UNIVERSITI SAINS MALAYSIA

Second Semester Examination
2017/2018 Academic Session

May/June 2018

ESA322/3 – Structural Dynamics
[Dinamik Struktur]

Duration : 3 hours
Masa : 3 jam

Please check that this paper contains **FIFTEEN (15)** printed pages included **TWO (2)** pages appendix and **FIVE (5)** questions before you begin the examination.

*[Sila pastikan bahawa kertas soalan ini mengandungi **LIMABELAS (15)** mukasurat bercetak termasuk **DUA (2)** mukasurat lampiran dan **LIMA (5)** soalan sebelum anda memulakan peperiksaan.]*

Instructions : Answer **ALL** questions.

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

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].

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 digunapakai].

1. [a] Answers the following questions in words supplemented with the relevant equation and diagram.

   (i) What is simple harmonic motion?

   (ii) What is viscous damping and how does it transpires?

   (iii) Write short notes about Fourier transform

(30 marks)

[b] Sketch vibration response that illustrates a single degree of freedom system undergoing oscillation for the following;

   (i) Frequency response for undamped forced vibration.

   (ii) Time response for beating phenomenon.

   (iii) Time response for critically damped system.

   Reponses must be label clearly.

(30 marks)

[c]

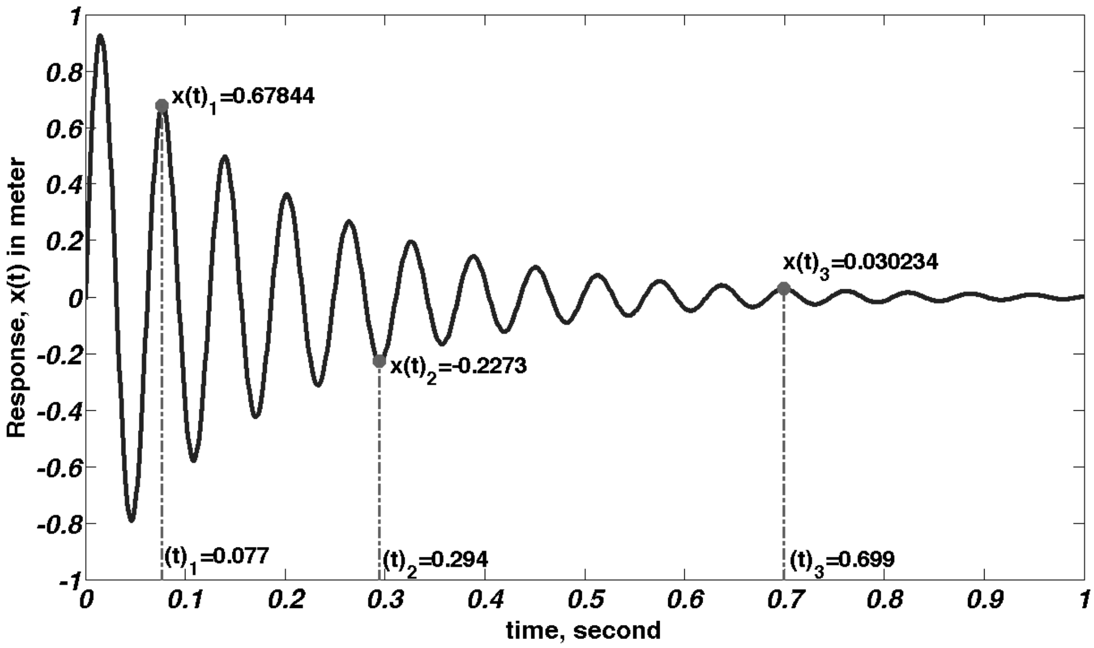


Figure 1

Figure 1 shows free response for a single degree of freedom system undergoing decay oscillation due to the existence of viscous damping. Based on **Figure 1**, 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 =4kg.

(40 marks)

2. [a] Shows that the expression for steady state amplitude for a single degree of freedom system undergoing undamped force oscillation is equivalent to

$$A = \frac{F_o / k}{1 - \left(\omega / \omega_n \right)^2}$$

(50 marks)

[b]

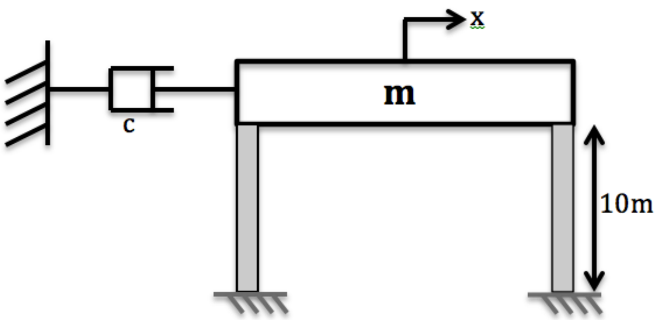


Figure 2

Figure 2 shows a building consisting of a rigid floor of mass *m* and two massless columns. At their upper end, the columns are fully clamped with the floor that is connected to a damper. At their lower end they are fix on the ground. The floor can only oscillates horizontally due to the flexibility of the columns. You must:

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

(ii) Derive the equation of motion of the system in terms of m, c and EI expression where the stiffness of each column is given as;

$$k = \frac{12EI}{h^3}$$

(iii) Find the natural frequency of the floor in Hz given EI = 20,000Nm^2 and mass m = 100kg.

(iv) Approximate the floor steady state amplitude if the system is excited at 0.02Hz with harmonic force F_o= 450N acting on the mass. Assume the value of viscous damping coefficient to be 100N-s/m.

(v) If the harmonic excitation is turned off, will the system's oscillation frequency remains the same, increase or decrease. Give reasons to your answer.

(50 marks)

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

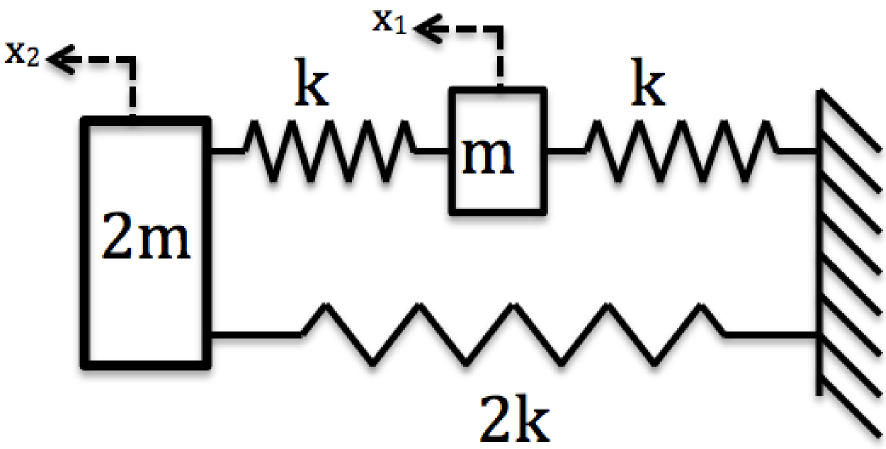


Figure 3

(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) Shock buffet

   (ii) Divergence

   (iii) Stall flutter

(40 marks)

[b] Discuss quasi steady and unsteady aerodynamics models used in aeroelastic analysis of aircraft structures including Thedorsen and Wagner function.

(60 marks)

5. [a] An airfoil section with mass M and Inertia I shown in **Figure 4** undergoes a combined bending and torsion modes of oscillation. The stiffness for the two-degree of freedom system is provided by linear and torsional springs. Obtain the equation of motion of the system using Lagrange's equation assuming there are unsteady aerodynamic forces (Lift L and pitching moment M) acting on the airfoil.

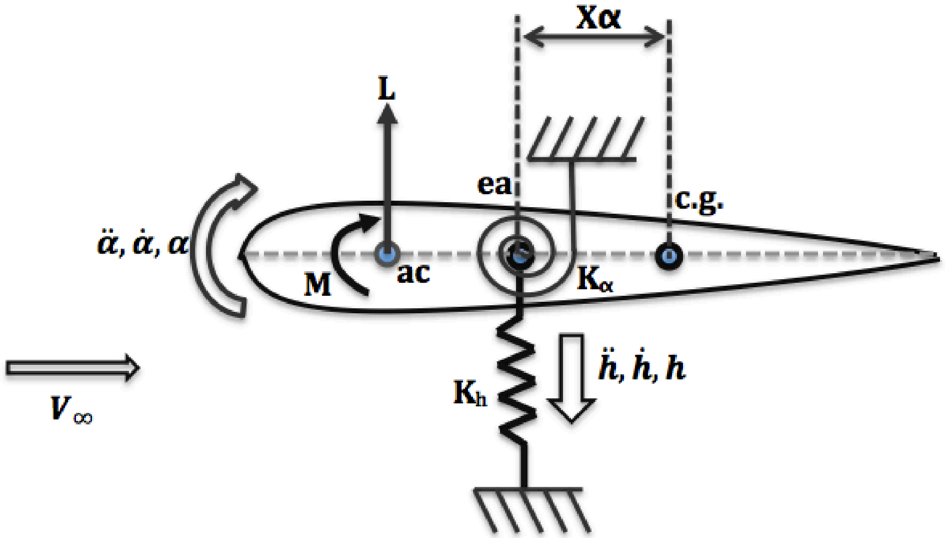


Figure 4

(40 marks)

[b] As the lead flight test engineer at United Aircraft Corporation, you are tasked with preparing with the flight flutter test of a new business jet. You must come up with a detail plan on how to conduct flight flutter test. The detail must include instrumentation, excitation system, data management and analysis.

(60 marks)

1. [a] Berikan jawapan kepada soalan berikut dalam bentuk perkataan dan disertakan dengan persamaan dan rajah yang berkaitan.

(i) Apakah gerakan mudah harmonik?

(ii) Apakah redaman likat dan bagaimana ia wujud?

(iii) Tulis nota ringkas mengenai jelmaan Fourier?

(30 markah)

[b] Lakarkan sambutan getaran yang mengambarkan sistem kebebasan satu darjah yang menjalani getaran berikut;

(i) Sambutan frekuensi untuk getaran paksa tidak teredam

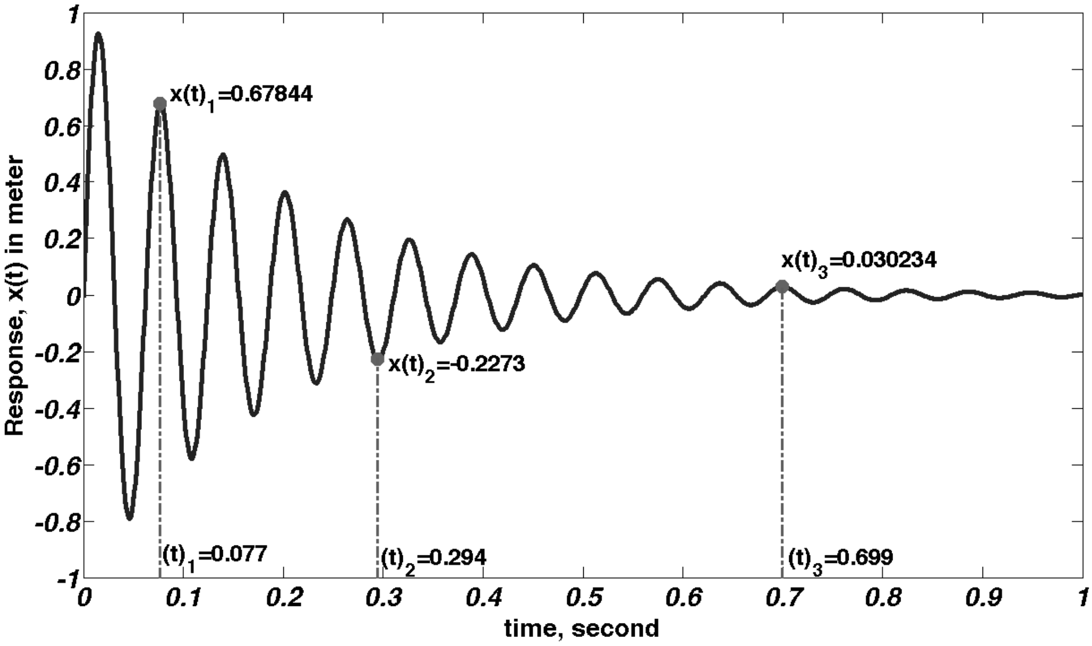
(ii) Sambutan masa untuk fenomena alun

(iii) Sambutan masa untuk getaran teredam kritikal

Lakaran mesti dilabel dengan jelas

(30 markah)

[c]



Rajah 1

Rajah 1 *menunjukkan getaran bebas untuk sistem kebebasan satu darjah yang mengalami getaran redaman disebabkan wujudnya redaman likat. Berdasarkan* ***Rajah 1****, kirakan:*

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

(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 = 4kg.*

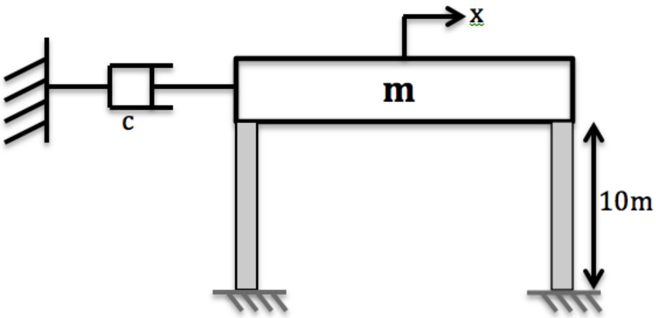
(40 markah)

2. *[a]* *Tunjukkan persamaan untuk getaran amplitud mantap bagi sistem kebebasan satu darjah yang menjalani getaran paksa tidak teredam adalah seperti berikut*

$$A = \frac{F_o/k}{1-\left(\omega/\omega_n\right)^2}$$

(50 markah)

[b]



Rajah 2

Rajah 2 *menunjukkan sebuah bangunan yang mengandungi lantai tegar berjisim* ***m*** *dan dua tiang tanpa jisim. Lantai diapit pada bahagian atas tiang-tiang tersebut serta disambung pada peredam. Tiang-tiang tersebut dimatikan pada bahagian tapak. Lantai tersebut hanya boleh mengalami getaran mendatar disebabkan keanjalan tiang-tiang tersebut. Anda mesti:*

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

(ii) *Terbitkan persamaan gerakan sistem tersebut dengan menggunakan ungkapan m, c and EI sahaja, di mana keanjalan setiap tiang diberi sebagai;*

$$k = \frac{12EI}{h^3}$$

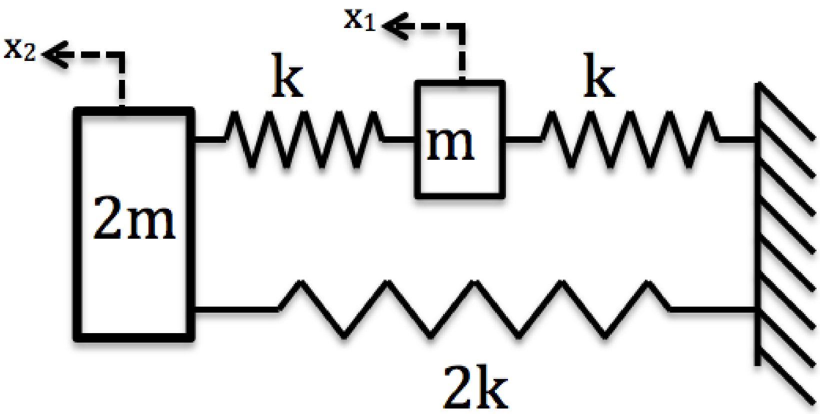
(iii) *Kira frekuensi tabii lantai dalam unit Hz jika nilai $EI=20,000Nm^2$ dan jisim m = 100kg.*

(iv) *Kira amplitud lantai jika sistem itu diuja pada 0.02Hz dengan daya harmonik F_o= 450N dikenakan pada jisim tersebut. Andaikan nilai pekali redaman likat sebanyak 100Ns/m.*

(v) *Jika pengujaan harmonik dihentikan, adakah nilai frekuensi getaran bebas sistem tersebut akan sama, meningkat atau menurun? Berikan sebab kepada jawapan anda.*

(50 markah)

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



Rajah 3

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

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

(iii) *Tentukan persamaan ciri.*

(iv) *Kira frekuensi tabii.*

(v) *Kira bentuk bentuk mod dan lakarkan.*

(100 markah)

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

(i) Palu gelombang

(ii) Pencapahan

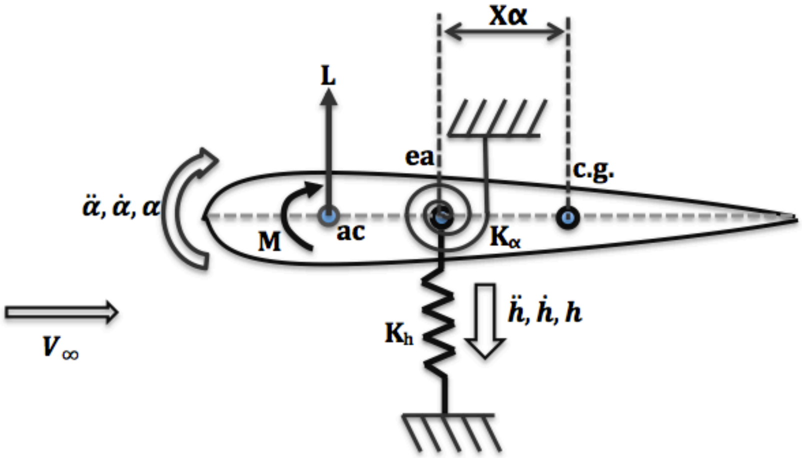
(iii) Kibaran pegun

(40 markah)

[b] *Bincangkan aliran quasi mantap dan aliran tak mantap yang diguna pakai untuk analisa struktur pesawat termasuk fungsi Theodorsen dan Wagner.*

(60 markah)

5. [a] *Satu kerajang sayap dengan jisim M_m dan Inertia I_I ditunjukkan dalam* ***Rajah 4*** *mengalami gerakan lenturan dan kilasan. Keanjalan untuk sistem dua darjah kebebasan tersebut dibekalkan oleh spring linear dan kilasan. Terbitkan persamaan gerakan sistem tersebut dengan menggunakan kaedah persamaan "Lagrange" dengan mengandaikan terdapat daya-daya aerodinamik (daya angkat L dan momen angguk M) bertindak keatas kerajang sayap tersebut.*



Rajah 4

(40 markah)

[b] *Sebagai seorang jurutera ujian penerbangan di United Aircraft Corporation, anda ditugaskan untuk melakukan persediaan bagi ujian kibaran terbang untuk jet bisnes yang baru. Anda mesti menyediakan pelan terperinci bagaimana untuk melakukan ujian kibaran terbang. Perincian perlu merangkumi instrumentasi, sistem pengujaan, pentadbiran dan analisa data.*

(60 markah)

APPENDIX 1 / *LAMPIRAN 1*

Fundamental Equations in Vibration

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

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

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

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

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

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

4. For base excitation

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

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

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

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

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

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

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

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

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

8. det(A) = $ad - bc$

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

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

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

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

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