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UNIVERSITI TUN HUSSEIN ONN MALAYSIA

FINAL EXAMINATION
SEMESTER II
SESSION 2023/2024

COURSE NAME	:	VIBRATION
COURSE CODE	:	BDA 31103
PROGRAMME CODE	:	BDD
EXAMINATION DATE	:	JULY 2024
DURATION	:	3 HOURS
INSTRUCTIONS	:	1. PART A: ANSWER ALL QUESTIONS. PART B: ANSWER **ONE (1)** QUESTION FROM TWO (2) QUESTIONS ONLY. 2. THIS FINAL EXAMINATION IS CONDUCTED VIA ☐ Open book ☒ Closed book 3. STUDENTS ARE **PROHIBITED** TO CONSULT THEIR OWN MATERIAL OR ANY EXTERNAL RESOURCES DURING THE EXAMINATION CONDUCTED VIA CLOSED BOOK.

THIS QUESTION PAPER CONSISTS OF **ELEVEN (11)** PAGES

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PART A - ANSWER ALL QUESTIONS. SHOW ALL CALCULATIONS IN THREE (3) DECIMAL POINTS.

Q1 Answer the following sound and noise problems:

(a) It is found that the sound power from a heavy machinery (assume ground source) in a construction site is 1.0 W. Determine the sound intensity and sound intensity level at a distance 50 meter from the heavy machinery.

(6 marks)

(b) In a factory, the total sound level in the main production area is measured at 100 dB. To improve worker safety and comfort, a noise reduction system is installed. This primarily targets to mitigate the noise produced by one particular high-power machine. When this machine is turned off, the remaining ambient noise in the production area is measured at 95 dB.

(i) Calculate the original decibel level of the noise produced by the high-power machine. Assume that the noise from the machine and the other ambient noise sources are independent of each other.

(4 marks)

(ii) If three (3) of such high-power machines are to be installed in the factory, determine the total sound level. Ignore the ambient noise.

(4 marks)

(c) Equivalent continuous noise level, L_{eq} is the sound pressure level of a steady sound that has, over a given period, the same energy as the fluctuating sound. It is an average and is being measured in dB(A). The equivalent continuous noise level, L_{eq} is calculated as:

$$L_{eq} = 10log\left(\frac{t_1 \times 10^{L1/10} + t_2 \times 10^{L2/10} + \cdots + t_n \times 10^{Ln/10}}{T}\right)$$

$$n = 1,2,3,...$$

Where:

L_{eq} is the equivalent continuous noise level.

t is the exposure duration at sound pressure of specific level.

L is the sound pressure level at specific location.

T is the total time over which the L_{eq} is required.

Assume a factory worker is exposed to different sound levels throughout an 8-hour workday. During the first 3 hours, the sound level is 90 dB, for the next 4 hours, it is 85 dB, and for the final 1 hour, it is 95 dB. Determine the L_{eq} value.

(5 marks)

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(d) Daily sound exposure is an important consideration in workplace safety. The concept of "daily sound dose" is used to quantify a worker's exposure to noise over a typical workday. The daily sound dose, expressed in percentage and denoted as "D" is calculated as:

$$D = 100 \times \left(\frac{C_1}{T_1} + \frac{C_2}{T_2} + \cdots + \frac{C_n}{T_n}\right) \quad n = 1,2,3,\ldots$$

Where:

D is the daily sound dose in percentage.

C is the time of exposure at specific noise level.

T is the permissible duration of exposed sound level.

Assume a factory worker is exposed to different sound levels throughout an 8-hour workday as in **Q1(c)**. Estimate the daily sound dose (D) for this worker. The daily exposure duration limit as stated in Industry Code of Practice (ICOP 2019) is given in **Table Q1.1**. Explain the significance of this calculation in the context of occupational health and safety.

Table Q1.1 Daily Exposure Duration Limit (ICOP 2019)

Noise Level (dBA)	Daily Exposure Duration Limit
82	16 hrs
85	8 hrs
88	4hrs
90	2 hrs 31 mins
91	2 hrs
95	48 mins
98	24 mins

(6 marks)

Q2 Answer the following vibration problems based on the scenarios below:

(a) You are an engineer tasked with assessing the health of a hand-held machine in a manufacturing plant. Part of your assessment involves analyzing the vibration levels of the equipment to ensure they are within safe operating limits. You have collected vibration data from sensors mounted on the machine in three axes: x, y, and z. The recorded vibration data over a certain period is as in **Table Q2.1** below:

Table Q2.1 Vibration data from sensors mounted on the machine in three axes

Axes	x	y	z
Acceleration (m/s^2)	5.1	3.4	4.2

(i) Estimate the total vibration level of the machinery.

(3 marks)

(ii) Determine if the machinery is operating within safe vibration limit for 4 hours of usage. The limit values for the daily vibration exposure A(8) is given in **Table APPENDIX A.1**. Based on the finding, what would be your action?

(6 marks)

(b) An operator controls a precision device in a factory where the floor transmits vibrations of different intensities and frequencies throughout the day. Recordings show that when the floor vibration reaches 2.3 m/s^2 at 25 Hz, the error rate in tasks increases significantly.

Determine the equivalent continuous vibration level over an 8-hour shift if the high vibration condition, 2.3 m/s^2 at 25 Hz lasts for 2 hours, and the rest of the time the vibration level is at a baseline of 0.5 m/s^2. The limit values for the daily vibration exposure A(8) is given in **Table APPENDIX A.1**. Additionally, identify whether the daily vibration limit has been exceeded?

(6 marks)

(c) **Figure Q2.1** shows a time-domain response of a vibrating system that consists of 3 components. Sketch the frequency-domain response for the system.

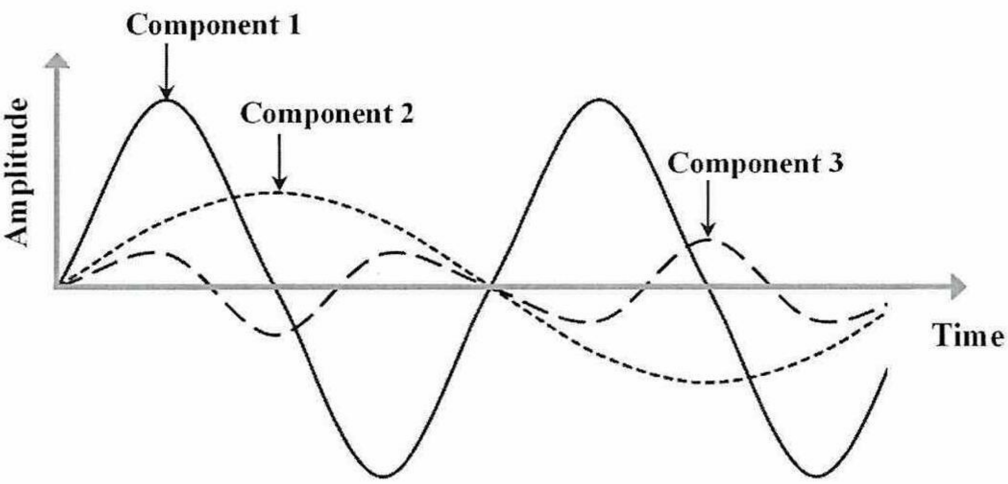

Figure Q2.1 Time domain response

(6 marks)

(d) Schematics of single degree of freedom and multi degree of freedom vibration systems are shown in **Figure Q2.2**. Sketch the expected responses in frequency-domain for each of the systems.

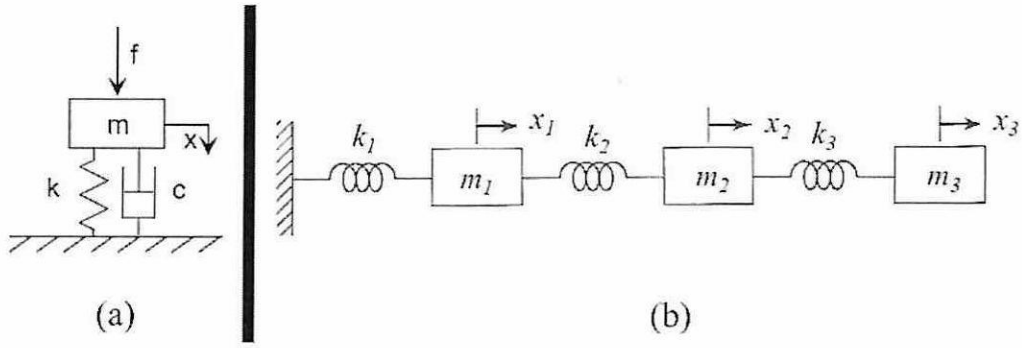

Figure Q2.2 (a) single degree of freedom and (b) multi degree of freedom systems

(4 marks)

Q3 In a newly designed fire safety system, a fire sprinkler pump is installed to ensure effective water distribution during emergencies. The pump with a mass of 550 kg, is supported by four identical vibration isolators at its base as shown in **Figure Q3.1**. These isolators are critical for reducing the vibration transmitted to the building structure, especially to the ground floor, to avoid noise and potential damage. The stiffness of each isolator is 5,000 N/m.

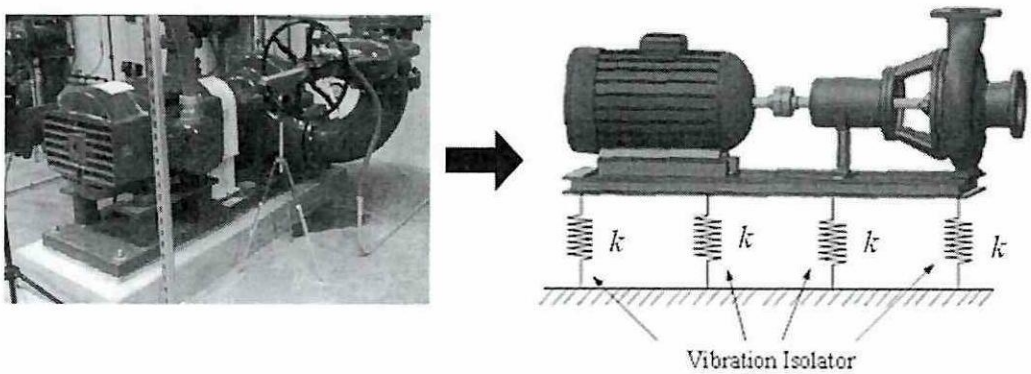

Figure Q3.1 Newly designed fire safety system

When the pump operates, it generates a vertical harmonic force described by the equation $F(t) = 100\sin(20t)$. The building design specifications require that only 10% or less of the vibration generated by the pump be transmitted to the ground floor to ensure the comfort and safety of the building's occupants and the integrity of the structure.

(a) As a future design engineer, you are required to provide a detailed analysis and calculations of the current design of the isolators in order to determine if they comply with the specified requirement that no more than 10% of the pump's vibration is allowed to be transmitted to the ground floor.

(10 marks)

(b) Calculate the dynamic force transmitted to the ground floor by the pump when it is operating under the given vertical harmonic force.

(3 marks)

(c) A new jockey pump with lighter weight of 150 kg is suggested to replace the fire sprinkler pump, determine whether the same four identical vibration isolators can be used to achieve the design specification that only 10% or less of the vibration generated by the pump be transmitted to the ground floor. Please provide a detailed analysis to evaluate the effectiveness of the vibration isolators with the new pump.

(8 marks)

(d) Explain why the answer in **Q3(c)** differs from **Q3(a)**. You are required to sketch the transmissibility against frequency ratio graph to support your explanation.

(4 marks)

PART B - ANSWER ONE QUESTION ONLY. SHOW ALL CALCULATIONS IN THREE (3) DECIMAL POINTS.

Q4 A structure is modelled by spring-mass system of two masses, m_1 and m_2 attached to the streched springs, k_1, k_2 and k_3 as shown in **Figure APPENDIX A.1**. Assume that $m_1 = 60$ kg, $m_2 = 20$ kg, $k_1 = 20$ N/m, $k_2 = 100$ N/m, and $k_3 = 70$ N/m.

(a) Determine the equation of motion in matrix form, complete with all known values by using the Newton Law. Sketch a free body diagram to support the answer.

(6 marks)

(b) Estimate the fundamental natural frequency in rad/s unit and its corresponding mode shape by using Standard Matrix Iteration approximation method. The initial trial vector is given as $\begin{pmatrix}1\\3\end{pmatrix}$ and show up to four (4) iterations calculation.

(15 marks)

(c) By using Rayleigh's method, predict the fundamental natural frequency in rad/s unit. Use the initial mode shape of $\begin{pmatrix}1\\1\end{pmatrix}$

(4 marks)

Q5 A structure is modelled by spring-mass system of two masses, m_1 and m_2 attached to the streched springs, k_1, k_2 and k_3 as shown in **Figure APPENDIX A.1**. Assume that $m_1 = 60$ kg, $m_2 = 20$ kg, $k_1 = 20$ N/m, $k_2 = 100$ N/m, and $k_3 = 70$ N/m.

(a) Determine the equation of motion in matrix form, complete with all known values by using the Newton Law. Use a free body diagram to support the answer.

(6 marks)

(b) By using Dunkerley method, predict the fundamental natural frequency for the system in rad/s unit.

(5 marks)

(c) Estimate the highest natural frequency in rad/s unit and its corresponding mode shape by using Standard Matrix Iteration approximation method. The initial trial vector is given as $\begin{pmatrix}1\\3\end{pmatrix}$ and show up to four (4) iterations calculation.

(14 marks)

- END OF QUESTIONS -

APPENDIX A

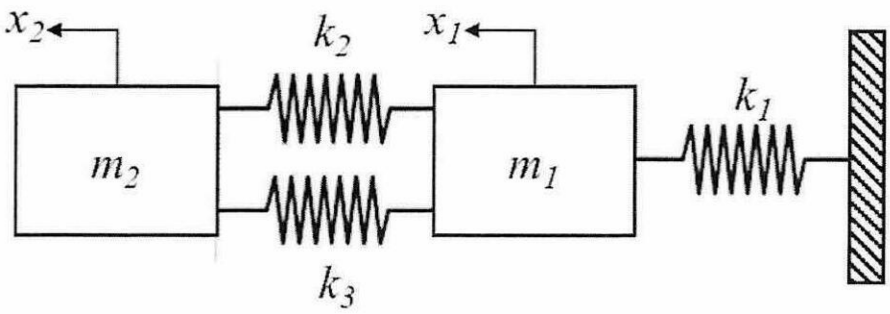

Figure APPENDIX A.1 Two degree of freedom system

Table APPENDIX A.1 EC Directive 2002/44/EC Daily Vibration Exposure Limit A(8)

A(8) Limit Values	**Hand-Arm Vibration**	**Whole-Body Vibration**
Exposure Action Value (EAV)	2.5 m/s^2	0.5 m/s^2
Exposure Limit Value (ELV)	5.0 m/s^2	1.15 m/s^2

USEFUL FORMULAS:

Sound power :

$$W = I \times 4\pi r^2 \quad \text{(for sphere source)}$$

$$W = I \times 2\pi r^2 \quad \text{(for hemisphere source)}$$

Sound Intensity:

$$I = \frac{P}{4\pi r^2}$$

Sound intensity level:

$$SIL = 10log\left(\frac{I}{I_{ref}}\right) \; ; \qquad I_{ref} = 1\times10^{-12}\ \text{W/m}^2$$

Noise – distance relationship:

$$dL = 20\ log\ \left(\frac{R_2}{R_1}\right)$$

$$dL = Lp_1 - Lp_2$$

Subtraction of sound:

$$L_2 = 10\ log\ (10^{Loverall/10} - 10^{L1/10})$$

Summation of sound :

$$L_{overall} = 10\ log\ (10^{L1/10} + 10^{L2/10} + ... + 10^{Ln/10})$$

Equivalent continuous noise level, L_{eq}:

$$L_{eq} = 10\log\{(t_1 \times 10^{L1/10} + t_2 \times 10^{L2/10} + \cdots + t_n \times 10^{Ln/10})/T\}$$

Daily noise exposure level, L_{EX}:

$$L_{EX,8h} = L_{eq,Te} + 10\log\left(\frac{T_e}{T_0}\right)$$

Daily personal noise dose:

$$Dose_{8h} = 100 \times \left(\frac{T_e}{T_0}\right) \times 10^{(L_{eq}-85)/10}$$

Vibration total value:

$$a_{hv} = \sqrt{a_{hwx}^2 + a_{hwy}^2 + a_{hwz}^2}$$

Daily Vibration Exposure:

$$A(8) = a_{hv}\sqrt{\frac{T}{T_0}}$$

Equivalent continuous vibration level (8 hours):

$$\mathrm{A(8)} = \sqrt{\frac{a_{hv1}{}^2 T_1 + a_{hv2}{}^2 T_2 + \cdots}{T_o}}$$

Natural frequencies of system with attached vibration absorber:

$$\left.\begin{matrix}(r_1)^2\\(r_2)^2\end{matrix}\right\} = \left[1 + \frac{\mu}{2}\right] \mp \sqrt{\left[1 + \frac{\mu}{2}\right]^2 - 1}$$

where $r_1 = \frac{\Omega_1}{\omega_2}$, $r_2 = \frac{\Omega_2}{\omega_2}$, $\mu = \frac{m_2}{m_1}$

Mass ratio, μ :

$$\mu = \left(\frac{r_1^4 + 1}{r_1^2}\right) - 2$$

Transmissibility ratio, T_r :

$$T_r = \frac{F_T}{F_0}$$

Transmissibility ratio for a small damping ratio, T_r :

$$T_r = \pm\left(\frac{1}{1 - r^2}\right)$$

Fundamental Natural frequency using Matrix Iteration Method:

$$\omega_n = \sqrt{\frac{1}{X_{normalized}}}$$

Rayleigh's quotient:

$$\omega^2 = \frac{\vec{X}^T[k]\vec{X}}{\vec{X}^T[m]\vec{X}} = R(\vec{X})$$

Dunkerley's formula:

$$\frac{1}{\omega_i^2} \approx a_{11}m_1 + a_{22}m_2 + \cdots + a_{nn}m$$

Cramer's Rule:

$$\begin{vmatrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{vmatrix} = 0 \qquad (A_{11})(A_{22}) - (A_{21})(A_{12}) = 0$$

Harmonic motion:

$$x = A\sin(\omega t + \emptyset)$$