Second Semester Examination
Academic Session 2018/2019

June 2019

ESA322 – Aerospace Structural Dynamics
[Dinamik Struktur Aeroangkasa]

Duration : 3 hours
(Masa : 3 jam)

Please check that this examination paper consists of **THIRTEEN (13)** pages of printed material before you begin the examination.

*[Sila pastikan bahawa kertas peperiksaan ini mengandungi **TIGA BELAS (13)** muka surat yang bercetak sebelum anda memulakan peperiksaan ini].*

Instructions : Answer **FIVE (5)** questions. **All questions are COMPULSORY**.

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

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

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

1. (a). Answer the following questions in words and supplemented with the relevant equation and diagram.

(i). What is periodic motion?

(ii). Write a short note about system identification in structural dynamics.

(iii). What is beating phenomenon?

(30 marks)

(b). Sketch the vibration response that illustrates a vibration system undergoing oscillation for the following cases;

(i). Time response for resonance phenomenon.

(ii). Frequency response for two degree of freedom system.

(iii). Time response for the overdamped system.

(30 marks)

(c). **Figure Q1(c)** shows a time response for a single degree of freedom system undergoing decay oscillation due to the existence of viscous damping. Based on **Figure Q1(c)**, compute:

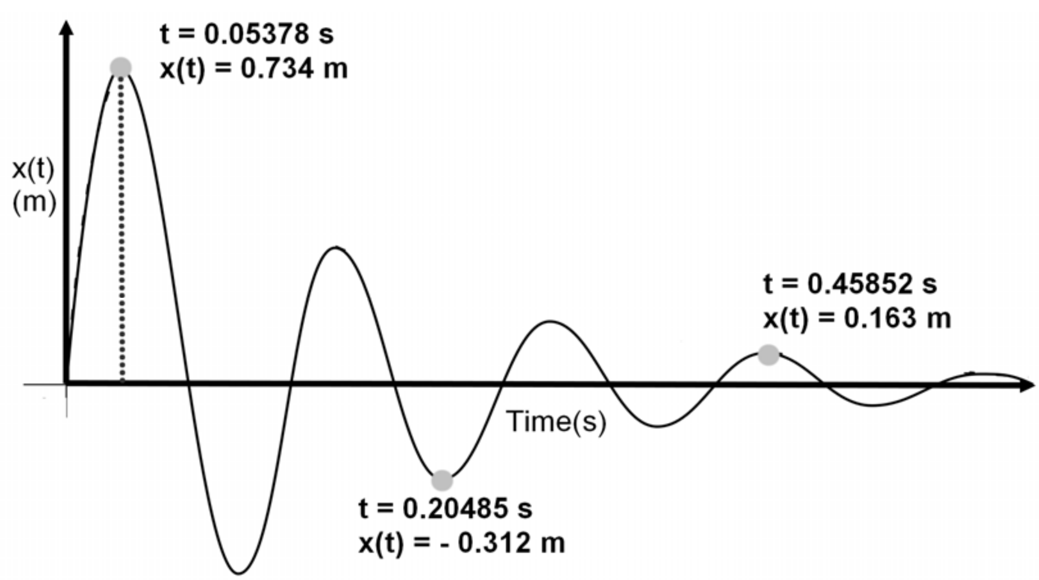


Figure Q1(c)

(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 the mass m = 2 kg.

(40 marks)

2. (a). A locomotive with mass of **2,000 kg** traveling at a velocity ***v* = 10 m/s** is stopped at the end of the tracks by a spring-damper system, as shown in **Figure Q2(a)**. If the stiffness of the spring is ***k* = 80 N/mm** and the damping constant is ***c* = 20 N-s/mm**. Determine the system's:

(i). Natural frequency.

(ii). Critical damping.

(iii). Damping ratio.

(iv). Maximum displacement of the locomotive after engaging the spring and damper.

(v). Time taken to reach the maximum displacement.

(50 marks)

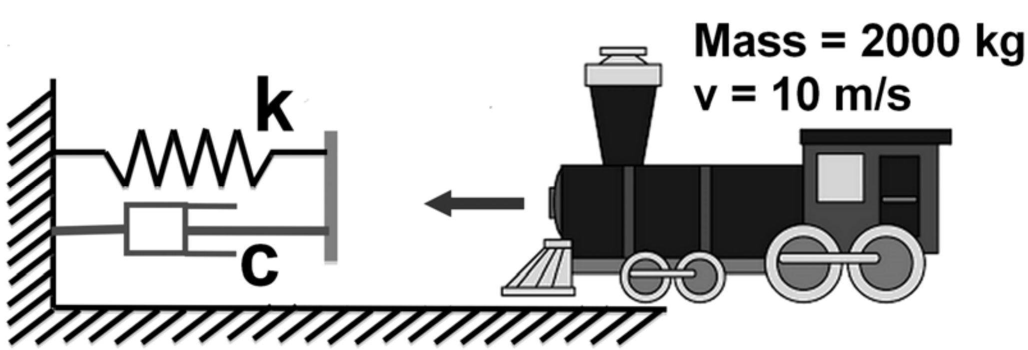


Figure Q2(a)

(b). A small wind turbine assembly is to be installed on a building roof to generate extra electrical energy. The entire assembly has a mass of 300 kg. One of the turbine blades has an unbalance mass of 3.0 kg with 0.15 m of eccentricity. The wind turbine will rotate at a constant speed of 975 rpm. The assembly will be placed on four springs arranged in parallel with each spring has 261,000 N/m of stiffness.

(i). Predict the undamped natural frequency of the entire assembly.

(ii). Compute the force amplitude acting on the system resulted from the unbalanced mass when the wind turbine is rotating.

(iii). Predict the amplitude of oscillation of the assembly if there is no damping exists in the system.

(iv). If there is a damper with damping ratio value of $\zeta = 0.01$ and the blades rotate at the same frequency as its natural frequency, compute the amplitude of the assembly?

(v). If the wind turbine blades suddenly stop rotating, will the wind turbine assembly continue to oscillate or not? Provide reason/s for your answer.

(50 marks)

3. Consider a two-degree of freedom system shown in **Figure Q3**, given mass, **m1 = m2 = 5 kg** and the spring stiffness, **k = 20 N/m**, you must:

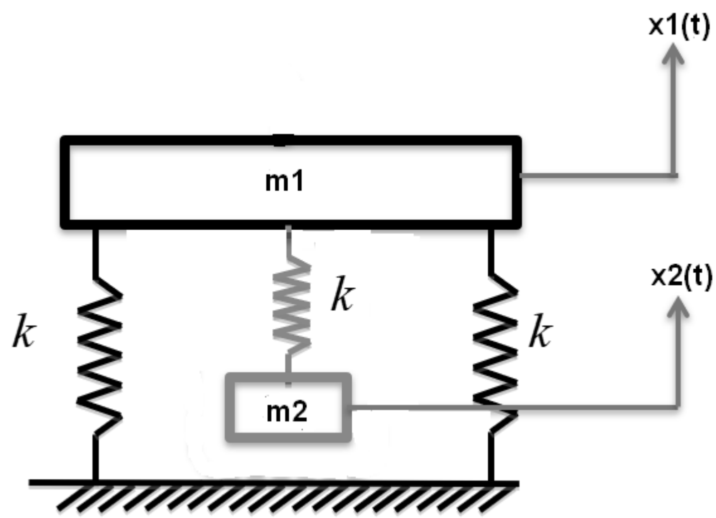


Figure Q3

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

(ii). Derive the equation of motion of the system in a 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). Bending torsion flutter.

(ii). Aileron buzz.

(iii). Aeroelastic galloping.

(iv). Divergence.

(v). Aileron reversal.

(50 marks)

(b) Within the scope of 2 dimensional incompressible flow regime, discuss in detail the **quasi-steady aerodynamics** and **unsteady aerodynamics** models that are used in aeroelastic analysis. List all the parameters that contribute to the aerodynamic forces for both models.

(50 marks)

5. (a). With the help of a divergence free body diagram, prove the divergence speed for the airfoil is equal to:

$$V_d = \sqrt{\frac{2K}{\rho Sec \frac{\delta C_L}{\delta \alpha}}}$$

(40 marks)

(b). A new aircraft company has just completed the flight tests of a light attack aircraft. The flight test results indicated that the aircraft's wings suffer from bending torsion flutter within the aircraft flight speed envelope. As an aeroelastician at the company, you are tasked to solve the flutter issue without compromising the aircraft flight speed envelope. Suggest three methods (2 passive and 1 active) of flutter suppression techniques that can be employed to solve the issue. Provide details on each of the techniques suggested.

(60 marks)

1. (a). *Berikan jawapan kepada soalan berikut dalam bentuk perkataan beserta persamaan dan gambarajah yang berkaitan.*

    (i). *Apakah maksud gerakan berulang?*

    (ii). *Tulis nota ringkas mengenai sistem pengenalan dalam struktur dinamik.*

    (iii). *Apakah yang dimaksudkan dengan fenomena paluan?*

(30 markah)

(b). *Lakar sambutan getaran yang menggambarkan satu sistem getaran yang mengalami getaran berikut;*

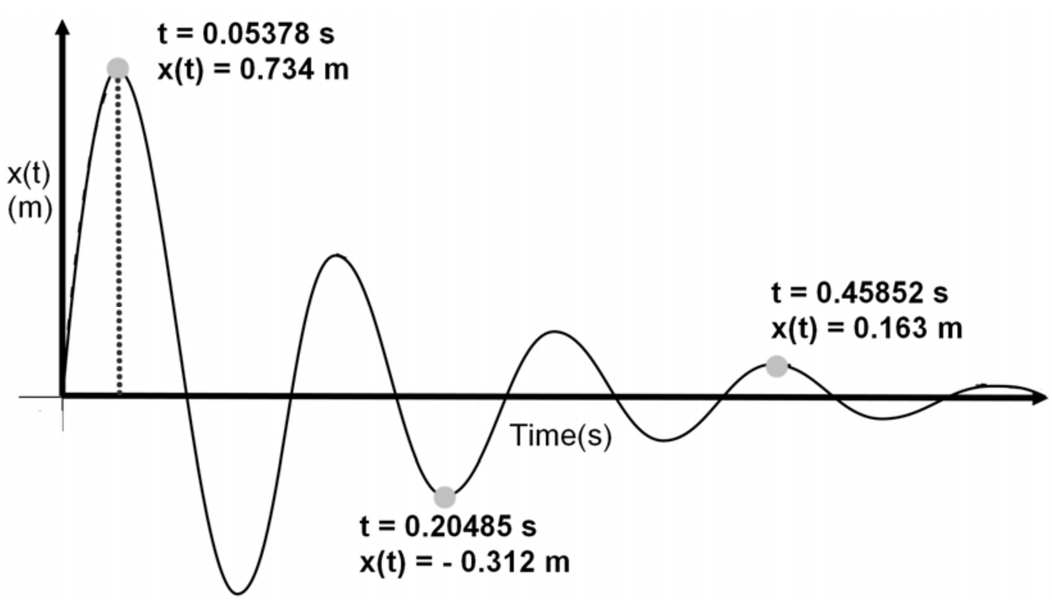
    (i). *Sambutan masa untuk fenomena resonans.*

    (ii). *Sambutan frekuensi untuk sistem dua darjah kebebasan.*

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

(30 markah)

(c). ***Rajah S1(c)*** *menunjukkan sambutan masa untuk sistem satu darjah kebebasan yang menjalani getaran teredam disebabkan oleh kewujudan redaman likat. Berdasarkan* ***Rajah S1(c),*** *kirakan:*



Rajah S1(c)

(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 = 2 kg**.*

(40 markah)

2. (a). *Sebuah lokomotif yang mempunyai jisim sebanyak **2,000 kg** bergerak dengan halaju **v = 10 m/s** dihentikan di hujung landasan dengan sistem spring-peredam seperti yang ditunjukkan dalam **Rajah S2(a)**. Jika kekakuan spring ialah **k = 80 N/mm** dan pekali redaman **c = 20 N-s/mm**. Kira:*

(i). *Frekuensi tabii.*

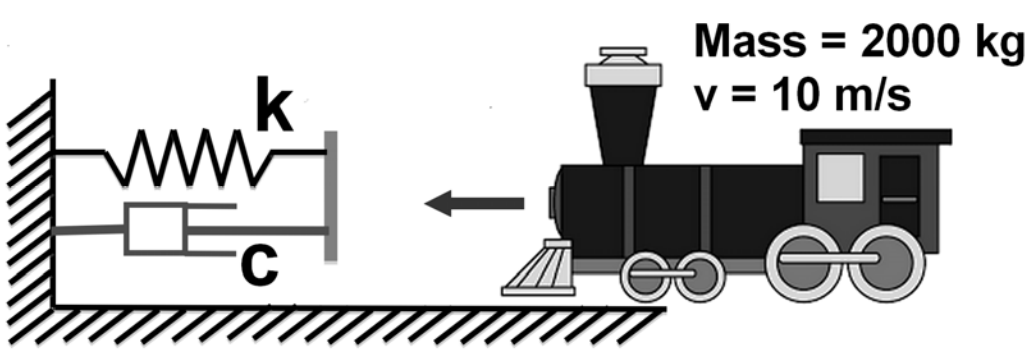
(ii). *Redaman kritikal.*

(iii). *Nisbah redaman.*

(iv). *Sesaran maksimum lokomotif tersebut selepas menyentuh spring dan peredam.*

(v). *Masa yang diambil oleh lokomotif tersebut untuk mencapai sesaran maksimum.*

(50 markah)



Rajah S2(a)

*(b). Sebuah turbin angin kecil akan dipasang di atas bumbung sebuah bangunan untuk menjana tenaga elektrik tambahan. Keseluruhan pemasangan berjisim **300 kg**. Satu daripada bilah turbin tersebut mempunyai jisim tidak seimbang sebanyak **3.0 kg** dengan jarak kesipian **0.15 m**. Turbin angin akan berputar pada kelajuan **975 psm**. Keseluruhan pemasangan turbin akan diletakkan di atas empat spring yang disusun secara selari dengan setiap satu spring mempunyai nilai keanjalan **261,000N/m.***

(i). Kira nilai frekuensi tabii tidak teredam keseluruhan pemasangan turbin tersebut.

(ii). Kira amplitud daya yang dikenakan ke atas sistem tersebut oleh kedudukan jisim yang tidak seimbang apabila turbin angin berputar.

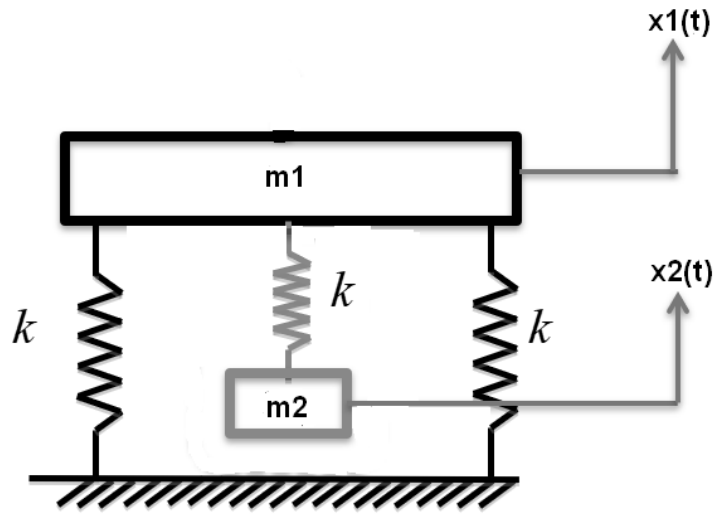
(iii). Ramal amplitud getaran keseluruhan pemasangan jika tiada redaman bertindak ke atas sistem tersebut.

(iv). Jika terdapat peredam dengan nilai nisbah redaman $\zeta = 0.01$ dan bilah turbin berputar pada frekuensi yang sama seperti frekuensi tabii, anggarkan amplitud keseluruhan pemasangan tersebut.

(v). Jika turbin angin berhenti berputar dengan serta-merta, adakah keseluruhan pemasangan turbin angin akan terus bergetar atau tidak. Sertakan alasan bersama jawapan yang anda berikan.

(50 markah)

3. *Sistem dua darjah kebebasan ditunjukkan dalam* ***Rajah S3****, jika jisim m****1 = m2 = 5 kg*** *dan keanjalan spring,* ***k = 20 N/m****, anda perlu:*



Rajah S3

(i). Lakarkan rajah badan bebas kedua-dua jisim.
(ii). Terbitkan persamaan gerakan sistem dalam bentuk matriks.
(iii). Tentukan persamaan ciri.
(iv). Kirakan frekuensi frekuensi tabii.
(v). Kirakan bentuk bentuk mod dan lakarkan.

(100 markah)

4. *(a). Dengan berpandukan Segitiga Collar , tulis nota ringkas mengenai fenomena-fenomena aeroleastik berikut;*

(i). Kibaran lentur kilas.
(ii). Getaran aileron.
(iii). Bergalop.
(iv). Pencapahan.
(v). Balikan aileron.

(50 markah)

(b) *Dalam skop aliran 2 dimensi tidak mampat, bincang dengan terperinci model aerodinamik kuasi mantap dan model aerodinamik tak mantap yang diguna pakai dalam analisa aeroelastik. Senaraikan semua parameter yang menyumbang kepada daya aerodinamik untuk kedua-dua model tersebut.*

(50 markah)

5. (a). *Dengan bantuan rajah badan bebas pencapahan, buktikan halaju pencapahan aerofoil adalah seperti berikut.*

$$V_d = \sqrt{\frac{2K}{\rho Sec \frac{\delta C_L}{\delta \alpha}}}$$

(40 markah)

(b). *Satu syarikat pengeluar pesawat yang baru telah menamatkan ujian penerbangan ke atas sebuah pesawat serangan ringan. Keputusan ujian penerbangan menunjukkan sayap pesawat mengalami masalah kibaran dalam sampul kelajuan penerbangan. Sebagai ahli aeroelastik di syarikat tersebut, anda ditugaskan untuk menyelesaikan isu kibaran tanpa menjejaskan sampul kelajuan penerbangan pesawat terbabit. Cadangkan 3 cara (2 pasif dan 1 aktif) teknik penindasan kibaran yang boleh diguna pakai untuk menyelesaikan isu tersebut. Berikan perincian kepada setiap teknik yang dicadangkan.*

(60 markah)

APPENDIX 1 / *LAMPIRAN 1*

Fundamental Equations in Vibration

$$\zeta = \frac{c}{2m\omega_n};$$

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

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

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

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

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

For base excitation

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

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

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

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

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

Vibration-related Formulas

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

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

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

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

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

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

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

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

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

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

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

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

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