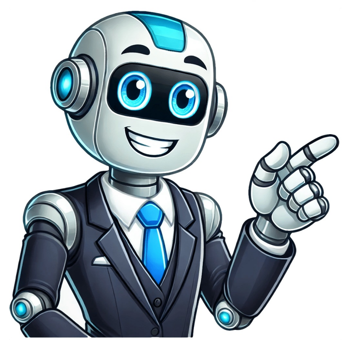

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The Fluke family includes many brands around the world including PLS, Pomona and Amprobe.Please use the drop down menu below to select the company you are looking for. Explore the fundamentals of free and forced vibrations, their characteristics, and applications in engineering, from structural stability to machinery performance and acoustics.Free and Forced Vibrations in the Study of VibrationsThe study of vibrations, a crucial aspect of mechanical and structural engineering, involves understanding how objects oscillate. Within this field, free and forced vibrations are fundamental concepts that describe different types of oscillatory motion. This article delves into these two types of vibrations, explaining their principles, characteristics, and applications.Free VibrationsFree vibrations occur when a system oscillates naturally without external forces acting upon it after an initial disturbance. This type of vibration can be observed in systems that are displaced from their equilibrium position and then released, allowing them to vibrate at their natural frequency.Characteristics of Free VibrationsNatural Frequency: The natural frequency is the frequency at which a system tends to oscillate in the absence of any driving force. It is determined by the system's physical properties, such as mass and stiffness. For a simple harmonic oscillator, the natural frequency fnf_nfn is given by:fn=12πkmwhere kkk is the stiffness of the system and mmm is the mass.Undamped and Damped Vibrations:Undamped Vibrations: In an ideal scenario without any energy loss, the system continues to oscillate indefinitely. These are called undamped free vibrations.Damped Vibrations: In real systems, damping mechanisms such as friction or air resistance cause the amplitude of vibrations to gradually decrease over time. The damping factor determines how quickly the vibrations decay.Energy Transfer: In free vibrations, the energy oscillates between kinetic and potential forms. At maximum displacement, potential energy is at its peak, while at equilibrium, kinetic energy is highest.Forced VibrationsForced vibrations occur when an external force continuously drives a system. Unlike free vibrations, forced vibrations depend on the characteristics of the external force rather than the natural properties of the system alone.Characteristics of Forced VibrationsDriving Frequency: The frequency of the external force, known as the driving frequency, determines the response of the system. The system can be driven at any frequency, but its behavior varies significantly depending on the relation between the driving frequency and the natural frequency.Resonance: When the driving frequency matches the system's natural frequency, resonance occurs, resulting in a dramatic increase in amplitude. This can lead to excessive vibrations and potential failure in mechanical structures. The resonance frequency frf_rfr is crucial in design considerations to avoid catastrophic outcomes.Steady-State and Transient Response:Transient Response: When the external force is first applied, the system experiences a transient response before reaching a steady state. The transient response fades away over time, influenced by the system's damping.Steady-State Response: After the transient effects diminish, the system reaches a steady-state response where it vibrates at the driving frequency.Damping Effects: Damping plays a significant role in forced vibrations. Higher damping reduces the amplitude of vibrations and broadens the resonance peak, making the system less sensitive to resonance. The quality factor QQQ is a measure of damping, defined as:Q=fnΔfwhere Δf\Delta fΔf is the bandwidth over which the system resonates.Applications and ImplicationsUnderstanding free and forced vibrations is crucial for designing and analyzing various mechanical and structural systems.Engineering Structures: In civil engineering, structures such as bridges and buildings must be designed to withstand vibrations from environmental forces like wind and earthquakes. Ensuring that these structures do not resonate with these forces is critical for their stability and integrity.Mechanical Systems: Machines and engines experience vibrations due to moving parts and external forces. Proper vibration analysis and control are essential to prevent mechanical failure and enhance performance. For instance, balancing rotating parts reduces vibrations and prolongs the lifespan of machinery.Aerospace Engineering: Aircraft and spacecraft are subjected to a wide range of vibrational forces during operation. Understanding and mitigating forced vibrations ensure the safety and reliability of these vehicles.Acoustics: In acoustics, the principles of free and forced vibrations are applied to design musical instruments and soundproofing materials. Controlling vibrations can enhance sound quality and reduce unwanted noise.ConclusionFree and forced vibrations are foundational concepts in the study of vibrations, each with distinct characteristics and implications. Free vibrations describe the natural oscillations of a system, while forced vibrations involve external forces driving the system. Both play a vital role in various fields, from engineering to acoustics, highlighting the importance of understanding and controlling vibrational behavior in practical applications. By mastering these concepts, engineers and scientists can design safer, more efficient, and more reliable systems. In physics, the meaning of oscillation is advanced as an intermittent variety on the schedule of a matter with regards to its mean worth or between two fixed states. One complete pattern of occasional forward and backward movement of a body about its mean position serves to characterise one oscillation. Example of oscillation is the motion of a pendulum.Simple Harmonic MotionSimple harmonic motion involves a simple repetitive motion of back and forth, a central position, and the furthermost displacement on either side of the central position is the same. Each vibration is completed in the same period. The force of motion is directed towards the central position at all times, and the force is directly proportional to the distance from the central position.F = -kx Where F is the force, x is the displacement, and k is restoring/spring constant. This is known as Hooke's law.Key terms:Frequency: The number of oscillations completed per unit of time is the frequency of the particle's simple harmonic motion. The SI unit of frequency is Hertz. Amplitude: The magnitude of maximum displacement of a particle from its mean position during simple harmonic motion is called its amplitude. Period: The time when the particle completes one oscillation is called its period. Mean position of equilibrium: The particle's position during the motion when the net force acting on it is zero.Examples of OscillationDid you have any idea that the vibration of a guitar string is an illustration of swaying? The movements of a jungle gym swing, tuning forks are additionally instances of oscillatory movement. Since these are mechanical in nature, they are additionally called vibrations. The movement of rotating flow is likewise an illustration of oscillatory movement.Free, damped, and forced oscillationsThere are three fundamental types of straightforward oscillation motion:(a) free oscillations – basic oscillation motion with a consistent frequency and period and no outside impacts.(b) damped oscillations – basic oscillation motion yet with a diminishing frequency and fluctuating period because of outside or inside damping powers.(c) forced oscillations – basic oscillation motion under external force.Free OscillationFree oscillation contains a consistent period and amplitude without needing any external force to set it. Generally, free oscillation does not go through damping. But in the region of all-natural systems, the process of damping is observed till any consistent external force comes to overcome it. In this system, every property remains constant, including frequency, amplitude, and energy.Damped oscillationsDamping can be defined as the process of controlling or restraining oscillatory motion. For instance, mechanical vibrations cause dissipation of energy. It is noted that oscillation tends to remain undamped when induced force is equal to the restoring force for restraining external constraints and ensuring the object oscillates on the same energy. Additionally, if the restoring force is halted, the oscillations will suddenly stop; however, when the restraining force is greater than the applied restoring force, damping is introduced.The difference classifies damped oscillations noted between energy-related to acting restraining force and applied to restore forces. Damped oscillation tends to fade over time; thus, its magnitude reduces. An ideal oscillating system is not classified under damped oscillations. The ideal oscillation case is when its magnitude does not reduce with time and the amplitude stays the same throughout the oscillation process. Swinging on swings can be used as an example of damped oscillation. Swing does not move unless an external force pumps it and the motion of swing tends to fade away slowly, which means swing will stop over time if an external force is not applied again.Forced OscillationForced oscillation refers to the circumstances when any external periodic force causes the body to oscillate. In this scenario, oscillation amplitude goes through a damping process. However, there are no changes in amplitude and it remains constant. It is because the system has an external energy supply. Example: One person needs to push the other person periodically on the swing to avoid a reduction in the swing's motion.ConclusionOscillations can be defined as the process concerning the repetition of variations of any quantity from its equilibrium over a definite period. The movements of a jungle gym swing, tuning forks are additionally instances of oscillatory motion. There are three fundamental types of oscillatory motion: free oscillation, damped oscillation and forced oscillation. Featuring state-of-the-art Lion Precision Eddy Current Sensors, the new EDA500 controller is the ideal off-the-shelf solution for FSM and differential sensing applications. High bandwidth High resolution Excellent temperature stability Radiation tested to 75 krad TID Lion Precision's latest capacitive technology. High-resolution, high-speed, digital capacitive sensors for ultimate precision are now in a 2U height enclosure. Designed to provide high resolution measurements. Developed to successfully operate at up to 150°C. Designed to provide non-contact displacement measurements while submerged in saltwater or corrosive fluid. 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Our goal is to take your difficult precision problem and be an innovation partner to help put you in motion. The study of Physics Topics can help us understand and solve real-world problems, from climate change to medical imaging technology. What is the Difference Between Free Vibration And Forced Vibration? Practically all vibrations are damped vibrations. The vibrating body works against different resistive forces. So its energy diminishes and the amplitude gradually decreases. To maintain a steady vibration, energy from an external source is needed. If energy is supplied from an external source in such a way that the rate of supply of energy exactly balances the rate of loss of energy, then the amplitude of the body remains constant. The value of the amplitude is similar to that of free vibration of the body. This type of vibration is called a forced vibration. For example, if we do not wind a pendulum clock, it will stop after a while due to damping. When we wind the clock, we compress a spring within the clock which stores potential energy and supplies that energy continuously. The pendulum oscillates continuously with constant amplitude and time period. External means are required not only for maintaining the vibration, but also to vibrate a body that is initially at rest. Examples of forced vibration: i) If we strike a prong of a tuning fork, the intensity of the emitted sound ¡s not very high and so it cannot be heard from a distance. Now, if the handle of the vibrating turning fork is made to touch the surface of a table, the tuning fork sets the table surface into forced vibration. Sound is emitted from the table also. Hence, the sound is amplified. It must be kept in mind that, according to the principle of conservation of energy, the total amount of energy cannot be increased. When the handle of the tuning fork is pressed against a table surface, a part of the energy from the tuning fork is transferred to the table. As the damping of the table is higher than that of the tuning fork, the energy transferred to the table by the tuning fork decays at a faster rate. Hence, the vibration of the table stops earlier and the intensity of the sound produced due to vibration of the table is comparatively higher. In this example of forced vibration, the upper surface of the table is made to vibrate by the tuning fork. The vibration of the tuning fork is the driving vibration and the vibration of the upper surface of the table is the driven vibration. ii) A thread is tied loosely between P and Q [Fig.]. Two pendulums C and D, having different lengths, are suspended from two points between P and Q. If the pendulum C is made to oscillate, it will continue its oscillation with its natural frequency. As the thread PQ is tied loosely, energy will be transferred from pendulum C to pendulum D through the thread. As a result, the pendulum D will begin to oscillate. As the lengths of the pendulums are different, their natural frequencies are not the same. It is found that the pendulum D initially tries to oscillate at its natural frequency. But its vibration is damped quickly. Then pendulum D begins to oscillate at the natural frequency of C. In this example, pendulum C provides the driving vibration and the vibration of pendulum D is the driven vibration. In these two examples, it is to be noted that the external driving forces are neither steady nor momentary. Rather, the force originating from the vibrating body is a periodic force. In fact, the spring of a clock exerts a periodic force on the pendulum. Definition: If an external periodic force is applied to a freely vibrating body, the body tries to maintain its vibrations at its own frequency; but after some time, the body begins to vibrate with the frequency of the applied periodic force. Such a vibration of a body is called a forced vibration. Equation of motion: A particle under forced harmonic vibration in one-dimension is subject to three types of forces: A restoring force: The resultant of all the resistive forces acting on a particle is, F2 = -k'v = -k'\(\frac{d x}{d t}\) where v is the velocity of the particle and k' is a constant. Externally impressed periodic force: This is of the form, FF3 = F0sinωt where ω is the circular frequency and F0 is the amplitude of the periodic force; both ω and F0 are constants. The acceleration of the particle is, a = \(\frac{d v}{d t}\) = \(\frac{d^2 x}{d t^2}\). Then from the relation F = ma, we get ma = F1 + F2 + F3 or, m\(\frac{d^2 x}{d t^2}\) = -kx – k'\(\frac{d x}{d t}\) + F0sinωt or, m\(\frac{d^2 x}{d t^2}\) + k'\(\frac{d x}{d t}\) + kx = F0sinωt or, \(\frac{d^2 x}{d t^2}\) + 2b\(\frac{d x}{d t}\) + \(\omega_0^2 x\) = a0sinωt …….. (1) where, ω0 = ±\(\sqrt{\frac{k}{m}}\), b = ±\(\frac{k^{\prime}}{2 m}\) and a0 = ±\(\frac{F_0}{m}\) The equation (1) is known as the equation of motion of a forced SHM. It is to be noted that, the natural frequency ω0 of the particle vibration is, in general, different from the frequency ω0 of the particle vibration is, in general, different from the frequency ω of the external periodic force. In the special case, when ω = ω0, the phenomenon of resonance comes into play. Comparison between Free Vibration and Forced Vibration Free Vibration Forced Vibration 1. A body has free vibration if no force other than the restoring force acts on it. 1. If an external periodic force acts on a body, it executes a forced vibration. 2. The frequency of free vibration of a body depends on density, shape and elasticity of its material. 2. The frequency of forced vibration becomes equal to that of the applied periodic force. 3. The total energy of the vibrating body remains conserved. 3. The rate of loss of energy due to resistive forces is exactly compensated by the rate of supply of energy by the periodic force. 4. Free vibration ideally never dies out. But in reality, due to presence of damping forces, it dies out gradually. 4. Forced vibration continues as long as the applied periodic force acts on the body even in the presence of damping forces. In this article, you'll learn What is Vibration? And different types of vibration and their working are all explained with pictures.Also, you can download the PDF file at the end of this article.Vibration is a mechanical phenomenon causing oscillations around a fixed point. The vibration occurs when elastic bodies, like springs, are displaced from their equilibrium (fixed) positions due to external forces.This is because when a body is moved by external application, internal forces in the form of elastic or tension energy are present. These try to return the body to its original position when the pressure is released.All of the elastic energy in the body is converted into kinetic energy when the body reaches equilibrium, causing it to move in the opposite direction. As a result, the body is again able to achieve equilibrium due to the conversion of kinetic energy into elastic or strain energy.Thus, the vibrational motion is repeated, and energy is exchanged. Now, let's understand the different types of vibrations with the examples below.Read Also: Mechanical Properties That Every Engineer Should KnowFollowing are the types of vibrations:Free or natural vibrationForced vibrationDamped vibrationAlso known as natural vibration, it occurs when no external force has been applied to the body after a displacement has been given. The frequency of this type of vibration is called free or natural frequency.These vibrations occur when a machine is started in motion with no initial input and allowed to vibrate freely. The machine vibrates at one or more natural frequencies before becoming stable. The resolution of free vibration is usually approximately sinusoidal. The amplitude appears to decrease with time.Swinging a child back and letting it go.Tapping and letting the tuning fork sound.The oscillation of the simple pendulum.Musical instrument notes.Fluctuations of an object attached to a horizontal spring.Read Also: What are the different types of metals and their uses?Free vibrations are further classified into three types, which are described below:Longitudinal vibrationTransverse vibrationTorsional vibrationB = Mean Position, A and C = Extreme PositionWhen vibration has applied, the particles of the shaft or disc travel parallel to the axis of the shaft; this is known as longitudinal vibration.In this condition, the shaft is alternately lengthened and shortened, creating tensile and compressive stresses in the shaft. 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The machine vibrates at one or more natural frequencies before becoming stable. The resolution of free vibration is usually approximately sinusoidal. The amplitude appears to decrease with time.Swinging a child back and letting it go.Tapping and letting the tuning fork sound.The oscillation of the simple pendulum.Musical instrument notes.Fluctuations of an object attached to a horizontal spring.Read Also: What are the different types of metals and their uses?Free vibrations are further classified into three types, which are described below:Longitudinal vibrationTransverse vibrationTorsional vibrationB = Mean Position, A and C = Extreme PositionWhen vibration has applied, the particles of the shaft or disc travel parallel to the axis of the shaft; this is known as longitudinal vibration.In this condition, the shaft is alternately lengthened and shortened, creating tensile and compressive stresses in the shaft. For a sound wave traveling through the air, these vibrations are described as longitudinal.B = Mean Position, A and C = Extreme PositionWhen vibration is applied, the particles of the shaft or disc move back and forth in a direction perpendicular to the shaft axis; this is known as transverse vibration. In this case, the shaft is straightened and bent, causing bending stress in the shaft.B = Mean Position, A and C = Extreme PositionWhen vibration is applied, the particles of the shaft or disc rotate around the axis of the shaft; it is called torsional vibration. In this way, the shaft is twisted and separated alternately, creating torsional shear stress in the shaft.Read Also: What is Mechanical Measurement? Definitions & Terms Used to MeasurementsWhen a mechanical system is subjected to a time-varying disturbance (load, displacement, velocity, or acceleration), forced vibration occurs. Or, when a machine vibrates under external force, the machine is said to be under forced vibration.External forces acting on the body are periodic disturbances caused by imbalances. The frequency of these vibrations is proportional to the force applied. A resonance occurs when the external force has the same frequency as the natural vibrations. In this type of vibration, it is observed that the amplitude remains constant concerning time.A harmonic or non-harmonic disturbance can be used as a periodic input for the forced vibration.Shaking of washing machine due to imbalance.Transport vibrations that are induced by an engine or uneven road.The vibration of a moving vehicle is forced vibration, as the engine, springs, road, etc., continue to vibrate it.Buildings or apartments vibration during an earthquake.Read Also: Types of Furnaces: Their Working & ApplicationsThe damping vibration of a body is periodic and has decreasing amplitude when it is accompanied by resistance forces. Or, when there is a decrease in amplitude at each vibration, the motion is said to be damped vibration.This is because a certain amount of energy is always dissipated near the vibrating system in order to overcome the frictional resistances of motion.In this types of vibration, it is observed that the amplitude suddenly decreases with time. These types of vibration include music produced by a tuning fork at a greater distance. The vibrations of the Earth's surface are damping-free in the absence of an external force.A damping force is typically assumed to be proportional to the vibration velocity at low speeds and proportional to the square of vibration velocity at high speeds.F∝ V at a lower speedF∝ V2 at a higher speedC = damping force per unit velocity (damping coefficient)ωn = frequency of undamped vibrationsDegree of dampness:Damping factor:Damping CoefficientWhen ξ = 1, it is damping critical, thus under critical damping conditionsξ = c/cc = Actual or Critical damping coefficient(ξ > 1) it means the system is overdamped(ξ < 1) it means the system is underdampedωd = ωn√(1-ξ2)In a critically damped system, the displaced mass returns to a state of rest without oscillation in the shortest possible time.Undamped systems (ξ = 0) vibrate at their own natural frequency, which is determined by the constant deflection at their mass center.In critical damping (ξ = 1); ωd = 0 and Td = ∞. No vibrations occur in this system, and the mass 'm' slowly returns to equilibrium.An overdamped system (ξ > 1), It behaves similarly to the critical damping system.Read Also: What Are Different Types of Pulleys? [PDF]There are several methods that can be used to find the natural frequency, which are described below:Equilibrium methodEnergy methodRayleigh's methodIt is the principle that when a vibrating system is in equilibrium, the algebraic sum of the forces and moments acting on it is zero. This corresponds to d'Alembert's principle, which states that the inertial forces and external forces acting on a body in equilibrium must be zero.Let consider,Δ = static deflectionk = Stiffness of the springInertial force = ma(upwards, a = acceleration)Spring force = kx (upwards)Now the equation we will get is,Linear frequency fn = (1/2π)√(k/m)Time period T = 1/fn = 2π√(m/k)It is the principle wherein the total mechanical energy, i.e., the sum of the kinetic and potential energies, remains constant in a conservative system (without any damping).d/dt (K.E+ P.E.) = 0According to this principle, the maximum kinetic energy at a mean position would be equal to the maximum potential energy (or strain energy) at an extremum position.The displacement of mass 'm' from the mean position is given byLet A = X cos φ; B = X Sin φVelocity, Acceleration,These above relations show thatThe velocity vector moves the displacement vector forward by π/2.The acceleration vector moves the displacement vector forward by π.Now, consider, 'm' = man of the spring wire per unit lengthl = length of the spring wire m1 = m'lKE of the spring = 1/3 * KE of a mass equal to a spring moving with the same velocity as the free end.Read Also: Types of Fasteners: Their Uses & Examples [Explained]The objectives of why vibration analysis is necessary are as follows:Vibration can cause extreme failure in machines and structures.Its analysis is essential to minimize vibration through the proper design of machines and their mountings.It is done to improve the efficiency of some machining, casting, forging, and welding processes.Vibration causes rapid wear as well as excessive noise.Due to the vibration, the metal gives a poor surface finish in the cutting process.This is done to study earthquake flares for geological research and in the design of nuclear reactors.That's it. Thanks for reading. I hope I have covered everything about the "Types of Vibration." If I missed something, or if you have any doubts, let me know in the comments. If you liked this article, please share it with your friends.Want free PDFs direct to your inbox? Then subscribe to our newsletter.Download PDF of this article:You might like to explore more interesting articles in our blog: 5.4 Forced vibration of damped, single degree of freedom, linear spring mass systems. Finally, we solve the most important vibration problems of all. In engineering practice, we are almost invariably interested in predicting the response of a structure or mechanical system to external forcing. For example, we may need to predict the response of a bridge or tall building to wind loading, earthquakes, or ground vibrations due to traffic. Another typical problem you are likely to encounter is to isolate a sensitive system from vibrations. For example, the suspension of your car is designed to isolate a sensitive system (you) from bumps in the road. Electron microscopes are another example of sensitive instruments that must be isolated from vibrations. Electron microscopes are designed to resolve features a few nanometers in size. If the specimen vibrates with amplitude of only a few nanometers, it will be impossible to see! Great care is taken to isolate this kind of instrument from vibrations. That is one reason they are almost always in the basement of a building: the basement vibrates much less than the floors above. We will again use a spring-mass system as a model of a real engineering system. As before, the spring-mass system can be thought of as representing a single mode of vibration in a real system, whose natural frequency and damping coefficient coincide with that of our spring-mass system. We will consider three types of forcing applied to the spring-mass system, as shown below: External Forcing models the behavior of a system which has a time varying force acting on it. An example might be an offshore structure subjected to wave loading. Base Excitation models the behavior of a vibration isolation system. The base of the spring is given a prescribed motion, causing the mass to vibrate. This system can be used to model a vehicle suspension system, or the earthquake response of a structure. Rotor Excitation models the effect of a rotating machine mounted on a flexible floor. The crank with small mass rotates at constant angular velocity, causing the mass m to vibrate. Of course, vibrating systems can be excited in other ways as well, but the equations of motion will always reduce to one of the three cases we consider here. Notice that in each case, we will restrict our analysis to harmonic excitation. For example, the external force applied to the first system is given by The force varies harmonically, with amplitude and frequency . Similarly, the base motion for the second system is and the distance between the small mass and the large mass m for the third system has the same form. We assume that at time t=0, the initial position and velocity of each system is In each case, we wish to calculate the displacement of the mass x from its static equilibrium configuration, as a function of time t. It is of particular interest to determine the influence of forcing amplitude and frequency on the motion of the mass. We follow the same approach to analyze each system: we set up, and solve the equation of motion. 5.4.1 Equations of Motion for Forced Spring Mass Systems Equation of Motion for External Forcing We have no problem setting up and solving equations of motion by now. First draw a free body diagram for the system, as show on the right Newton's law of motion gives Rearrange and susbstitute for F(t) Check out our list of solutions to standard ODEs. We find that if we set , our equation can be reduced to the form which is on the list. The (horrible) solution to this equation is given in the list of solutions. We will discuss the solution later, after we have analyzed the other two systems. Equation of Motion for Base Excitation Exactly the same approach works for this system. The free body diagram is shown in the figure. Note that the force in the spring is now k(x-y) because the length of the spring is . Similarly, the rate of change of length of the dashpot is d(x-y)/dt. Newton's second law then tells us that Make the following substitutions and the equation reduces to the standard form Given the initial conditions and the base motion we can look up the solution in our handy list of solutions to ODEs. Equation of motion for Rotor Excitation Finally, we will derive the equation of motion for the third case. Free body diagrams are shown below for both the rotor and the mass Note that the horizontal acceleration of the mass is Hence, applying Newton's second law in the horizontal direction for both masses: Add these two equations to eliminate H and rearrange To arrange this into standard form, make the following substitutions whereupon the equation of motion reduces to Finally, look at the picture to convince yourself that if the crank rotates with angular velocity , then where is the length of the crank. The solution can once again be found in the list of solutions to ODEs. 5.4.2 Definition of Transient and Steady State Response. If you have looked at the list of solutions to the equations of motion we derived in the preceding section, you will have discovered that they look horrible. Unless you have a great deal of experience with visualizing equations, it is extremely difficult to work out what the equations are telling A Java applet posted at should help to visualize the motion. The applet will open in a new window so you can see it and read the text at the same time. The applet simply calculates the solution to the equations of motion using the formulae given in the list of solutions, and plots graphs showing features of the motion. You can use the sliders to set various parameters in the system, including the type of forcing, its amplitude and frequency; spring constant, damping coefficient and mass; as well as the position and velocity of the mass at time t=0. Note that you can control the properties of the spring-mass system in two ways: you can either set values for k, m and using the sliders, or you can set , K and instead. We will use the applet to demonstrate a number of important features of forced vibrations, including the following: The steady state response of a forced, damped, spring mass system is independent of the initial conditions. To convince yourself of this, run the applet (click on `start' and let the system run for a while). Now, press `stop'; change the initial position of the mass, and press `start' again. You will see that, after a while, the solution with the new initial conditions is exactly the same as it was before. Change the type of forcing, and repeat this test. You can change the initial velocity too, if you wish. We call the behavior of the system as time gets very large the `steady state' response; and as you see, it is independent of the initial position and velocity of the mass. The behavior of the system while it is approaching the steady state is called the `transient' response. The transient response depends on everything… Now, reduce the damping coefficient and repeat the test. You will find that the system takes longer to reach steady state. Thus, the length of time to reach steady state depends on the properties of the system (and also the initial conditions). The observation that the system always settles to a steady state has two important consequences. Firstly, we rarely know the initial conditions for a real engineering system (who knows what the position and velocity of a bridge is at time t=0?) . Now we know this doesn't matter the response is not sensitive to the initial conditions. Secondly, if we aren't interested in the transient response, it turns out we can greatly simplify the horrible solutions to our equations of motion. When analyzing forced vibrations, we (almost) always neglect the transient response of the system, and calculate only the steady state behavior. If you look at the solutions to the equations of motion we calculated in the preceding sections, you will see that each solution has the form The term accounts for the transient response, and is always zero for large time. The second term gives the steady state response of the system. Following standard convention, we will list only the steady state solutions below. You should bear in mind, however, that the steady state is only part of the solution, and is only valid if the time is large enough that the transient term can be neglected. 5.4.3 Summary of Steady-State Response of Forced Spring Mass Systems. This section summarizes all the formulas you will need to solve problems involving forced vibrations. Solution for External Forcing Equation of Motion with Steady State Solution: The expressions for and are graphed below, as a function of (a) (b) Steady state vibration of a force spring-mass system (a) amplitude (b) phase. Solution for Base Excitation Equation of Motion with Steady State solution The expressions for and are graphed below, as a function of (a) (b) Steady state vibration of a base excited springmass system (a) Amplitude and (b) phase Solution for Rotor Excitation Equation of Motion with Steady State solution The expressions for and are graphed below, as a function of (a) (b) Steady state vibration of a rotor excited springmass system (a) Amplitude (b) Phase 5.4.4 Features of the Steady State Response of Spring Mass Systems to Forced Vibrations. Now, we will discuss the implications of the results in the preceding section. The steady state response is always harmonic, and has the same frequency as that of the forcing. To see this mathematically, note that in each case the solution has the form . Recall that defines the frequency of the force, the frequency of base excitation, or the rotor angular velocity. Thus, the frequency of vibration is determined by the forcing, not by the properties of the spring-mass system. This is unlike the free vibration response. You can also check this out using our applet. To switch off the transient solution, click on the checkbox labeled `show transient'. Then, try running the applet with different values for k, m and , as well as different forcing frequencies, to see what happens. As long as you have switched off the transient solution, the response will always be harmonic. The amplitude of vibration is strongly dependent on the frequency of excitation, and on the properties of the springmass system. To see this mathematically, note that the solution has the form . Observe that is the amplitude of vibration, and look at the preceding section to find out how the amplitude of vibration varies with frequency, the natural frequency of the system, the damping factor, and the amplitude of the forcing. The formulae for are quite complicated, but you will learn a great deal if you are able to sketch graphs of as a function of for various values of . You can also use our applet to study the influence of forcing frequency, the natural frequency of the system, and the damping coefficient. If you plot position-v-time curves, make sure you switch off the transient solution to show clearly the steady state behavior. Note also that if you click on the `amplitude v- frequency' radio button just below the graphs, you will see a graph showing the steady state amplitude of vibration as a function of forcing frequency. The current frequency of excitation is marked as a square dot on the curve (if you don't see the square dot, it means the frequency of excitation is too high to fit on the scale if you lower the excitation frequency and press `start' again you should see the dot appear). You can change the properties of the spring mass system (or the natural frequency and damping coefficient) and draw new amplitude-v-frequency curves to see how the response of the system has changed. Try the following tests (i) Keeping the natural frequency fixed (or k and m fixed), plot ampltude-v-frequency graphs for various values of damping coefficient (or the dashpot coefficient). What happens to the maximum amplitude of vibration as damping is reduced? (ii) Keep the damping coefficient fixed at around 0.1. Plot graphs of amplitude-v-frequency for various values of the natural frequency of the system. How does the maximum vibration amplitude change as natural frequency is varied? What about the frequency at which the maximum occurs? (iii) Keep the dashpot coefficient fixed at a lowish value. Plot graphs of amplitude-v-frequency for various values of spring stiffness and mass. Can you reconcile the behavior you observe with the results of test (ii)? (iv) Try changing the type of forcing to base excitation and rotor excitation. Can you see any differences in the amplitude-v-frequency curves for different types of forcing? (v) Set the damping coefficient to a low value (below 0.1). Keep the natural frequency fixed. Run the program for different excitation frequencies. Watch what the system is doing. Observe the behavior when the excitation frequency coincides with the natural frequency of the system. Try this test for each type of excitation. If the forcing frequency is close to the natural frequency of the system, and the system is lightly damped, huge vibration amplitudes may occur. This phenomenon is known as resonance. If you ran the tests in the preceding section, you will have seen the system resonate. Note that the system resonates at a very similar frequency for each type of forcing. As a general rule, engineers try to avoid resonance like the plague. Resonance is bad vibrations, man. Large amplitude vibrations imply large forces; and large forces cause material failure. There are exceptions to this rule, of course. Musical instruments, for example, are supposed to resonate, so as to amplify sound. Musicians who play string, wind and brass instruments spend years training their lips or bowing arm to excite just the right vibration modes in their instruments to make them sound perfect. There is a phase lag between the forcing and the system response, which depends on the frequency of excitation and the properties of the spring-mass system. The response of the system is . Expressions for are given in the preceding section. Note that the phase lag is always negative. You can use the applet to examine the physical significance of the phase lag. Note that you can have the program plot a graph of phase-v-frequency for you, if you wish. It is rather unusual to be particularly interested in the phase of the vibration, so we will not discuss it in detail here. 5.4.5 Engineering implications of vibration behavior The solutions listed in the preceding sections give us general guidelines for engineering a system to avoid (or create!) vibrations. Preventing a system from vibrating: Suppose that we need to stop a structure or component from vibrating e.g. to stop a tall building from swaying. Structures are always deformable to some extent this is represented qualitatively by the spring in a spring-mass system. They always have mass this is represented by the mass of the block. Finally, the damper represents energy dissipation. Forces acting on a system generally fluctuate with time. They probably aren't perfectly harmonic, but they usually do have a fairly well defined frequency (visualize waves on the ocean, for example, or wind gusts. Many vibrations are man-made, in which case their frequency is known for example vehicles traveling on a road tend to induce vibrations with a frequency of about 2Hz, corresponding to the bounce of the car on its suspension). So how do we stop the system from vibrating? We know that its motion is given by Our vibration solution predicts that the mass vibrates with displacement Again, the graph is helpful to understand how the vibration amplitude varies with system parameters. Clearly, we can minimize the vibration amplitude of the mass by making . We can do this by making the spring stiffness as small as possible (use a soft spring), and making the mass large. It also helps to make the damping small. This is counter-intuitive people often think that the energy dissipated by the shock absorbers in their suspensions that makes them work. There are some disadvantages to making the damping too small, however. For one thing, if the system is lightly damped, and is disturbed somehow, the subsequent transient vibrations will take a very long time to die out. In addition, there is always a risk that the frequency of base excitation is lower than we expect if the system is lightly damped, a potentially damaging resonance may occur. Suspension design involves a bit more than simply minimizing the vibration of the mass, of course the car will handle poorly if the wheels begin to leave the ground. A very soft suspension generally has poor handling, so the engineers must trade off handling against vibration isolation. 5.4.6 Using Forced

Vibration Response to Measure Properties of a System. We often measure the natural frequency and damping coefficient for a mode of vibration in a structure or component, by measuring the forced vibration response of the system. Here is how this is done. We find some way to apply a harmonic excitation to the system (base excitation might work; or you can apply a force using some kind of actuator, or you could deliberately mount an unbalanced rotor on the system). Then, we mount accelerometers on our system, and use them to measure the displacement of the structure, at the point where it is being excited, as a function of frequency. We then plot a graph, which usually looks something like the picture on the right. We read off the maximum response , and draw a horizontal line at amplitude . Finally, we measure the frequencies , and as shown in the picture. We define the bandwidth of the response as Like the logarithmic decrement, the bandwidth of the forced harmonic response is a measure of the damping in a system. It turns out that we can estimate the natural frequency of the system and its damping coefficient using the following formulae The formulae are accurate for small - say . To understand the origin of these formulae, recall that the amplitude of vibration due to external forcing is given by We can find the frequency at which the amplitude is a maximum by differentiating with respect to , setting the derivative equal to zero and solving the resulting equation for frequency. It turns out that the maximum amplitude occurs at a frequency For small , we see that Next, to get an expression relating the bandwidth to , we first calculate the frequencies and . Note that the maximum amplitude of vibration can be calculated by setting , which gives Now, at the two frequencies of interest, we know , so that and must be solutions of the equation Rearrange this equation to see that This is a quadratic equation for and has solutions Expand both expressions in a Taylor series about to see that so, finally, we confirm that 5.4.7 Example Problems in Forced Vibrations Example 1: A structure is idealized as a damped springmass system with stiffness 10 kN/m; mass 2Mg; and dashpot coefficient 2 kNs/m. It is subjected to a harmonic force of amplitude 500N at frequency 0.5Hz. Calculate the steady state amplitude of vibration. Start by calculating the properties of the system: Now, the list of solutions to forced vibration problems gives For the present problem: Substituting numbers into the expression for the vibration amplitude shows that Example 2: A car and its suspension system are idealized as a damped springmass system, with natural frequency 0.5Hz and damping coefficient 0.2. Suppose the car drives at speed V over a road with sinusoidal roughness. Assume the roughness wavelength is 10m, and its amplitude is 20cm. At what speed does the maximum amplitude of vibration occur, and what is the corresponding vibration amplitude? Let s denote the distance traveled by the car, and let L denote the wavelength of the roughness and H the roughness amplitude. Then, the height of the wheel above the mean road height may be expressed as Noting that , we have that i.e., the wheel oscillates vertically with harmonic motion, at frequency . Now, the suspension has been idealized as a springmass system subjected to base excitation. The steady state vibration is For light damping, the maximum amplitude of vibration occurs at around the natural frequency. Therefore, the critical speed follows from Note that K=1 for base excitation, so that the amplitude of vibration at is approximately Note that at this speed, the suspension system is making the vibration worse. The amplitude of the car's vibration is greater than the roughness of the road. Suspensions work best if they are excited at frequencies well above their resonant frequencies. Example 3: The suspension system discussed in the preceding problem has the following specifications. For the roadway described in the preceding section, the amplitude of vibration may not exceed 35cm at any speed. At 55 miles per hour, the amplitude of vibration must be less than 10cm. The car weighs 3000lb. Select values for the spring stiffness and the dashpot coefficient. We must first determine values for and that will satisfy the design specifications. To this end: (i) The specification requires that at resonance. Examine the graph of shown with the solutions to the equations of motion. Recall that K=1 for a base excited springmass system. Observe that, with , the amplification factor never exceeds 1.75. (ii) Now, the frequency of excitation at 55mph is We must choose system parameters so that, at this excitation frequency, . Examine the graph showing the response of a base excited springmass system again. We observe that, for , for . Therefore, we pick . Finally, we can compute properties of the system. We have that Similarly An oscillation is simply the periodic back-and-forth motion between two positions or states. We have seen many real-life scenarios of such motion in daily life, such as the side-to-side swing of a pendulum or the up-and-down motion of spring with a weight show oscillation. Due to the absence of 'eternal motion' in physical experiments, we encounter various types of oscillations, including free, forced, and damped oscillations. The derived mathematical expressions of such motion become very useful in tailoring the efficiency of a mechanical system. Periodic motion repeats itself in a regular cycle, like a sine wave—a wave with eternal motion. Oscillation depends upon the period, frequency and amplitude of oscillation. An oscillating movement occurs around an equilibrium point. Here, we will learn more about free, forced, and damped oscillations and solve some related questions. [Click Here for Sample Questions] Oscillation is the periodic fluctuation of an object about its mean value or between two fixed states. The point at which the body starts moving is called the mean or equilibrium position. It is a time-dependent quantity that is calculated in terms of a condition of equilibrium. The motion produces a continuous, repeated, alternating waveform without any input. The unit of oscillation is Hertz. We can also induce electrical oscillations in a circuit through a device called an oscillator. The oscillograph and oscilloscope are two more instruments based on oscillation principles. Oscillators might be mechanical or electrical, but they all function in the same way. It occurs in everything from tides and the pendulum of a clock to our decision-making process. Damped, free and forced oscillation depends upon three quantities, which are as follows: Physical Quantities Definition S.I Unit Time Period The time taken by the oscillating body to complete one complete oscillation is called the period of oscillation. Second Frequency The number of oscillations completed by oscillating body per second is called the frequency of oscillation. Hertz Amplitude The maximum displacement of the oscillating body with respect to the mean position is called the amplitude of oscillation. Metre Oscillation Damped, Free and Forced Oscillation [Click Here for Sample Questions] Oscillation can be classified into three categories: Damped, free and forced oscillation. Damped Oscillation Damped oscillation is a type of oscillation in which the amplitude decreases with respect to time. The reduction in amplitude is due to external variables like friction or air resistance, which cause damping, resulting in energy loss from the system. An object is called damped when there is a difference between the applied restoring force and the restraining force acting on the object. The fading oscillations of a pendulum are an example. Underdamped and overdamped oscilllation are two different types of damped oscillation. The situation when the amplitude of oscillation never becomes zero even after significant deceleration is called underdamped oscillation. The situation when the amplitude of oscillation reaches zero due to a significant reduction in amplitude is called overdamped oscillation. Free Oscillation A free oscillation occurs when a body vibrates at its own frequency. Without any external force to set the oscillation, this oscillation has a constant amplitude and time. Free oscillation does not experience any form of damping. It is a type of oscillation that exhibits natural frequency, which corresponds to the constant amplitude, energy, and time period. The vibrations in a tuning fork are an example. Forced Oscillation A forced oscillation occurs when any object oscillates as a result of an external periodic force. Since other external energy is supplied to it, the amplitude of the oscillation is damped but remains constant. It is also known as a driven or forced harmonic oscillator. Example of Forced Oscillation For instance, when you're playing with a toy that requires you to sustain an object using an elastic band dangling from your finger. If you keep your finger motionless, the object will bounce up and down with a modest bit of dampening at first. The thing will follow your finger as you move it up and down. As you raise the frequency with which you move your fingers, the item responds by oscillating with increasing amplitude. Calculation of Damped, Free and Forced Oscillation [Click Here for Sample Questions] When a body is in the oscillatory motion then three terms are used in the calculation namely time period, frequency and amplitude. Each succeeding string vibration takes the same amount of time as the preceding one. So, we get 'period' (T), the amount of time it takes to complete one oscillation. Consider l l be the length of the string, then its time period is given by $T=2\pi\sqrt{l/g}$ Where, T : time period of oscillation L : length of string g : acceleration due to gravity The relation between time period and frequency is given by frequency (η) = 1/ time period (T) $\eta = 1/T$ Examples of Oscillations [Click Here for Sample Questions] Oscillatory motion is prominent in- Pendulum Clock. Tuning Fork. Swing. Flapping of Wings. A freely hanging Bob. String Musical Instruments. Spring Toy. Alternating Current. Simple Harmonic Motion [Click Here for Sample Questions] Simple harmonic motion is defined as a repeated back-and-forth movement about a central position with the maximum displacement on one side equal to the maximum displacement on the other. The time interval between each full vibration is the same. It is characterized by a variable acceleration that is proportionate to the displacement from the equilibrium point. It is a special case of oscillatory motion. Linear Simple Harmonic Motion and Angular Simple Harmonic Motion are two types of Simple Harmonic Motion. Furthermore, the time period between complete vibrations is constant and independent of the greatest displacement size. Mathematically, it can be represented as: $F = -kx$ where F stands for force x stands for displacement k stands for a constant or restoring force constant. The vibrating of a mass coupled to a vertical spring, the other end of which is anchored in a ceiling, is an example of a simple harmonic oscillator. The spring is at its most tensioned at maximum displacement x, which forces the mass upward. The spring reaches its greatest compression at maximum displacement +x, which forces the mass downward again. At either side of maximum displacement, the force is largest and directed toward the equilibrium position, the mass's velocity (v) is zero, its acceleration is at a maximum, and the mass changes direction. In the equilibrium position, the velocity is at its highest, and the acceleration (a) is zero. An example of Simple Harmonic Oscillator Things to Remember Oscillation refers to the periodic back-and-forth movement of something between two positions or states. Resonance is the phenomenon of driving a system with a frequency equal to its natural frequency. The forced oscillation occurs when a body oscillates as a result of an external periodic force. A free oscillation occurs when a body vibrates at its frequency. Damped oscillation is a type of oscillation that reduces with time. Ques. Can a motion be periodic and not oscillatory? Explain. (2 marks) Ans: Although every oscillatory motion is periodic, not all periodic motions are oscillatory. Circular motion is a periodic but not oscillatory motion. The difference between oscillations and vibrations is insignificant. Ques. What is resonance, and how can it be detected? (2 marks) Ans: When a system can store and quickly transfer energy between two or more separate storage modes (such as kinetic and potential energy in the case of a basic pendulum), it is said to be in resonance. Some systems have numerous resonance frequencies that are distinct. Ques. Is it possible for a motion to be oscillatory while not being simple harmonic? Give a reasoned explanation. (2 marks) Ans: Yes, when a ball is dropped from a height onto a completely elastic surface, the motion is oscillatory but not simple harmonic since the restoring force F = mg = constant rather than $F \propto -x$, which is a need for S.H.M. Ques. What are the conditions for simple harmonic motion? (2 marks) Ans: The conditions for simple harmonic motion are as follows: The system must be subjected to an elastic restoring force. Inertia is required in the system. The system's acceleration should be proportional to its displacement and always point to the mean location. Ques. How does the damping affect amplitude in forced oscillation? (3 marks) Ans: An under-damped oscillator's amplitude diminishes exponentially. Damping is the process of reducing the magnitude of oscillations due to energy dissipation. The bigger the amplitude of the induced oscillations towards resonance, the less damping a system has. A system's response to varied driving frequencies is broader the more damping it has. Ques. When can resonance be observed? (2 marks) Ans: When a system can store and transmit energy between two or more separate storage modes (for example, kinetic and potential energy in the case of a basic pendulum), it is said to be in resonance. The resonance frequencies of certain systems are many and different. Ques. Explain demonstration of resonance with tuning forks? (2 marks) Ans: The times of the tuning fork vibrate at their natural frequency, causing sound waves to impinge on the resonance tube's opening. The impinging sound waves from the tuning fork cause the air within the resonance tube to vibrate at the same frequency. Ques. What happens when the oscillation is damped? (2 marks) Ans: Non-conservative forces diminish the energy of damped harmonic oscillators. Without overshooting, critical damping brings the system to equilibrium as quickly as possible. In an underdamped system, the equilibrium position will oscillate. Ques. A spring with a 2500 N/m spring constant is crushed by 0.87m. What is the total amount of potential energy that has been generated? (3 marks) Ans. The potential energy of a spring is given by : PE = 1/2kx2 Putting the value of k, spring constant, and x, displacement in the above equation, we get: PE = ½ (2500) (0.87) PE = 1087.5 J Ques. A 0.7kg mass is linked to one of the springs, which oscillates with a 5 s period. What is the frequency of the event? (2 marks) Ans. The link between frequency and period is unaffected by mass. The equation that describes this relationship is: f = 1/T The frequency will be equal to the reciprocal of the period. f = 1/T => f = ⅕=> f = 0.2 Hz Ques. A spring with a 500 N/m spring constant is crushed by 0.17m. What is the total amount of potential energy that has been generated? (3 marks) Ans. The potential energy of a spring is given by : PE = 1/2kx2 Putting the value of k, spring constant, and x, displacement in the above equation, we get : PE = ½ (500) (0.17) PE = 42.5 J