UNIVERSITI SAINS MALAYSIA

Second Semester Examination
2015/2016 Academic Session

June 2016

ESA 251/3 – Control System Theory
[Teori Sistem Kawalan]

Duration : 3 hours
Masa : 3 jam

Please check that this paper contains **THIRTEEN (13)** printed pages included **TWO (2)** pages appendix and **FOUR (4)** questions before you begin the examination.

*Sila pastikan bahawa kertas soalan ini mengandungi **TIGA BELAS (13)** mukasurat bercetak termasuk **DUA (2)** mukasurat lampiran dan **EMPAT (5)** soalan sebelum anda memulakan peperiksaan.*

Instructions : Answer **ALL** questions.

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

Appendix/*Lampiran*:

1. Appendix A : Laplace transform table. [**1 page**/*mukasurat*]
   Lampiran A : Jadual Laplace transform.
2. Appendix B: Second order time domain specification. [**1 page**/*mukasurat*]
   Lampiran B:Spesifikasi domain masa sistem tertib kedua

You may answer all questions in **English** OR **Bahasa Malaysia** OR a **combination of both.**

*Calon boleh menjawab semua soalan dalam **Bahasa Malaysia** ATAU **Bahasa Inggeris** ATAU **kombinasi kedua-duanya.***

Answer to each question must begin from a new page.

Jawapan untuk setiap soalan mestilah dimulakan pada mukasurat yang baru.

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.

1. [a] (i) Briefly explain what is control system?

(2 marks)

(ii) Draw a separate block diagram for open-loop and close-loop systems. State the advantages and the disadvantages of each system.

(4 marks)

(iii) Based on your understanding, propose one example of the actual close-loop system and briefly explain how the system works.

(4 marks)

[b] **Figure 1[b]** shows a mass-spring-damper system for the aircraft's landing gear. D and K_1 represent the suspension system. M_1 and M_2 represent the mass of the aircraft and the suspension itself. K_1 is the spring effect of the tire (assume no friction).

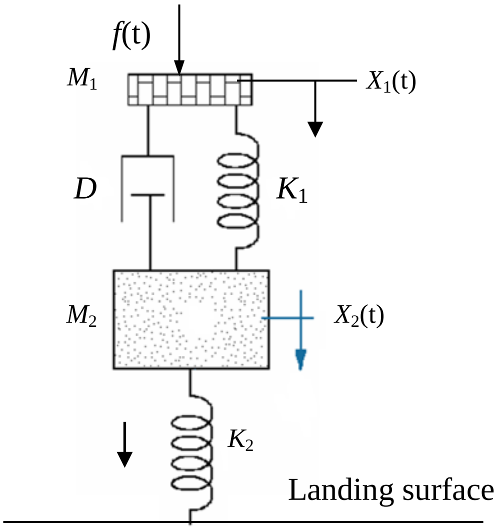


Figure 1[b]

During landing, the force exerted by the mechanism is given by f(t).

Based on the model above,

(i) With the help of free body diagrams, model the system using differential equations based on the motion of M_1 and M_2.

(5 marks)

(ii) Find the transfer function relating the displacement of X_2(s) to the landing force, F(s) (you may use Cramer's rule to solve this).

(5 marks)

(iii) Represent the system in state-space using state equation and output equation.

(5 marks)

2. **Figure 2** represents a block diagram of a control system with gain K_P and a contant K_T .

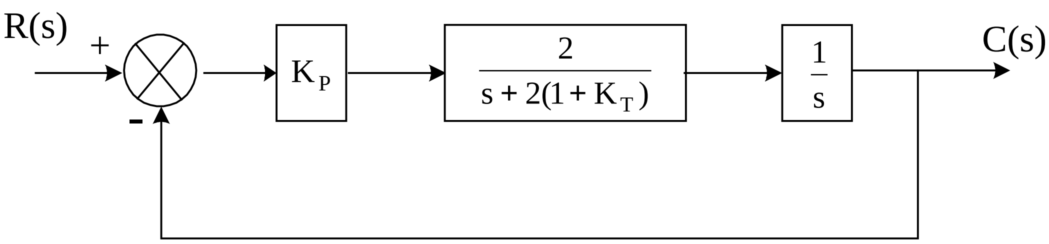


Figure 2

[a] Find the system's transfer function $G(s)$.

(3 marks)

[b] Given, K_T = 2.2, Steady-state error for a unit ramp input, e_{ss} = 0.08
Determine the required value of :

(i) Determine K_P .

(3 marks)

(ii) Find the close-loop transfer function $T(s)$,

(3 marks)

(iii) Natural frequency, ω_n .

(3 marks)

(iv) Damping ratio, ζ .

(3 marks)

Using the values of gain K_P and K_T obtained above, calculate the value of :

(v) The percentage of maximum overshoot, %*C*p.

(3 marks)

(vi) Settling time, t_s (use 5% criteria).

(2 marks)

[c] If a unit step input is applied to the system with K_P = 9 and K_T = 2.

(i) Determine the output response $c(t)$ and sketch the response (you may use partial fraction to solve this).

(3 marks)

(ii) Determine the peak time, t_p.

(2 marks)

3. **Figure 3[a]** shows a transfer function with unity feedback, where *R*(s) and *C*(s) is the system's input and the system's output respectively.

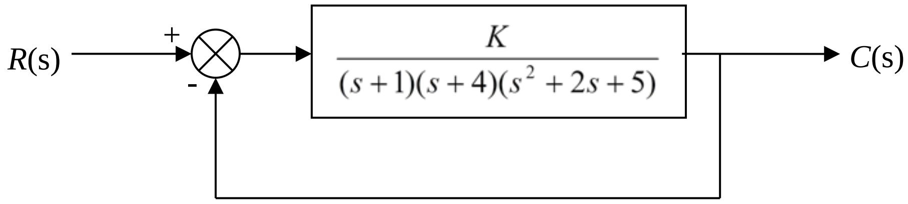


Figure 3[a]

[a] With the help of the plotting rules, sketch the root locus on the graph paper provided as the value of *K* increase from zero to infinity.

(4 marks)

[b] From the root locus, determine:

(i) The angle of departure (θ) from the complex poles.

(3 marks)

(ii) The crossing point on the imaginary axis.

(3 marks)

(iii) The value of gain *K* at the point of imaginary axis crossing.

(3 marks)

(iv) Find the break-away point from the real axis.

(3 marks)

(v) The range of gain *K* to keep the system in stable state.

(3 marks)

[c] **Figure 3[c]** shows four different root locus plots.

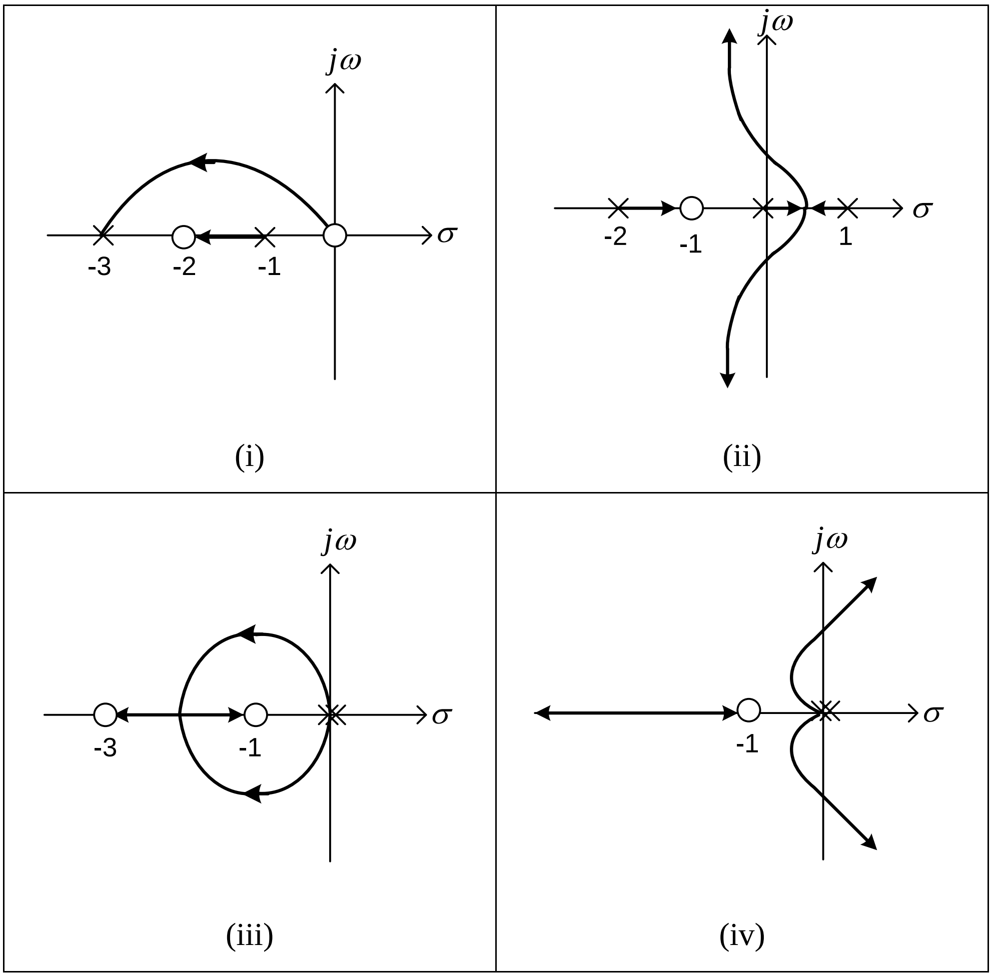


Figure 3[c]

(i) Identify the plot that do not comply with root locus rules and give your reasons.

(2 marks)

(ii) From **Figure 3[c]** (ii), (iii) and (iv) briefly explain the stability behavior of the system as the system's gain (K) increases from zero to infinity.

(4 marks)

4. A system with unity feedback is represented by the following transfer function.

$$G(s) = \frac{K}{s(s+3)(s+20)}$$

From the transfer function,

[a] Construct Bode plot using the $\log_{10}$-scale graph paper provided.

(9 marks)

[b] Find gain margin (GM) and phase margin (ΦM) if K=50.

(4 marks)

[c] Find the value of K to keep the system stable.

(4 marks)

[d] Determine the value of K for gain margin (GM) to be 10 dB.

(4 marks)

[e] Determine the value of K for phase margin (ΦM) to be 50^0

(4 marks)

1. [a] (i) *Terangkan secara ringkas apakah yang dimaksudkan dengan sistem Kawalan?*

(2 markah)

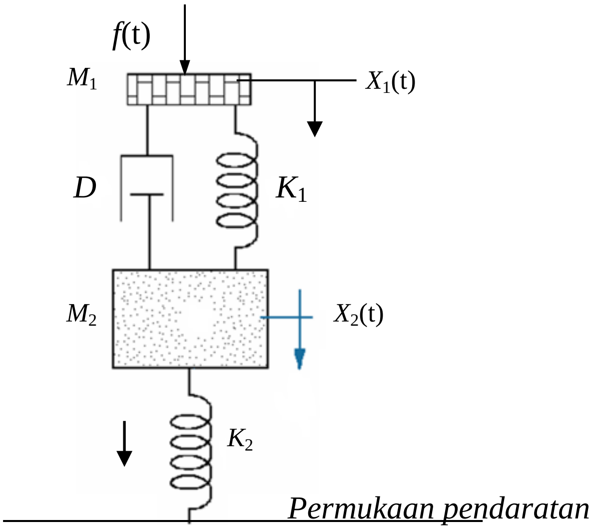
(ii) *Lukiskan gambarajah blok berasingan untuk sistem gelung terbuka dan sistem gelung tertutup. Terangkan kelebihan dan kekurangan sistem masing-masing.*

(4 markah)

(iii) *Berdasarkan pemahaman anda, cadangkan satu contoh sistem gelung tertutup dan terangkan secara ringkas bagaimana ianya berfungsi.*

(4 markah)

[b] ***Rajah 1[b]*** *menunjukkan sistem mass-spring-damper mewakili sistem gantungan pendaratan untuk sebuah pesawat. D dan K_1 mewakili sistem gantungan. M_1 dan M_2 masing-masing merupakan jisim pesawat dan sistem gantungan. Manakala, K_1 pula merupakan kesan spring daripada tayar (anggapkan tiada geseran).*



Rajah 1[b]

(i) *Dengan bantuan gambarajah bebas, dapatkan persamaan-persamaan perbezaan dari sistem tersebut terhadap pergerakan M_1 dan M_2.*

(5 markah)

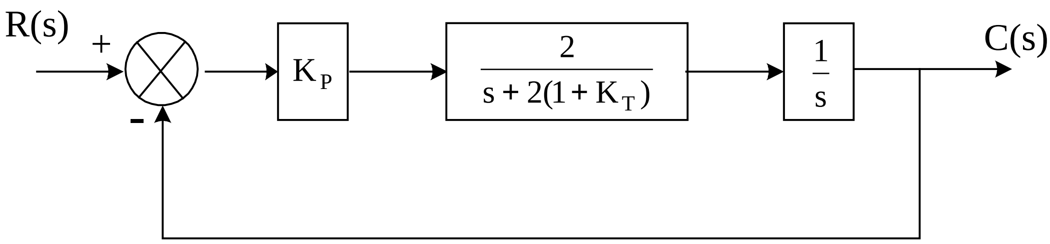
(ii) *Dapatkan rangkap pindah yang menghubungkan sasaran $X_2(s)$ dan daya pendaratan F(s) (anda boleh menggunakan Cramer's rule untuk menyelesaikannya).*

(5 markah)

[iii] *Wakilkan sistem di atas dengan menggunakan state-space dalam bentuk persamaan state dan persamaan keluaran.*

(5 markah)

2. ***Rajah 2*** *menunjukkan sebuah blok diagram untuk sebuah sistem kawalan proses dengan nilai gandaan K_p dan pemalar K_T.*



Rajah 2

[a] *Dapatkan rangkap pindah G(s) untuk sistem tersebut.*

(3 markah)

[b] *Di beri, K_T =2.2,Ralat keadaan mantap untuk masukan unit ramp, ess=0.08, Dapatkan,*

(i) *Nilai K_p.*

(3 markah)

(ii) *Dapatkan rangkap pindah gelung tertutup T(s),*

(3 markah)

(iii) *Frekuensi tabii tanpa redam, ω_n.*

(3 markah)

(iv) *Nisbah redaman, ζ.*

(3 markah)

Menggunakan nilai K_P dan K_T diperolehi di atas, kirakan nilai:

(v) *Peratusan lajakan maksimum,%Cp.*

(3 markah)

(vi) *Masa pengenapan, t_s (use 5% criteria).*

(2 markah)

[c] *Sekiranya sistem dikenakan masukan unit langkah dengan nilai gandaan* $K_P = 9$ *dan* $K_T = 2$,

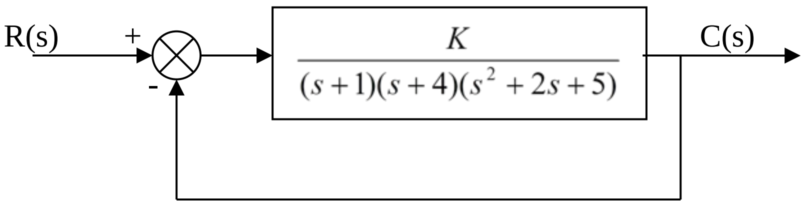
(i) *Dapatkan sambutan keluaran c(t) dan lakarkan sambutan keluaran system (Anda boleh menggunakan metod pecahan separa).*

(3 markah)

(ii) *Tentukan masa puncak,* t_p

(2 markah)

3. ***Rajah 3[a]*** *menunjukkan sebuah rangkap pindah dengan suapbalik uniti untuk sebuah sistem mekanikal dimana, R(s) merupakan masukan kepada sistem dan C(s) merupakan keluarannya.*



Rajah 3[a]

[a] *Berdasarkan syarat-syarat plot, lakarkan root locus di atas kertas graf yang disediakan dengan mengambilkira nilai K berubah dari kosong ke infiniti.*

(4 markah)

[b] *Daripada londar punca tersebut, kira,*

(i) *Sudut berlepas* (θ) *londar punca dari kutub kompleks.*

(3 markah)

(ii) *Titik persilangan londar punca di paksi khayal*

(3 markah)

(iii) *Nilai gandaan K di paksi khayal*

(3 markah)

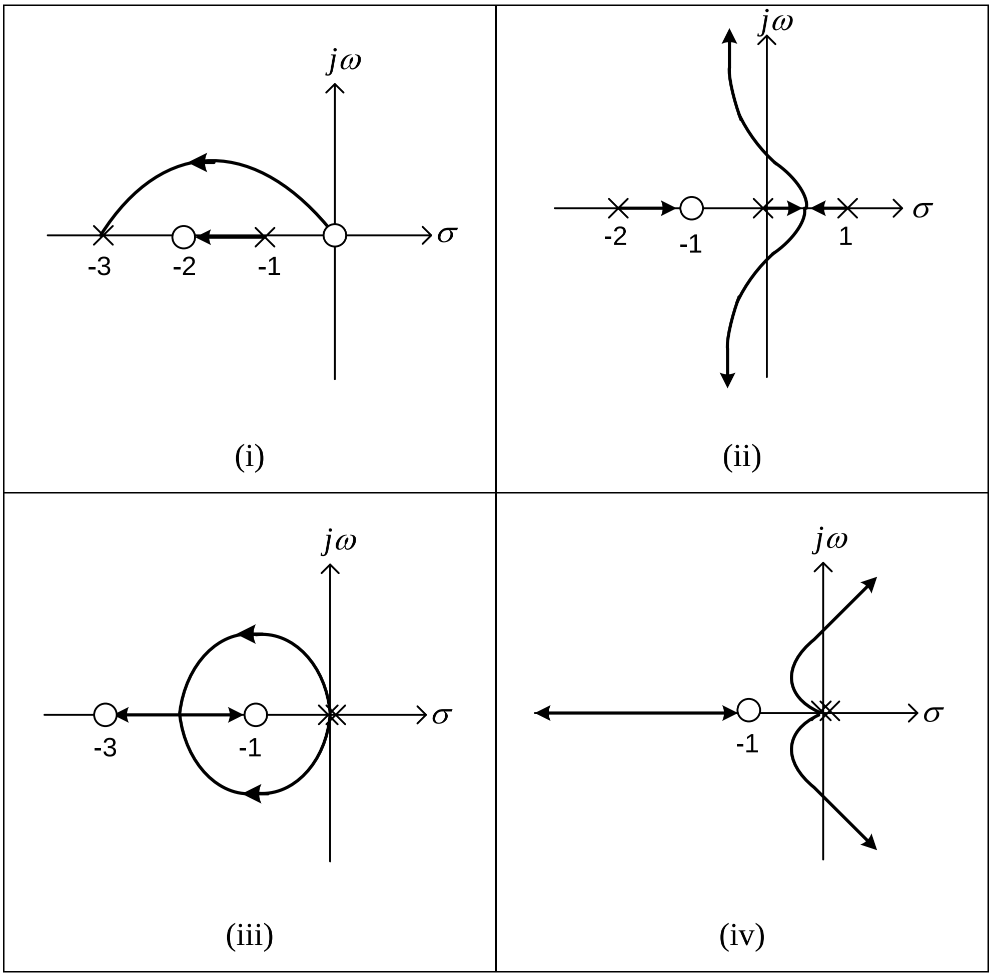
(iv) *Dapatkan titik pecah dari paksi nyata.*

(3 markah)

(v) *Julat gandaan K supaya sistem gelung tertutup adalah stabil*

(3 markah)

[c] ***Rajah 3[c]*** *menunjukkan empat jenis londar punca yang berbeza.*



Rajah 3[c]

(i) *Daripada rajah tersebut, tentukan rajah londar punca yang manakah tidak memenuhi kriteria londar punca dan beri alasan anda.*

(2 markah)

(ii) *Dari* ***Rajah 3[c]*** *(ii), (iii) dan (iv) terangkan secara ringkas kestabilan setiap sistem apabila gandaan (K) diubah dari sifar ke infiniti.*

(4 markah)

4. *Rangkap pindah gelung-buka untuk sistem suapbalik uniti ialah,*

$$\frac{K}{s(s+3)(s+20)}$$

Daripada rangkap pindah di atas,

[a] *Bina Plot Bode menggunakan kertas graf berskala* $\log_{10}$.

(9 markah)

[b] *Tentukan Jidar gandaan (GM) dan jidar fasa* (ΦM) *jika K=50.*

(4 markah)

[c] *Tentukan julat nilai K supaya sistem stabil.*

(4 markah)

[d] *Nilai K untuk jidar gandaan (GM) menjadi 10 dB.*

(4 markah)

[e] *Tentukan nilai K untuk jidar fasa* (ΦM) menjadi 50^0.

(4 markah)

APPENDIX A/ *LAMPIRAN A* : *LAPLACE TRANSFORM TABLE*

Laplace transform	*Time function*	*Description of time function*
1		A unit impulse
$\frac{1}{s}$		A unit step function
$\frac{e^{-st}}{s}$		A delayed unit step function
$\frac{1-e^{-st}}{s}$		A rectangular pulse of duration T
$\frac{1}{s^2}$	t	A unit slope ramp function
$\frac{1}{s^3}$	$\frac{t^2}{2}$	
$\frac{1}{s+a}$	e^{-at}	Exponential decay
$\frac{1}{(s+a)^2}$	te^{-at}	
$\frac{2}{(s+a)^3}$	t^2e^{-at}	
$\frac{a}{s(s+a)}$	$1-e^{-at}$	Exponential growth
$\frac{a}{s^2(s+a)}$	$t-\frac{(1-e^{-at})}{a}$	
$\frac{a^2}{s(s+a)^2}$	$1-e^{-at}-ate^{-at}$	
$\frac{s}{(s+a)^2}$	$(1-at)e^{-at}$	
$\frac{1}{(s+a)(s+b)}$	$\frac{e^{-at}-e^{-bt}}{b-a}$	
$\frac{ab}{s(s+a)(s+b)}$	$1-\frac{b}{b-a}e^{-at}+\frac{a}{b-a}e^{-bt}$	
$\frac{1}{(s+a)(s+b)(s+c)}$	$\frac{e^{-at}}{(b-a)(c-a)}+\frac{e^{-bt}}{(c-a)(a-b)}+\frac{e^{-ct}}{(a-c)(b-c)}$	
$\frac{\omega}{s^2+\omega^2}$	$\sin\omega t$	Sine wave
$\frac{s}{s^2+\omega^2}$	$\cos\omega t$	Cosine wave
$\frac{\omega}{(s+a)^2+\omega^2}$	$e^{-at}\sin\omega t$	Damped sine wave
$\frac{s+a}{(s+a)^2+\omega^2}$	$e^{-at}\cos\omega t$	Damped cosine wave
$\frac{\omega^2}{s(s^2+\omega^2)}$	$1-\cos\omega t$	
$\frac{\omega^2}{s^2+2\zeta\omega s+\omega^2}$	$\frac{\omega}{\sqrt{(1-\zeta^2)}}e^{-\zeta\omega t}\sin[\omega\sqrt{(1-\zeta^2)}t]$	
$\frac{\omega^2}{s(s^2+2\zeta\omega s+\omega^2)}$ with $\zeta<1$	$1-\frac{1}{\sqrt{(1-\zeta^2)}}e^{-\zeta\omega t}\sin[\omega\sqrt{(1-\zeta^2)}t+\phi]$ with $\zeta=\cos\phi$	

APPENDIX B/ *LAMPIRAN B*:

SECOND ORDER TIME DOMAIN SPECIFICATION
(*SPESIFIKASI DOMAIN MASA SISTEM TERTIB KEDUA*)

% Overshoot, (%*Lanjakan Maksimum*) $$\%C_P = 100e^{-\left[\frac{\zeta\pi}{\sqrt{1-\zeta^2}}\right]}$$

Peak Time, *Masa puncak*, $$t_p = \frac{\pi}{\omega_n\sqrt{1-\zeta^2}}$$

Rise time, *Masa menaik*, $$t_r = \frac{\pi - \cos^{-1}\zeta}{\omega_n\sqrt{1-\zeta^2}}$$

Settling time, *Masa pengenapan*, $$t_s = \frac{3}{\zeta\omega_n}$$ (for 5% criteria/ kriteria 5%)

Settling time, *Masa pengenapan*, $$t_s = \frac{5}{\zeta\omega_n}$$ (for 2% criteria/kriteria 2%)

Error Steady State, *Ralat keadaan mantap*, $$e_{ss} = \lim_{s\to 0}\frac{sR(s)}{1+G(s)H(s)}$$

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