kawasan, satu pembolehubah*
U = *pekali pemindahan haba keseluruhan*

Model lengkap Ahmad termasuk kehilangan haba melalui sinaran dan haba terhasil disebabkan penambahan bahan kimia, tetapi ia telah mengesahkan bahawa terma-terma ini boleh diabaikan.

[i] *Lukiskan gambarajah skema bagi kolam tersebut dan semua alatan kawalan. Tunjukkan semua masukan dan keluaran termasuk semua pembolehubah gangguan.*

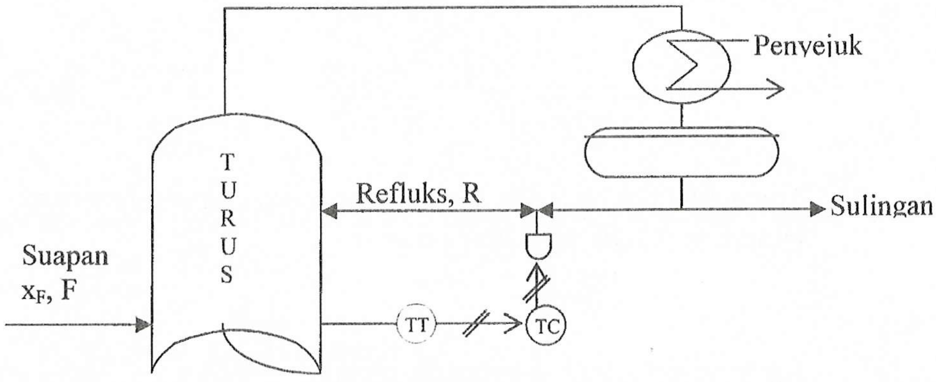
[ii] *Apakah pembolehubah tambahan yang perlu diukur untuk menambah kawalan suap depan kepada pengawal suap balik bagi suhu kolam yang sedia ada?*

[iii] *Tuliskan imbangan tenaga pada keadaan mantap. Bagaimanakah anda dapat menentukan pembolehubah gangguan mana seperti yang disenaraikan di bahagian (i), merupakan paling atau kurang penting?*

[iv] *Apakah cadangan-cadangan yang anda akan berikan pada Ahmad berkaitan harapan untuk menambahkan kawalan suap depan?*

[10 markah]

[d] *Satu sistem kawalan suhu bagi satu turus penyulingan ditunjukkan dalam Rajah S.1:*



Rajah S.1: Sistem kawalan suhu bagi satu turus penyulingan.

Suhu bagi dulang berhampiran bahagian atas turus dikawal dengan mengubah kadar aliran refluks, R. Lukiskan satu gambarajah blok bagi sistem kawalan suap balik itu. Anda boleh menganggap kedua-dua kadar aliran suapan F dan komposisi suapan X_F adalah pembolehubah-pembolehubah gangguan. Semua alatan termasuk pengawal adalah pneumatik.

[5 markah]

...6/-

2. [a] [i] Find the transfer functions $\frac{H_2}{Q}$ and $\frac{H_3}{Q}$ for the three-tank system shown in Figure Q.2. H_2, H_3 and Q are deviation variables. Tank 1 and Tank 2 are interacting

[ii] For a unit-step change in q (i.e. $Q = \frac{1}{s}$), determine $H_3(0)$, $H_3(\infty)$ and sketch $H_3(t)$ versus t.

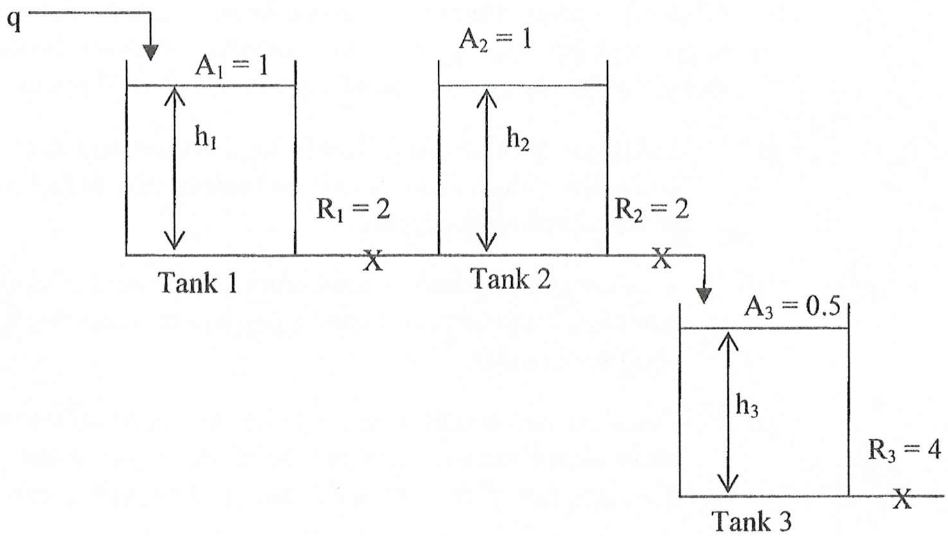


Figure Q.2 : Three-tank system.

[15 marks]

[b] Find the upper bound on proportional gain (for P-only control) for closed-loop stability of the following process.

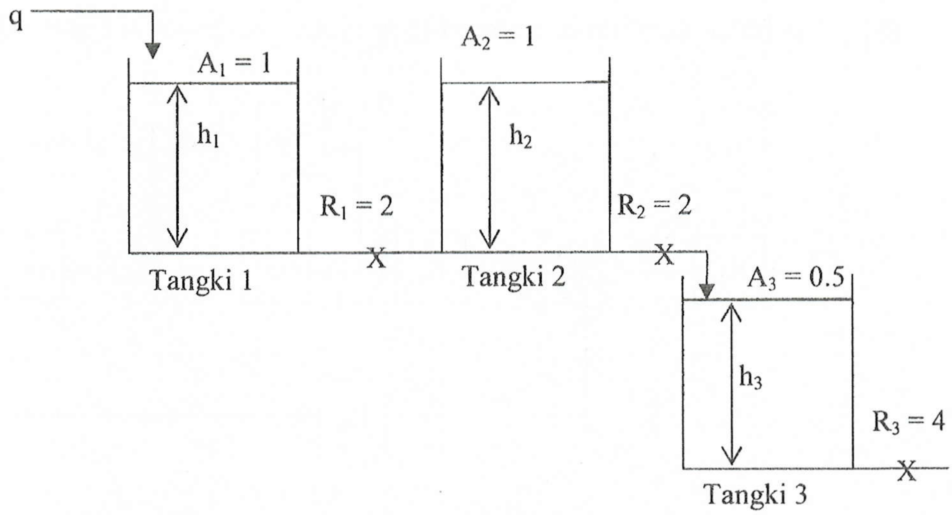
$$G_p(s) = \frac{1}{(3s+1)(2s+1)(s+1)}$$

The model has included actuator and measurement dynamics.
Hint: Use Routh array method.

[10 marks]

2. *[a]* *[i]* *Cari rangkap-rangkap pindah* $\frac{H_2}{Q}$ *dan* $\frac{H_3}{Q}$. *bagi sistem tiga tangki yang ditunjukkan dalam Rajah S.2.* H_2, H_3 *dan* Q *adalah pembolehubah –pembolehubah sisihan. Tangki 1 dan Tangki 2 adalah saling tindak.*

[ii] *Bagi satu unit tukar langkah, dalam q* ($Q = \frac{1}{s}$)*, tentukan* $H_3(0)$, $H_3(\infty)$ *dan lakarkan* $H_3(t)$ *melawan t.*



Rajah S.2 : Sistem tiga tangki.

[15 markah]

[b] *Carikan batasan atas bagi gandaan berkadaran (bagi kawalan P-sahaja) bagi kestabilan gelung tertutup untuk proses berikut.*

$$G_p(s) = \frac{1}{(3s+1)(2s+1)(s+1)}$$

Model tersebut termasuk penggerak dan dinamik pengukuran.
Petunjuk: Gunakan kaedah tatasusunan Routh.

[10 markah]

3. [a] An exothermic reaction, $A \rightarrow 2B$, takes place adiabatically in a stirred-tank system. This liquid phase reaction occurs at constant volume in a 380 litre reactor. The reaction can be considered to be first order and irreversible with rate constant given by

$$k = 2.4 \times 10^{15} \exp^{-11,000/T} \ (\text{min}^{-1}).$$

Where T is in Kelvin. Using the information below, derive a transfer function relating the exit temperature T to the inlet concentration C_{Ai}. State any assumptions that you make. Simplify the transfer function by making a first-order approximation and show that the approximation is valid by comparing the step response of both the original and the approximate models. Available information:-

[i] Nominal steady-state conditions are:-

$$\bar{T} = 65°C \ , \quad \bar{C}_{Ai} = 12.8 \text{ gmol/liter}$$

$$q = 75 \text{ liter/min} = \text{flow rate in and out of the reactor}$$

[ii] Physical property data for the mixture at the nominal steady state,
$C_p = 3.35$ J/g°C , $\rho = 833$ g/liter, $-\Delta H_R = 1.1$ kJ/gmol

[20 marks]

...8/-

[b] A block diagram of a closed-loop system is shown in Figure Q.3.

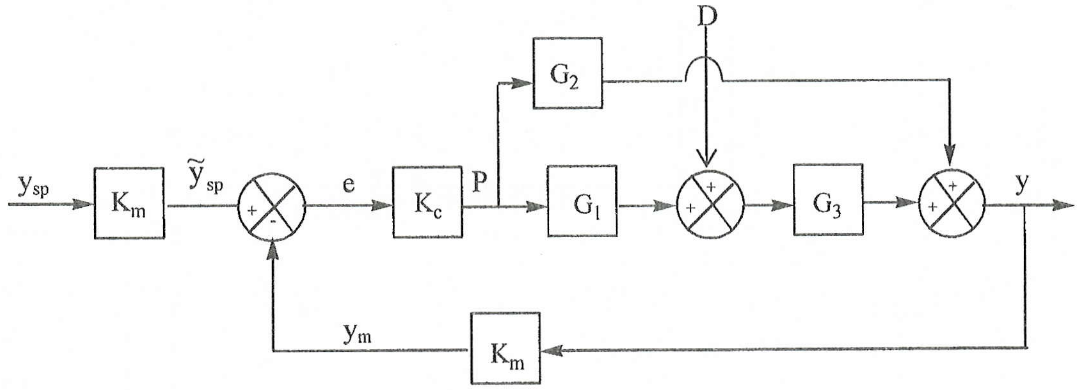


Figure Q.3.: Block diagram of closed-loop system

Derive a closed-loop transfer function for disturbance changes, $\dfrac{Y(s)}{D(s)}$.

[5 marks]

3. *[a]* *Satu tindakbalas eksotermik, $A \rightarrow 2B$, berlaku secara adiabatik di dalam sistem tangki teraduk. Tindakbalas fasa cecair ini berlaku di dalam reaktor berisipadu tetap 380 L. Tindakbalas tesebut boleh dianggap sebagai tindakbalas tertib pertama dan tidak berbalik dengan pemalar kadar diberikan oleh:-*

$$k = 2.4 \times 10^{15} \exp^{-11,000/T} (min^{-1}).$$

Di mana T dalam Kelvin. Dengan menggunakan maklumat di bawah, terbitkan satu rangkap pindah menghubungkan suhu keluar T dengan kepekatan masukan C_{Ai}. Nyatakan sebarang anggapan yang anda buat. Ringkaskan rangkap pindah tersebut dengan penghampiran tertib pertama dan tunjukkan bahawa penghampiran tersebut adalah sah dengan membandingkan sambutan langkah bagi kedua-dua model asal dan penghampiran. Maklumat diberi:-

[i] *Keadaan-keadaan pada keadaan mantap ialah:-*

$$\bar{T} = 65°C, \quad \bar{C}_{Ai} = 12.8 \text{ gmol/liter}$$

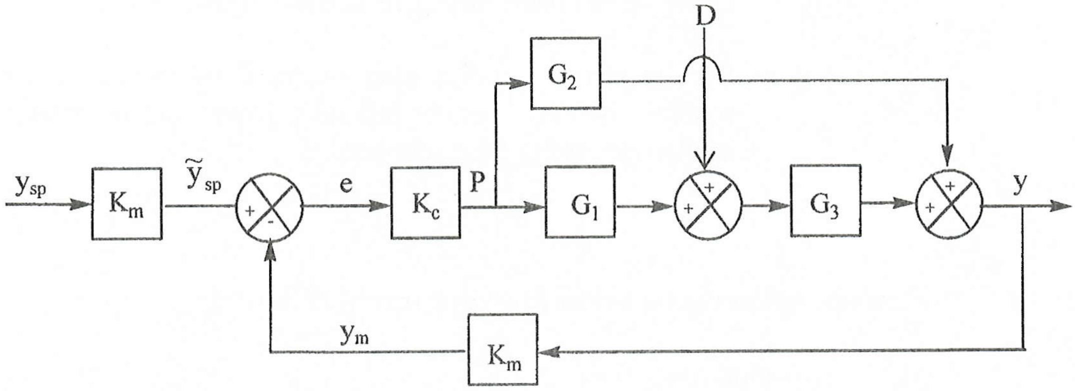
q = 75 liter/min = kadar aliran masuk dan keluar bagi reaktor

[ii] *Data sifat fizik bagi campuran pada keadaan mantap:-*
$C_p = 3.35\ J/g^oC$, $\rho = 833$ g/liter, $-\Delta H_R = 1.1$ kJ/gmol

[20 markah]

...9/-

[b] *Satu gambarajah blok bagi satu sistem gelung tertutup ditunjukkan dalam Rajah S.3.*



Rajah S.3: Gambarajah blok bagi sistem gelung tertutup.

Terbitkan satu rangkap pindah gelung tertutup bagi perubahan gangguan, $\frac{Y(s)}{D(s)}$.

[5 markah]

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

4. Considered the following control schemes

[a] Feedback control

[i] Describe the basic objective of this control scheme.

[ii] Draw a block diagram representation of the control scheme.

[iii] Give a process engineering example where the use of this control scheme would be beneficial. Draw a diagram showing the implementation of the scheme.

[9 marks]

[b] Feedforward control

[i] Describe the basic objective of this control scheme.

[ii] Draw a block diagram representation of the control scheme.

[iii] Give a process engineering example where the use of this control scheme would be beneficial. Draw a diagram showing the implementation of the scheme.

[9 marks]

...10/-

[c] Ratio control

[i] Describe the basic objective of this control scheme.

[ii] Give a process engineering example where the use of this control scheme would be beneficial. Draw a diagram showing the implementation of the scheme.

[7 marks]

4. *Pertimbangkan skema kawalan proses seperti di bawah:*

[a] Kawalan Suap Balik

[i] Huraikan apakah objektif asas skema kawalan ini.

[ii] Lukiskan gambarajah blok mewakili skema kawalan ini.

[iii] Berikan satu contoh kejuruteraan proses di mana skema kawalan ini akan mendatangkan manfaat. Lakarkan gambarajah yang menunjukkan perlaksanaan skema kawalan ini.

[9 markah]

[b] Kawalan Suap Depan

[i] Huraikan apakah objektif asas skema kawalan ini.

[ii] Lukiskan gambarajah blok mewakili skema kawalan ini.

[iii] Berikan satu contoh kejuruteraan proses di mana skema kawalan ini akan mendatangkan manfaat. Lakarkan gambarajah yang menunjukkan perlaksanaan skema kawalan ini.

[9 markah]

[c] Kawalan Nisbah

[i] Huraikan apakah objektif asas skema kawalan ini.

[ii] Berikan satu contoh kejuruteraan proses di mana skema kawalan ini akan mendatangkan manfaat. Lakarkan gambarajah yang menunjukkan perlaksanaan skema kawalan ini.

[7 markah]

5. [a] Describes the experimental procedure known as an open loop step test. Detail how you would obtain the parameter of a first order plus dead time transfer function model using data obtained from an open loop step test on a process plant.

[10 marks]

[b] Estimate the effective dead time, time constant and gain based on the method stated in (a) based on the open loop response shown in Figure Q. 5 below after 5% step changed on the control valve opening at t = 0. Indicates the units of the dead time, time constant and gain. **Please attach Appendix A as part of your answer.**

[6 marks]

[c] Describe the Ziegler-Nichols continuous cycling method for tuning a proportional-intergral-derivatives controller (PID). Your explanation should detail:

[i] The experimental method

[ii] The rules for determination of the controller parameters

[iii] The advantages and disadvantages of the method

[9 marks]

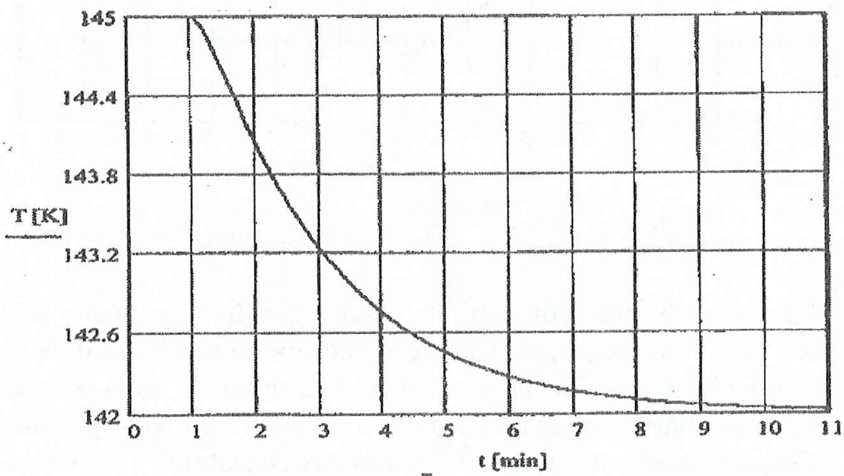


Figure Q.5.: Open loop response

5. *[a] Huraikan tatacara eksperimen yang dikenali sebagai ujian langkah gelung terbuka. Terangkan secara terperinci bagaimana parameter bagi model rangkap pindah tertib pertama dengan masa lengah diperolehi melalui ujian langkah gelung terbuka untuk loji proses.*

[10 markah]

[b] Anggarkan masa lengah efektif, pemalar masa dan gandaan berdasarkan kaedah yang dinyatakan di [a] melalui tindakbalas gelung terbuka yang ditunjukkan di Gambarajah S.5 selepas perubahan langkah sebanyak 5 % bagi injap kawalan yang terbuka pada masa t = 0. Nyatakan unit untuk masa lengah yang efektif, pemalar masa dan gandaan. ***Sila kepilkan graf di Lampiran A bersama buku jawapan anda sebagai sebahagian daripada jawapan anda.***

[6 markah]

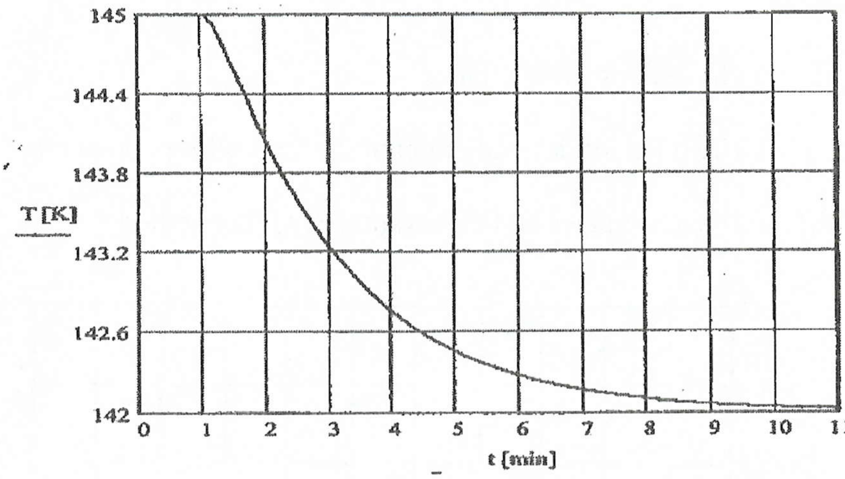
[c] *Huraikan kaedah kitaran selanjar Ziegler-Nichols bagi penalaan pengawal kadaran-kamiran-bezaan (PID). Penerangan anda hendaklah memperincikan:*

[i] *Kaedah ujikaji*

[ii] *Kaedah untuk menentukan parameter pengawal*

[iii] *Kelebihan dan kekurangan kaedah tersebut*

[9 markah]



Gambarajah S.5.: Tindakbalas gelung terbuka

6. [a] PID control is the industrial standard algorithm and many alternative tuning procedures has been proposed to determine the best possible method to get a reasonable setting for the controller. The methods aims is to satisfy a variety of a quantitative performance measure. Described what you understand by the following performance measure and gives examples of output loops where they would be useful indicators of performance

[i] Decay ratio

[ii] Settling time

[iii] Rise time

[12 marks]

[b] Cascade control schemes are commonly found in process plant.

[i] With the aid of a process example, describe the structure of the cascade control.

[ii] With reference to the example, draw the block diagram of the proposed cascade control scheme and explain how the cascade control strategy gives superior performance compare to a single feedback control loop.

[iii] What are the steps involved in tuning the two controllers within the cascade controller.

[13 marks]

6. [a] *Kawalan PID adalah algoritma piawai industri dan pelbagai kaedah penalaan telah dicadangkan bagi menentukan kaedah terbaik untuk mencari nilai parameter pengawal. Kaedah tersebut diperkenalkan adalah bertujuan untuk memuaskan pelbagai ukuran prestasi kuantitatif. Huraikan apakah yang anda fahami mengenai ukuran prestasi di bawah dan berikan contoh gelung keluaran di mana ianya akan menjadi petunjuk prestasi yang berguna*

[i] *Nisbah reputan*

[ii] *Masa penetapan*

[iii] *Masa naik*

[12 markah]

[b] *Skema kawalan lata biasanya dijumpai di loji proses.*

[i] *Dengan bantuan satu contoh proses, huraikan struktur kawalan lata.*

[ii] *Merujuk kepada contoh di atas, lakarkan gambarajah blok bagi skema kawalan lata yang dicadangkan dan terangkan bagaimana strategi kawalan lata memberikan prestasi yang lebih baik dibandingkan dengan gelung kawalan suap balik tunggal.*

[iii] *Apakah langkah-langkah yang terlibat dalam penalaan dua pengawal bagi pengawal lata.*

[13 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.

Lampiran A