UNIVERSITI SAINS MALAYSIA

Second Semester Examination
2015/2016 Academic Session

June 2016

ESA 322/3 – Structural Dynamics
[Dinamik Struktur]

Duration : 3 hours
[Masa : 3 jam]

Please check that this paper contains **THIRTEEN (13)** printed pages included **TWO (2)** pages appendix and **FIVE (5)** questions before you begin the examination.

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

Instructions : Answer **FIVE (5)** questions.

*[**Arahan :** Jawab **LIMA (5)** soalan.]*

Answer to each question must begin from a new page.

[Jawapan untuk setiap soalan mestilah dimulakan pada mukasurat yang baru.]

Appendix/*Lampiran :*

1. Fundamental Equations in Vibration **[1 page**/*mukasurat*]
2. Vibration-Related Formulas **[1 page**/*mukasurat*]

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] Answer the following questions in words. Supplement your answer with diagrams if required.

   (i) What is the meaning of degrees of freedom in structural dynamics?

   (ii) Differentiate between deterministic and un-deterministic vibration system.

   (iii) What is natural frequency and how does it relate to mass and stiffness in a single degree of freedom system?

(30 marks)

   [b] Plot vibration response that illustrates a single degree of freedom system undergoing oscillation for these cases;

   (i) Frequency response for undamped forced vibration.

   (ii) Time response for beating phenomenon.

   (iii) Time response for overdamped system.

   Responses must be plotted on separate axis and label clearly.

(30 marks)

[c] **Figure 1** shows a free response of a single degree of freedom system undergoing decay oscillation due to the existence of viscous damping. Based on **Figure 1** and by using appropriate equations, compute:

(i) Damped natural frequency of the system in rad/s.

(ii) Damping ratio of the system.

(iii) Undamped natural frequency of the system in rad/s.

(iv) Viscous damping coefficient of the system in N-s/m if mass m = 10.0 kg.

(40 marks)

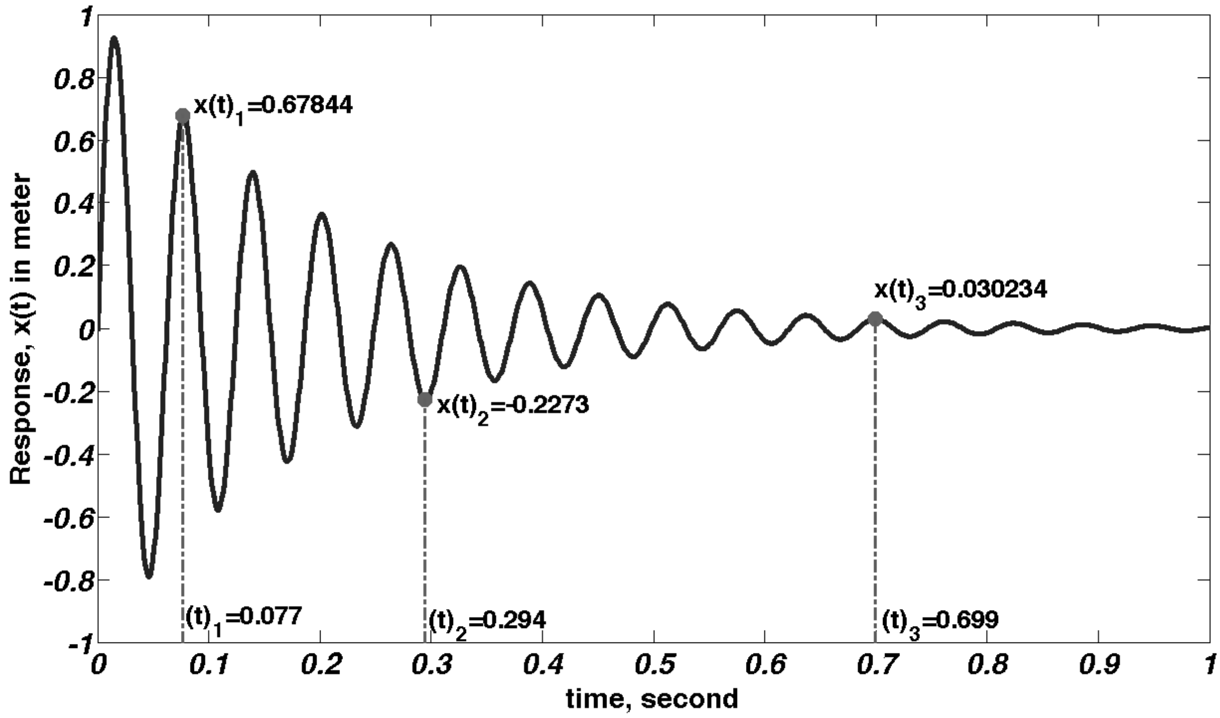


Figure 1

2. [a] Show the solution to the characteristic equation for damped free vibration for a single degree of freedom system is equivalent to

$$\lambda_1 = \omega_n\left(-\zeta + \sqrt{\zeta^2 - 1}\right)$$
$$\lambda_2 = \omega_n\left(-\zeta - \sqrt{\zeta^2 - 1}\right)$$

(50 marks)

[b] A blade of a wind turbine as shown in **Figure 2** has an unbalanced mass of m = 2.5 kg at a distance of e = 0.1 meter from the axis of rotation. The tower height measures 4 meters while the entire nacelle assembly including all the blades has a mass M equal to 300 kg. The tower stiffness is 20 kN/m, and a damping ratio of 0.15. Assuming the tower can only sway horizontally and the blades are spinning, do the following;

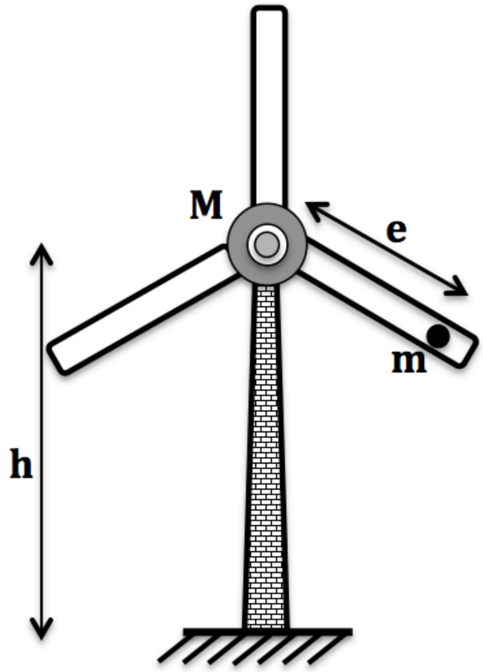


Figure 2

(i) Sketch a dynamic free body diagram of the system.

(10 marks)

(ii) Derive the equation of motion of the system in terms of **M**, **c** and **k** expression **when there is no external force acting on the structure**.

(10 marks)

(iii) Compute the undamped natural frequency of the tower.

(10 marks)

(iv) Describe the trend of the magnification factor of the nacelle assembly if the blades rotational speed increases causing the excitation frequency to be higher than the structure's natural frequency. Provide reasons for your answer.

(20 marks)

3. Consider a two-degree of freedom system shown in **Figure 3**. Given mass, m = 10 kg, the spring stiffness, k = 5 N/m. You are required to;

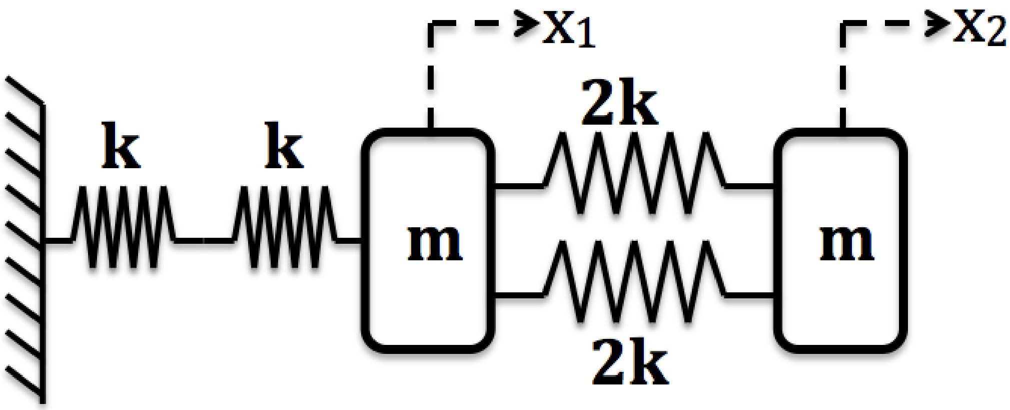


Figure 3

(i) Draw the free body diagram of the system.

(ii) Derive the equation of motion of the system in matrix form.

(iii) Determine the characteristic equation.

(iv) Calculate the natural frequencies.

(v) Calculate and draw the mode shapes.

(100 marks)

4. [a] With the help of Collar's triangle, write short notes on the following aeroelastic phenomena.

(i) Galloping

(ii) Stall flutter

(iii) Bending torsion flutter

(45 marks)

[b] Discuss in detail Vortex lattice aerodynamics model that are used in aeroelastic analysis. What are the strengths and limitations of Vortex Lattice approach?

(55 marks)

5. [a] A typical airfoil section that illustrates a divergence model of a simple wing is shown in **Figure 5**. Derive the expression for divergence dynamic pressure q_D
.

$$q_D = \frac{K}{S\left(\frac{\delta C_L}{\delta \alpha}\right) e}$$

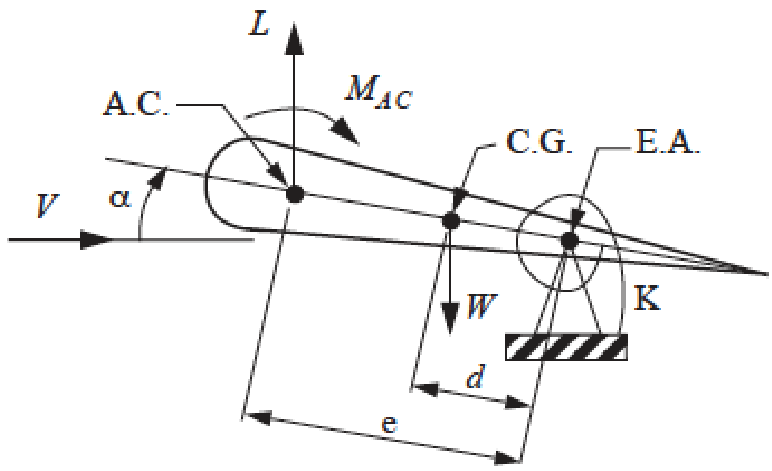


Figure 5

(30 marks)

[b] A new aircraft company is building a light aircraft for recreational purpose. As an aeroelastician at the company, you are tasked with clearing the new aircraft's flutter speed. Develop a **four stage** process for flutter clearance program and explain the objectives and procedures for each stage.

(70 marks)

1. [a] *Berikan jawapan kepada soalan berikut dalam bentuk perkataan. Lengkapkan jawapan dengan rajah jika perlu.*

(i) *Dalam bidang struktur dinamik, apakah yang dimaksudkan dengan darjah kebebasan?*

(ii) *Bezakan diantara sistem getaran tentu dan tidak tentu*

(iii) *Apakah maksud frekuensi tabii dan bagaimana ia berkait dengan jisim dan kekakuan bagi sistem getaran satu darjah kebebasan?*

(30 markah)

[b] *Lakarkan sambutan getaran yang menggambarkan sistem satu darjah kebebasan yang menjalani getaran untuk setiap kes berikut;*

(i) *Sambutan frekuensi untuk getaran paksa tidak teredam.*

(ii) *Sambutan masa untuk fenomena alun.*

(iii) *Sambutan masa untuk sistem yang mempunyai redaman lebih.*

Sambutan getaran mesti di lakarkan di atas paksi berasingan dan dilabel dengan lengkap.

(30 markah)

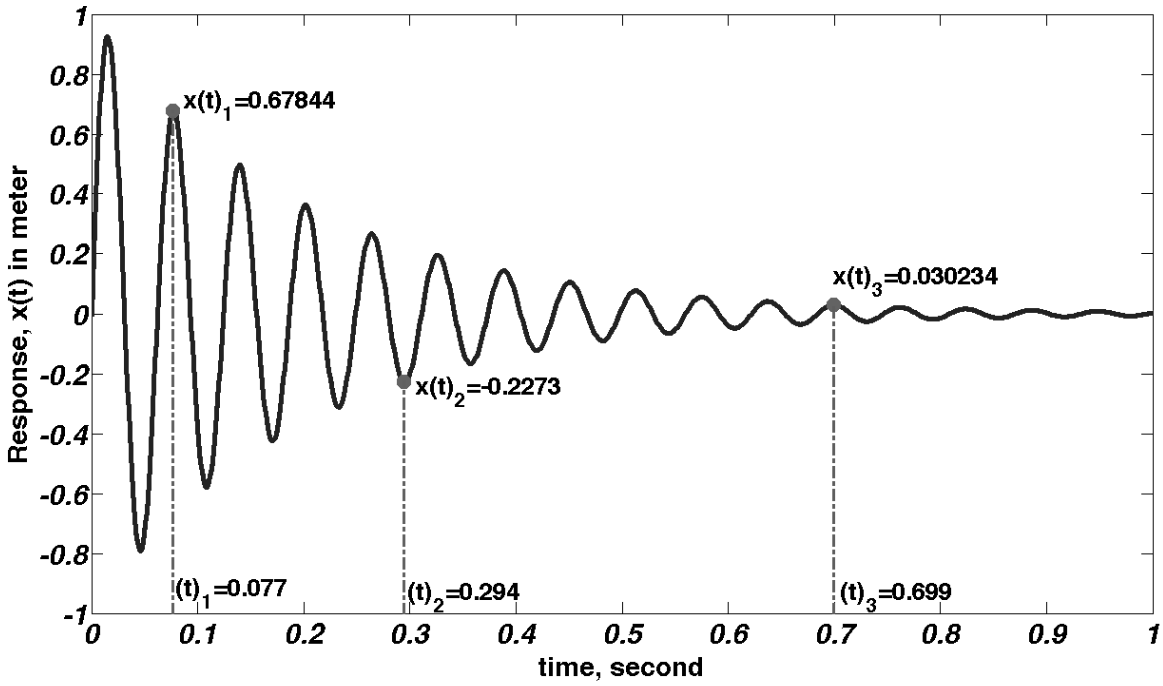
[c] ***Rajah 1*** *menunjukkan sambutan getaran bebas untuk sistem satu darjah kebebasan yang mengalami getaran redaman disebabkan wujudnya redaman likat. Berdasarkan* ***Rajah 1*** *dan dengan menggunakan persamaan-persamaan yang berkenaan, kirakan :*

(i) *Frekuensi tabii teredam sistem tersebut dalam unit rad/s.*

(ii) *Nisbah redaman sistem tersebut.*

(iii) *Frekuensi tidak teredam sistem tersebut dalam unit rad/s.*

(iv) *Pekali redaman likat sistem tersebut dalam unit N-s/m jika jisim m = 1 kg.*



Rajah 1

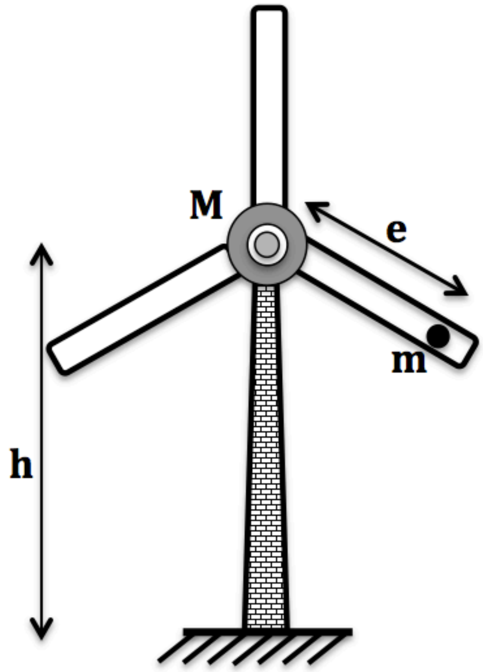
(40 markah)

2. [a] *Tunjukkan penyelesaian kepada persamaan karakteristik untuk sistem getaran bebas teredamsatu darjah kebebasan ialah sepert;;*

$$\lambda_1 = \omega_n\left(-\zeta + \sqrt{\zeta^2 - 1}\right)$$
$$\lambda_2 = \omega_n\left(-\zeta - \sqrt{\zeta^2 - 1}\right)$$

(50 markah)

[b] *Satu bilah turbin angin seperti yang ditunjukkan dalam **Rajah 2** mempunyai jisim tidak seimbang m sebanyak 2.5 kg pada jarak e = 0.1 meter dari paksi putaran. Ketinggian menara turbin angin ialah 4 meter sementara jisim keseluruhan pemasangan nasel termasuk semua bilah mempunyai jisim sebanyak 300 kg. kekakuan menara ialah 20 kN/m dan nisbah redaman ialah 0.15. Dengan anggapan bahawa menara tersebut hanya boleh hayun secara mengufuk dan bilah-bilah sedang berputar, buat yang berikut ;*



Rajah 2

(i) *Lakarkan rajah badan bebas dinamik sistem tersebut.*

(10 markah)

(ii) *Terbitkan persamaan gerakan sistem dengan menggunakan ungkapan **M, c dan k apabila tiada daya bertindak pada struktur.***

(10 markah)

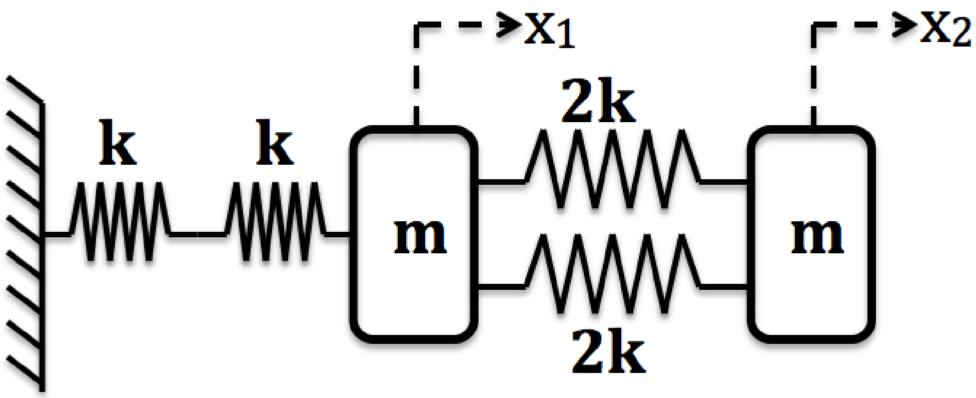
(iii) *Jangkakan frekuensi tabii tidak teredam menara tersebut.*

(10 markah)

(iv) *Terangkan tren faktor pembesaran pemasangan nasel jika kelajuan bilah-bilah meningkat sehingga menyebabkan frekuensi uja menjadi lebih tinggi dari frekuensi tabii struktur tersebut. Berikan alasan untuk jawapan anda.*

(20 markah)

3. *Sistem dua darjah kebebasan ditunjukkan dalam* ***Rajah 3*** *mengandungi roda takal yang tidak mempunyai jisim. Anggapkan m =10 kg dan keanjalan spring bersamaan dengan k = 5 N/m. Anda perlu :*



Rajah 3

(i) *Lakarkan rajah badan bebas kedua-dua jisim.*

(ii) *Terbitkan persamaan gerakan sistem dalam bentuk matriks.*

(iii) *Tentukan persamaan ciri sistem tersebut.*

(iv) *Kirakan frekuensi-frekuensi tabii.*

(v) *Kirakan dan lakarkan bentuk-bentuk mod.*

(100 markah)

4. [a] *Dengan berpandukan segitiga Collar, tulis nota ringkas mengenai fenomena-fenomena aeroleastik berikut;*

(i) bergalop

(ii) kibaran pegun

(iii) kibaran lentur kilas

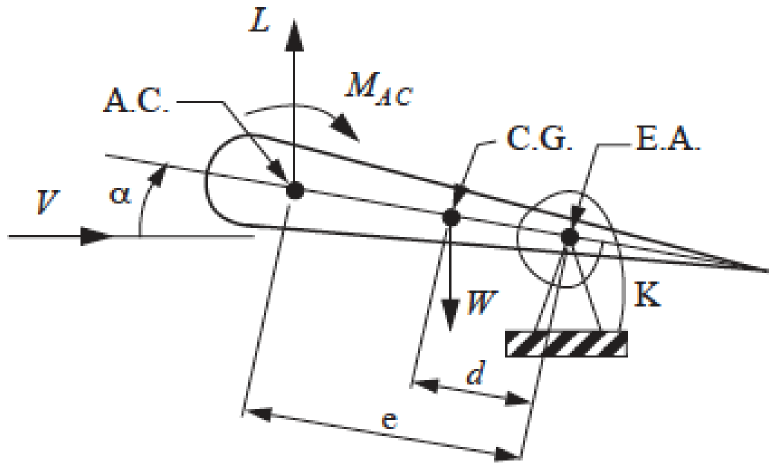
(45 markah)

[b] *Bincangkan dengan terperinci mengenai model aerodinamik kekisi vorteks yang digunapakai untuk analisa aeroelastik. Apakah kelebihan dan kekurangan pendekatan kaedah kekisi vorteks.*

(55 markah)

5. [a] *Model ringkas kecapahan satu kerajang sayap tipikal ditunjukkan dalam **Rajah 4.** Terbitkan persamaan tekanan dinamik kecapahan q_D .*

$$q_D = \frac{K}{S\left(\frac{\delta C_L}{\delta \alpha}\right)e}$$



Rajah 4

(30 markah)

[b] *Satu syarikat baru sedang membina pesawat ringan untuk kegunaan rekreasi. Sebagai seorang ahli aeroelastik yang bekerja di syarikat tersebut, anda ditugaskan untuk melegakan pesawat dari halaju kibaran. Bangunkan proses **empat peringkat** untuk program kelegaan kibaran serta terangkan objektif dan prosedur untuk setiap peringkat.*

(70 markah)

APPENDIX 1 / *LAMPIRAN 1*

Fundamental Equations in Vibration

1. $\zeta = \dfrac{c}{2m\omega_n}$;

2. $x(t) = Ce^{-\zeta\omega_n t}\sin(\omega_d t + \psi)$; $\omega_d = \sqrt{1-\zeta^2}\,\omega_n$

$$C = \sqrt{x_0^2 + \frac{(\dot{x}_0 + \zeta\omega_n x_0)^2}{(1-\zeta^2)\omega_n^2}} \quad ; \quad \psi = \tan^{-1}\frac{\sqrt{1-\zeta^2}\,\omega_n x_0}{\dot{x}_0 + \zeta\omega_n x_0}$$

3. For $F(t) = me\omega^2 \sin\omega t$

$$X = \frac{me\omega^2}{\sqrt{(k-M\omega^2)^2 + (c\omega^2)^2}}; \quad \phi = \tan^{-1}\left[\frac{c\omega}{k-M\omega^2}\right]$$

$$\frac{F_T}{F_0} = \left[\frac{1+(2\zeta r)^2}{(1-r^2)^2+(2\zeta r)^2}\right]^{1/2}$$

3. For base excitation

$$\frac{X}{Y} = \left[\frac{1+(2\zeta r)^2}{(1-r^2)^2+(2\zeta r)^2}\right]^{1/2} \quad \phi = \tan^{-1}\left[\frac{2\zeta r^3}{1+(4\zeta^2-1)r^2}\right]$$

$$\frac{F_T}{kY} = r^2\left[\frac{1+(2\zeta r)^2}{(1-r^2)^2+(2\zeta r)^2}\right]^{1/2}$$

5. $\begin{pmatrix} a & b \\ c & d \end{pmatrix}^{-1} = \begin{pmatrix} d & -b \\ -c & a \end{pmatrix}\dfrac{1}{\Delta(\omega)}$; $\det\begin{pmatrix} a & b \\ c & d \end{pmatrix} = ad - bc$

6. For cantilever beam with load *P* at the free end, $\delta_{max} = PL^3(3EI)^{-1}$

7. For cantilever beam with uniform load *w*, $\delta_{max} = wL^4(8EI)^{-1}$

APPENDIX 2/*LAMPIRAN 2*

Vibration-related Formulas

1. $\zeta = \frac{c}{2\omega_n m}$

2. $x(t) = e^{-\zeta\omega_n t}\left(A_1\cos(\omega_d t) + A_2\sin(\omega_d t)\right)$

3. $\omega_d = \sqrt{1-\zeta^2}\,\omega_n$

4. $x_p = X\sin(\omega t - \varphi)$, $X = \frac{F_0 / k}{\left((1-r^2)^2 + (2\zeta r)^2\right)^{1/2}}$, $\varphi = \tan^{-1}\frac{2\zeta r}{1-r^2}$

5. $\frac{X}{Y} = \left[\frac{1+(2\zeta r)^2}{(1-r^2)^2+(2\zeta r)^2}\right]^{1/2}$ $\quad \phi = \tan^{-1}\left[\frac{2\zeta r^3}{1+(4\zeta^2-1)r^2}\right]$

6. $\frac{F_T}{kY} = r^2\left[\frac{1+(2\zeta r)^2}{(1-r^2)^2+(2\zeta r)^2}\right]^{1/2}$

7. $TR = \left[\frac{1+(2\zeta r)^2}{(1-r^2)^2+(2\zeta r)^2}\right]^{1/2}$

8. $\frac{mX}{m_0 e} = \frac{r^2}{\left[(1-r^2)^2+(2\zeta r)^2\right]^{1/2}}$

9. $A^{-1} = \frac{1}{det(A)}\begin{bmatrix} d & -b \\ -c & a \end{bmatrix}$

10. $\det(A) = ad - bc$

11. $f_d = \frac{1}{T}$

12. $\omega_d = \frac{2\pi n}{\Delta T}$

13. $\delta = \frac{1}{n}\ln\left(\frac{y_0}{y_n}\right)$

14. $\xi = \frac{1}{\sqrt{1+\left(\frac{2\pi}{\delta}\right)^2}}$

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