UNIVERSITI SAINS MALAYSIA

First Semester Examination
Academic Session 2008/2009

November 2008

EKC 361 – Process Dynamics and Control
[Kawalan Dinamik dan Proses]

Duration : 3 hours
[Masa : 3 jam]

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

[Sila pastikan bahawa kertas peperiksaan ini mengandungi SEPULUH muka surat yang bercetak dan DUA 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 the question 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] Briefly define the following terms: -
Takrifkan secara ringkas sebutan-sebutan berikut: -

[i] Underdamped and overdamped process
Proses kurang redam dan teredam lebih

[ii] Step and ramp input
Masukan langkah dan tanjakan

[iii] Time delay
Masa lengah

[iv] Reverse-acting and direct-acting controller
Pengawal tindakan-balikan dan tindakan-terus

[v] Servo and regulator problem
Masalah servo and pengatur

[5 marks/markah]

[b] A process furnace heats a process stream from near ambient temperature to a desired temperature of 300°C. The process stream outlet temperature is regulated by manipulating the flow rate of fuel gas to the furnace, as shown in Figure Q.1. [b].
Satu relau memanaskan satu aliran proses daripada suhu hampir persekitaran ke suhu yang diingini iaitu 300°C. Suhu aliran keluar tersebut diatur dengan mengolah kadar aliran gas bahan api kepada relau tersebut seperti yang ditunjukkan dalam Rajah S.1.[b]

[i] Discuss the objectives of this control strategy.
Bincangkan objektif-objektif strategi kawalan tersebut.

[ii] What is the measured output?
Apakah keluaran terukur?

[iii] What is the manipulated input?
Apakah masukan olahan?

[iv] What are possible disturbances?
Apakah gangguan-gangguan yang mungkin?

[v] Is this a continuous or batch process?
Adakah proses ini berterusan atau kelompok?

[vi] Is this a feed-forward or feedback controller?
Adakah ia pengawal suap-depan atau suap-balik?

[vii] Draw the control block schematic diagram and label all signals and blocks on the diagram.
Lukis gambarajah skema blok kawalan dan tandakan semua isyarat dan blok dalam gambarajah tersebut.

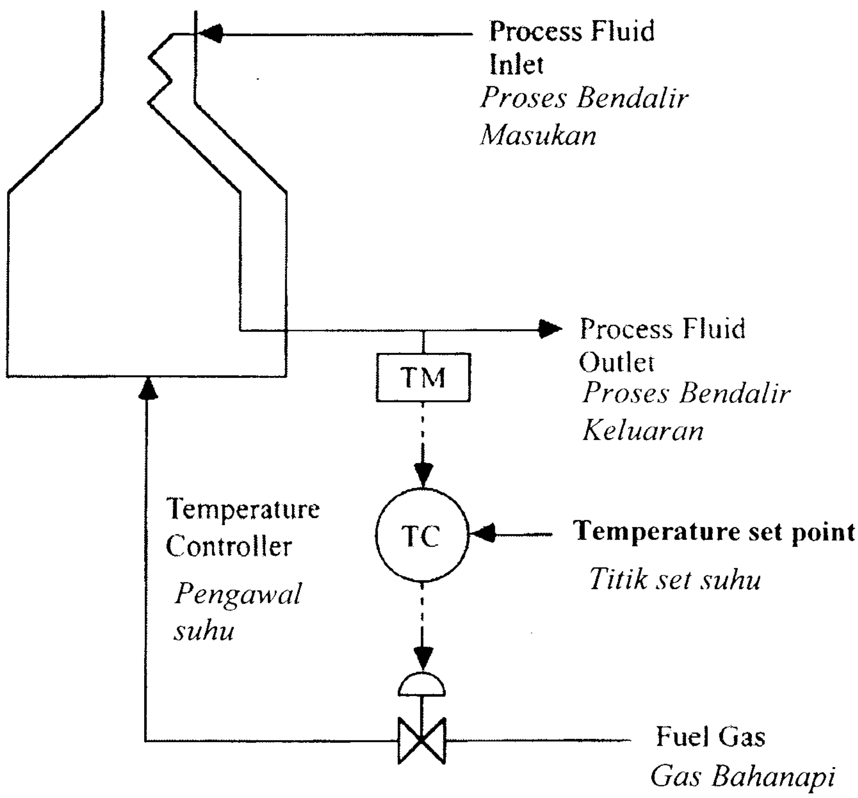

Figure Q.1. [b]: Furnace
Rajah S.1.[b]: Relau

[10 marks/markah]

[c] The parallel form of the PID controller has the transfer function given by:
Bentuk selari pengawal PID mempunyai rangkap pindah:

$$\frac{P'(s)}{E(s)} = K_c\left[1 + \frac{1}{\tau_I s} + \tau_D s\right]$$

Many commercial analog controllers can be described by the series form given by:
Banyak pengawal analog komersil boleh diwakili dalam bentuk siri iaitu:

$$\frac{P'(s)}{E(s)} = K_c\left(\frac{\tau_I s + 1}{\tau_I s}\right)\left(\frac{\tau_D s + 1}{\alpha\tau_D s + 1}\right)$$

[i] For the simplest case, $\alpha \rightarrow 0$, find the relations between the settings (K_c, τ_I, τ_D) for the parallel and the series form.
Bagi kes yang paling ringkas, $\alpha \rightarrow 0$, cari hubungan-hubungan di antara parameter (K_c, τ_I, τ_D) bagi bentuk selari dan siri.

[ii] Does the series form make each controller settings (K_c, τ_I, τ_D) larger or smaller than would be expected for the parallel form?

Adakah bentuk siri membuatkan setiap set pengawal (K_c, τ_I, τ_D) lebih besar atau lebih kecil daripada yang dijangkakan bagi bentuk selari?

[iii] What are the magnitudes of these interaction effects for $K_c = 4$, $\tau_I = 10$ min, $\tau_D = 2$ min?

Apakah magnitud bagi kesan interaksi bagi $K_c = 4$, $\tau_I = 10$ min, $\tau_D = 2$ min?

[iv] What can you say about the effect of non-zero α on these relations?

Apakah yang boleh anda katakan tentang kesan bukan sifar, α terhadap hubungan-hubungan ini?

[10 marks/markah]

2. [a] A second-order process with one pole at the origin has a transfer function:

Proses tertib kedua dengan satu kutub pada asalan mempunyai rangkap pindah:

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

Find the output as a function of time, for a unit step input change. Sketch the expected behavior.

Carikan keluaran sebagai fungsi masa bagi perubahan satu unit langkah masukan. Lakarkan kelakuan yang dijangkakan.

[10 marks/markah]

[b] As a process engineer, you decide to develop a first-order plus time delay model of a process using a step test. The process is initially at steady state, with an input flow rate of 5 gpm and an output of 0.75 mol/L. You make a step increase of 0.5 gpm at 3:00 p.m. and do not observe any changes until 3:07 p.m. At 3:20 p.m., the value of the output is 0.8 mol/L. You become distracted and do not have a chance to look at the output variable again, until you leave for happy hour at a local watering hole at 6:30 p.m. You note that the output has ceased to change and has achieved a new steady-state value of 0.85 mol,/L. What are the values of the process parameters, with units? Show your calculations.

Sebagai seorang jurutera proses, anda membuat keputusan untuk membina satu model tertib pertama dengan masa lengah bagi satu proses menggunakan satu ujian langkah. Proses tersebut pada awalnya dalam keadaan mantap dengan kadar aliran masukan 5 gpm dan keluaran 0.75 mol/L. Pada jam 3.00 p.m., anda melakukan penambahan langkah sebanyak 0.5 gpm dan anda perhatikan tiada sebarang perubahan sehingga jam 3:07 p.m. Pada jam 3:20 p.m., nilai keluaran ialah 0.8 mol/L. Anda rasa terganggu dan tiada peluang melihat pembolehubah keluaran tersebut sehingga anda pergi berehat di bilik rehat pada jam 6:30 p.m. Anda dapati bahawa keluaran telah berhenti berubah dan mencapai keadaan mantap yang baru iaitu pada nilai 0.85 mol/L. Apakah nilai-nilai proses parameter dengan unitnya? Tunjukkan pengiraan anda.

[10 marks]

[c] Match the transfer functions with the responses to a unit step input, shown in Figure Q.2. [c].

Padankan rangkap-rangkap pindah dengan sambutan-sambutan terhadap satu unit langkah masukan seperti ditunjukkan dalan Rajah S.2.[c].

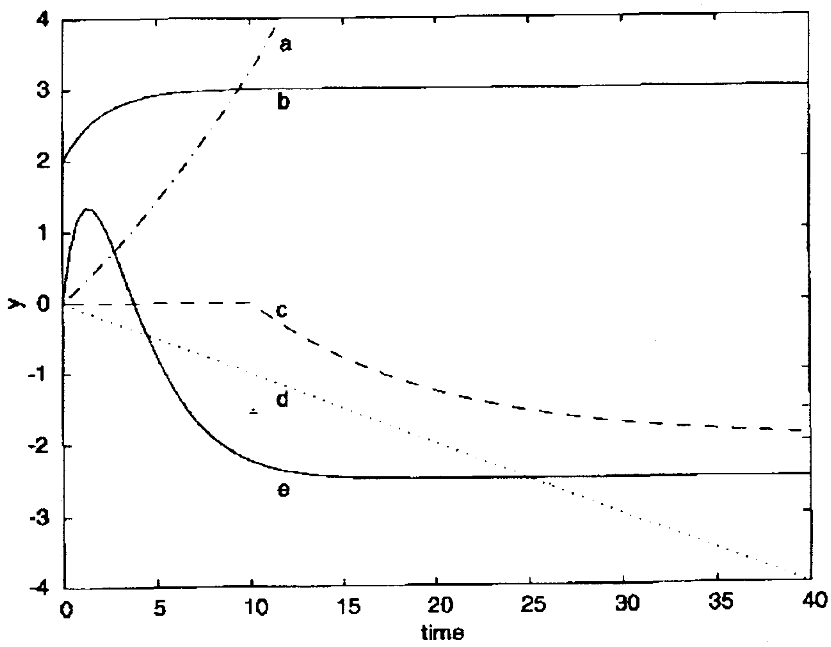

Figure Q.2. [c] : Responses to a unit step input
Rajah S.2.[c]: Sambutan kepada satu unit langkah masukan

[i] $\dfrac{-2.5(-4s+1)}{4s^2+4s+1}$

[ii] $\dfrac{-2e^{-10s}}{10s+1}$

[iii] $\dfrac{-5}{-20s+1}$

[iv] $\dfrac{-0.1}{s}$

[v] $\dfrac{4s+3}{2s+1}$

[5 marks/markah]

3. [a] Process wastewater (density = 1000 kg/m^3) flows at 500 m^3/h into a holding pond with a volume of 5000 m^3 and then flows from the pond to a river. Initially, the pond is at steady state with a negligible concentration of pollutants [x(0) = 0].

Because of a malfunction in the wastewater treating process, the concentration of pollutants in the inlet stream suddenly increases to 500 ppm (kg of pollutant per million kg of water) and stays constant at that value.

Air sisa proses (ketumpatan = 1000 kg/m^3) mengalir pada 500 m^3/jam ke dalam satu kolam penahan yang berisipadu 5000 m^3 dan kemudiannya mengalir ke sebuah sungai. Pada awalnya, kolam tersebut berada pada keadaan mantap dengan kepekatan pencemar boleh diabaikan [x(0) = 0]. Disebabkan kegagalan proses perawatan air sisa, kepekatan pencemar dalam aliran masukan meningkat secara tiba-tiba kepada 500 ppm (kg pencemar per juta kg air) dan kekal pada nilai tersebut.

[i] Assuming a perfectly mixed pond, obtain the transfer function of the pollutant concentration in the outlet stream to the concentration of the inlet stream, and determine for how long the process malfunction can go undetected before the outlet concentration of pollutants exceeds the regulated maximum value of 350 ppm.

Anggap kolam bercampur secara sempurna, dapatkan rangkap pindah bagi kepekatan pencemar dalam aliran keluar terhadap kepekatan pencemar pada aliran masuk dan tentukan berapa lamakah masa diambil dari mula kegagalan proses sehingga kepekatan keluaran melebih nilai maksimum 350 ppm.

[ii] Repeat part [i], assuming that the water flows in plug flow (without mixing) through the pond. Note that this means the pond behaves as a pipe and the response of the concentration is a pure transportation lag.

Ulangi bahagian [i], anggap air mengalir dalam aliran palam (tanpa bercampur)- melalui kolam tersebut. Keadaan ini bermaksud, kolam bertindak seperti satu paip dan sambutan terhadap kepekatan adalah masa lengah tulen.

[iii] In both parts [i] and [ii], it is assumed that the entire volume of the pond is active. How would your answers be affected if portions of the pond were stagnant and were not affected by the flow of water in and out?

Dalam kedua-dua bahagian [i] dan [ii], kesemua isipadu kolam dianggap aktif. Bagaimanakah kesan terhadap jawapan anda jika sebahagian daripada kolam tersebut adalah tidak aktif dan tidak dipengaruhi oleh aliran air masuk dan keluar?

[12 marks/markah]

[b] As a newly hired engineer of one company, you are trying to make a reputation in the Process Control Group. However, this objective turns out to be a real challenge with Mr. Ramli as your supervisor. At lunch one day, Mr. Ramli declares that a simple second-order process with a PI controller will always have a stability upper limit on K_c, that is, K_c is limited for all values of $\tau_I > 0$. His best argument is that the open-loop process with the controller is third order. Furthermore, he claims that any critically damped second-order process will show he is right. You leave his office and quickly investigate the properties of

Sebagai jurutera baru dalam sebuah syarikat, anda cuba untuk membuat reputasi bagi Kumpulan Kawalan Proses. Walau bagaimanapun, objektif ini bertukar menjadi cabaran dengan penyelia anda, En Ramli. Pada satu hari, semasa makan tengahari, En Ramli mengisytiharkan bahawa proses tertib kedua dengan pengawal PI akan sentiasa mempunyai had atas kestabilan pada K_c, *iaitu* K_c *dihadkan bagi semua nilai* $\tau_I > 0$. *Alasan terbaik beliau ialah proses gelung terbuka dengan pengawal adalah tertib ketiga. Beliau juga menyatakan bahawa sebarang proses teredam kritikal akan menyokong kenyataan beliau. Anda meninggalkan meja makan tersebut dan segera menyiasat ciri-ciri*

$$GvGpGm = \frac{5}{(10s+1)^2}$$

[i] What are the necessary and sufficient conditions for closed-loop stability for a PI controller?

Apakah syarat-syarat yang diperlukan bagi kestabilan gelung tertutup bagi pengawal PI?

[ii] From these conditions, can you find a relationship for τ_I in terms of K_c that will guarantee stability? Show the stability region in a plot of τ_I versus K_c.

Daripada syarat-syarat ini, carikan hubungan bagi τ_I *dalam sebutan* K_c *yang menjamin kestabilan? Tunjukkan kawasan kestabilan dalam plot* τ_I *melawan* K_c.

[iii] Do some values of τ_I guarantee stability for all values of K_c? If so, what is the smallest value?

Adakah nilai-nilai tertentu bagi τ_I *yang menjamin kestabilan bagi semua nilai* K_c*? Jika ada, apakah nilai yang paling kecil?*

[13 marks/markah]

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

4. [a] Even though frequency response (FR) analysis is not generally used by industrial process control engineers, why is frequency response analysis important to the understanding of feedback systems?

Walaupun analisis sambutan frekuensi biasanya tidak digunakan oleh jurutera kawalan proses di industri, tetapi mengapa analisis sambutan frekuensi begitu penting dalam mengenali sistem suapbalik?

[5 marks/markah]

[b] Frequency response testing on open loop process yielded the following data:

Sambutan frekuensi terhadap proses gelung terbuka telah menghasilkan data berikut:

Frequency (rad/time) *Frekuensi (rad/masa)*	AR(dB) *AR(dB)*	Phase-shift (deg) *Fasa anjakan (darjah)*
0.01	3.35	-14.17
0.02	2.88	-27.53
0.03	2.19	-39.56
0.04	1.37	-50.12
0.06	-0.35	-67.38
0.11	-4.14	-97.07
0.16	-6.99	-118.48
0.21	-9.18	-136.77
0.26	-10.96	-153.60
0.31	-12.44	-169.65
0.36	-13.71	-185.23
0.41	-14.82	-200.50
0.46	-15.80	-215.58
0.51	-16.69	-230.50
0.56	-17.50	-245.33
0.61	-18.23	-260.07
0.66	-18.91	-274.74
0.71	-19.55	-289.37
0.76	-20.13	-303.96
0.81	-20.68	-318.52
0.86	-21.20	-333.04
0.91	-21.69	-347.55
0.96	-22.16	-362.04

[i] Comment briefly on the structure of the process
Secara ringkas, komen tentang struktur proses tersebut.

[5 marks/markah]

[ii] What are the gain and phase margin of the open loop system when the following controller is placed in series with the above process
Apakah perolehan dan fasa susur sistem tersebut bila pengawal berikut diletakkan secara bersiri dengan proses yang dinyatakan di atas,

$$Gc(s) = 2\left[1 + \frac{1}{10s}\right]$$

[15 marks/markah]

5. [a] Write a short notes describing each of the following
Tuliskan secara ringkas setiap perkara yang tertera di bawah

[i] An experimental procedure that may be used to determine the parameter of a first order plus dead time process transfer function
Kaedah ujikaji yang boleh diguna untuk menentukan parameter tertib pertama dengan masa lengahan

[5 marks/markah]

[ii] Ratio control
Kawalan nisbah

[2 marks/markah]

[iii] Cascade control
Kawalan lata

[2 marks/markah]

Draw a sketch to illustrate your answer
Lukiskan lakaran untuk menjelaskan jawapan anda

[b] Draw a block diagram of a closed loop control system that is design to control the temperature in the reactor by varying the cooling water flow to the jacket. Include in your diagram blocks describing the dynamics characteristic of the

Lukiskan gambarajah blok bagi rangkap pindah gelung tertutup yang dibina untuk mengawal suhu di dalam reaktor dengan mempelbagaikan kadar aliran air penyejuk ke dalam jaket. Sila masukkan ciri-ciri dinamik berikut dalam gambarajah blok yang anda lukis:

[i] Controller
Pengawal

[ii] Valve
Injap

[iii] Thermocouple
Pengganding suhu

[iv] Process
Proses

[6 marks/markah]

[c] If cooling water supply pressure was found to upset the closed loop system, where would you add this influence in your diagram? Explain on how this new control schemes can improve or overcome the instability in closed loop process?

Jika tekanan air penyejuk didapati akan mengganggu kestabilan sistem gelung tertutup, di manakah anda akan masukkan gangguan ini dalam gambarajah blok anda? Terangkan bagaimana skema kawalan baru anda akan memperbaiki atau mengatasi ketidakstabilan proses gelung tertutup?

[10 marks/markah]

6. [a] What is the characteristics equation of a feedback loop and what is its significance?

Apakah persamaan ciri gelung suapbalik dan mengapa ia begitu bererti?

[3 marks/markah]

[b] To apply the Cohen Coon method, what information about the process is required? Please briefly explain your answer.

Untuk menggunakan kaedah Cohen Coon, apakah maklumat tentang proses yang diperlukan? Sila terangkan dengan ringkas jawapan anda.

[3 marks/markah]

...10/-

[c] Derive the closed loop equation that describes how the process output responds to a change in setpoint (servo control). Gp(s) is the process dynamics while the Gc(s) is the controller dynamics.

Terbitkan rangkap pindah gelung tertutup yang menghuraikan bagaimana proses keluaran bertindak bila titik set berubah (kawalan servo). Gp(s) ialah proses dinamik manakala Gc(s) adalah pengawal dinamik.

[3 marks/markah]

[d] [i] If the process dynamics and the controller dynamics are represented by the following transfer function

Jika proses dan pengawal dinamik diwakili oleh rangkap pindah seperti yang ditunjukkan di bawah

$$Gp(s) = \frac{3}{5s+1}, Gc(s) = 0.5\left(1 + \frac{1}{10s}\right)$$

By substitution into the closed loop transfer function find the actual transfer function describing how the process responds to a change in setpoint for servo control.

Dengan menggantikannya ke dalam rangkap pindah gelung tertutup, cari rangkap pindah sebenar yang menerangkan bagaimana tindakbalas proses terhadap perubahan di titik set.

[3 marks/markah]

[ii] Sketch the response characteristic of the process output with respect to time when subject to a unit change in setpoint.

Lakarkan ciri sambutan proses keluaran dengan masa yang dirujuk kepada satu unit perubahan di titik set.

[3 marks/markah]

[iii] If the desired response is:

Jika sambutan yang dikehendaki ialah:

$$\frac{Y(s)}{SP(s)} = \frac{1}{5s+1}$$

use the tuning method to obtain the settings of an ideal proportional-integral controller.

gunakan kaedah penalaan untuk mendapatkan tetapan bagi pengawal kadaran-kamiran (PI) yang unggul.

[10 marks/markah]

- 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. $\frac{1}{b_1-b_2}(e^{-b_2t}-e^{-b_1t})$		$\frac{1}{(s+b_1)(s+b_2)}$
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. $1+\frac{1}{\tau_2-\tau_1}(\tau_1 e^{-t/\tau_1}-\tau_2 e^{-t/\tau_2})$ $(\tau_1\neq\tau_2)$		$\frac{1}{s(\tau_1 s+1)(\tau_2 s+1)}$
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. $1+\frac{\tau_3-\tau_1}{\tau_1-\tau_2}e^{-t/\tau_1}+\frac{\tau_3-\tau_2}{\tau_2-\tau_1}e^{-t/\tau_2}$ $(\tau_1\neq\tau_2)$		$\frac{\tau_3 s+1}{s(\tau_1 s+1)(\tau_2 s+1)}$
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.

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 controller (PID): $G_c(s) = K_c\left(1 + \frac{1}{\tau_I s} + \tau_D s\right)$