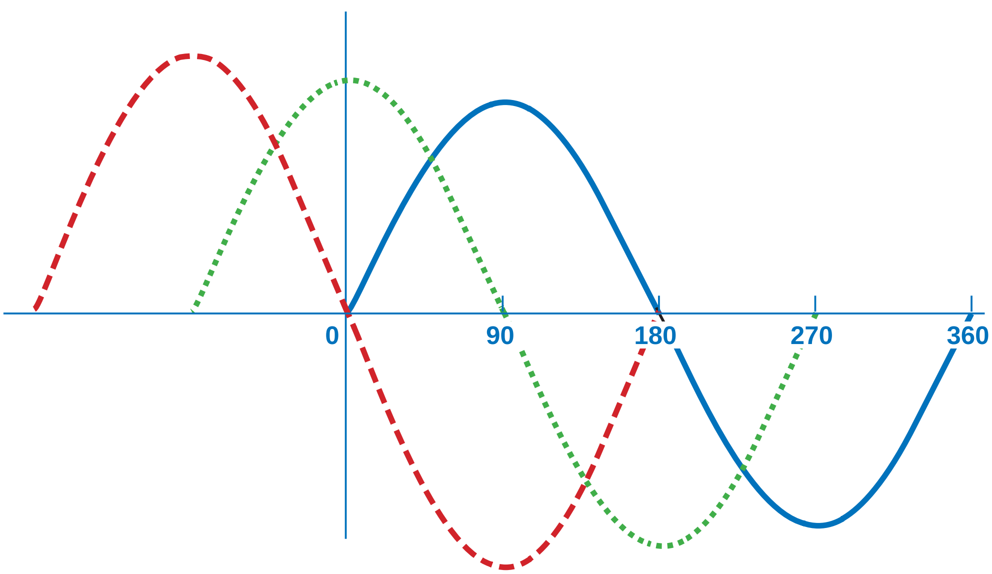
Training Module

Describe Basic Vibration Concepts



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- Training Module and Self-Check
- Blank Answer Sheet
- Knowledge Check and Answer Key
- Performance Check

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Contents

Contents (continued)

Training Objectives

Upon completion of this training kit, you will be able to:

- Describe the purpose and importance of vibration detection and analysis
- Describe the roles of operators and maintenance personnel in vibration detection and analysis
- Describe vibration characteristics
- Identify the three most common sources of vibration
- Describe the vibration characteristics for each source of vibration
- Identify the common types of vibration transducers
- Describe the effectiveness of different types of transducer mounting methods
- Describe vibration measurement instruments
- Complete the site vibration familiarization checklist

This training kit may contain technical terms which are new to you. Refer to the glossary, located at the end of this module, for an explanation of terms.

1 Introduction

Each major piece of equipment must function reliably to ensure optimal productivity. Of all the different types of equipment, rotating equipment tends to be among the most critical because:

- rotating equipment has moving parts that are more likely to fail than stationary parts
- failure of rotating equipment that is part of a process system often results in a loss of system throughputs and can potentially cause a complete shutdown of the system

All rotating equipment vibrates. The amount of vibration indicates the condition of the equipment. Because vibration can be seen, felt, and heard, you can determine if rotating equipment is operating normally or if there is a change in the equipment's vibration.

Using your senses to determine vibration levels requires experience. You must first be able to identify the vibration created by equipment operating normally (that is, establish a base line for normal vibration) in order to identify abnormal vibration. When the vibration of a piece of equipment slowly changes over a period of time (for example, six months), you may not be able to recognize the change in vibration because:

- the day-to-day change in vibration is too small to be detected
- you may forget the baseline vibration of the equipment

As rotating equipment technology improves and becomes more reliable and energy efficient, vibration levels drop. Using your senses to detect and measure these lower levels of vibration is not sufficiently reliable to determine the operating condition of the equipment. Using vibration detection and diagnostic instruments improve the reliability of vibration measurements. Vibration instruments also provide data on specific vibration characteristics such as frequency and amplitude.

Vibration detection and diagnostic instruments may either be permanently installed or portable:

- **permanently installed** vibration detection instruments continuously monitor the vibration levels of rotating equipment.

  If the rotating equipment exceeds a preset vibration limit, the vibration detection instruments sound an alarm to notify you of the operating condition. If the rotating equipment's vibration level continues to rise and exceeds a second preset vibration limit, the vibration detection instruments will shut down the rotating equipment.

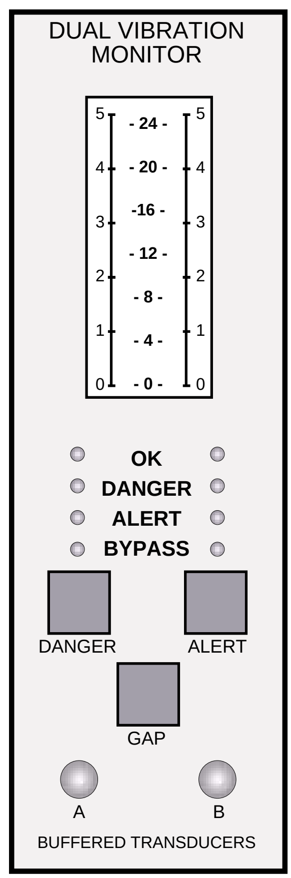


Figure 1—Fixed Vibration Detection Instrument

- **portable vibration detection** instruments allow company personnel to measure equipment vibration on both a routine and a needs basis. On a needs basis, vibration readings can help to determine the specific location and cause of vibration.

Figure 2—Handheld Vibration Detection Instrument

Vibration detection instruments detect vibration by converting vibration to electrical signals. The signals are amplified and then displayed as data on a meter, a digital display, or a chart. Personnel then interpret the data to determine the location and specific cause of the vibration. The vibration may be due to a number of factors including:

- imbalance
- misalignment
- resonance
- mechanical defects of bearing, couplings, etc.

Often, routine equipment vibration measurements are taken as part of a facility's preventative and predictive maintenance program. When new or rebuilt rotating equipment is first operated, a base line for vibration is established. As the equipment wears, company personnel can compare the current vibration data with base line vibration data to determine the degree of change in equipment operating conditions. The information is then used to identify the cause of the abnormal vibration and predict when a failure might occur. A more informed decision can then be made as to the type of corrective action required to optimize production and minimize losses.

This module, *Describe Basic Vibration Concepts*, describes vibration characteristics, causes of vibration, and methods used to detect vibration. This module also describes common types of instruments used to measure vibration and identifies the vibration instruments' specific applications. A more advanced module titled *Perform Vibration Analysis* provides directions for using vibration data to identify sources of vibration, to determine the severity of the vibration, and to help decide on the best course of action.

2 Purpose and Importance of Vibration Analysis

All rotating equipment vibrates to some degree. Maintaining the equipment's vibration level within the manufacturer's specifications contributes to the safe and cost-effective operation of that equipment. Excessive equipment vibration could lead to premature equipment failure, increased maintenance cost, and decreased productivity. To effectively monitor equipment vibration, maintenance personnel periodically conduct a vibration analysis. Vibration analysis is the process by which maintenance personnel:

- take vibration readings from rotating equipment
- determine the severity of the vibration
- identify the cause of excessive vibration in the equipment
- suggest corrective action to eliminate the vibration problem

At some facilities, vibration analysis is used as part of a comprehensive preventative and predictive maintenance program. Maintenance personnel use vibration data to predict the amount of time the rotating equipment can run before breakdown. Preventative action can then be taken to avoid costly repairs and lost productivity. If an effective preventative and predictive maintenance program is used, the following benefits can be realized:

- safer work environment
- higher productivity
- increased operating time

- higher levels of rotating equipment performance
- decreased maintenance cost
- lower energy cost
- reduced product waste

3 Rotating Equipment Vibration and Vibration Characteristics

Vibration is defined as a back and forth motion across a neutral position (equilibrium). The back and forth motion of a vibrating object is complex because the vibrating motion has several different characteristics including:

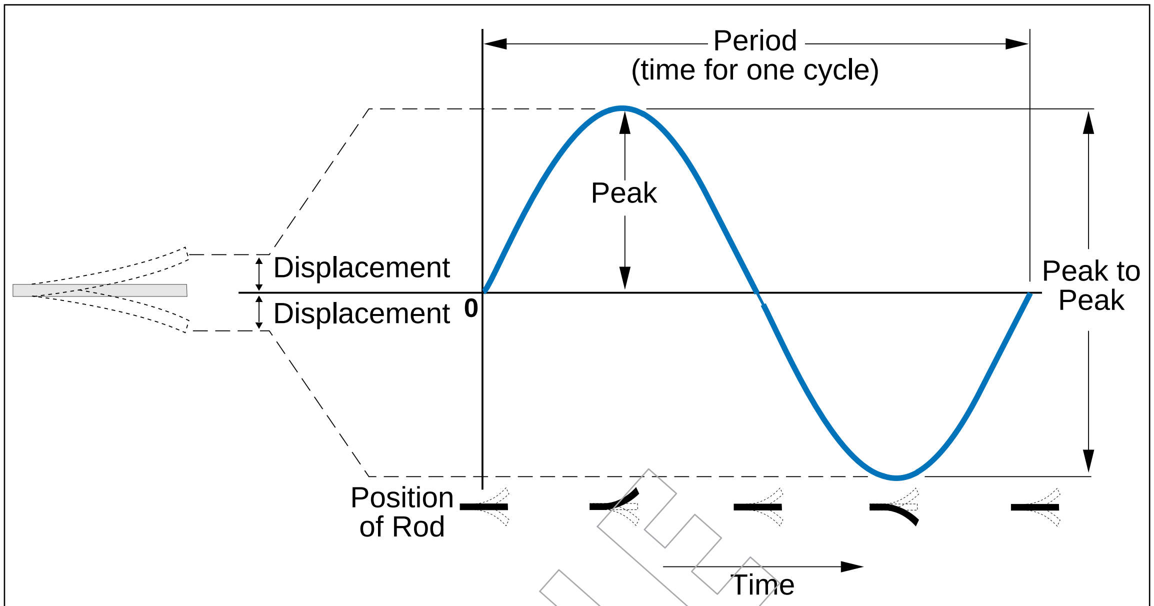
- displacement
- frequency
- velocity
- acceleration
- phase

Industry uses several different methods, including numerical values and graphs, to describe these characteristics of vibration. Maintenance must be able to use the various forms of vibration data to analyze equipment vibration and determine the vibration's source.

3.1 Vibration Displacement and Frequency

Graphs of the vibrating motion are often used to describe the characteristics of the vibration. For example, the back and forth motion of the vibrating rod in Figure 3 can be measured and results plotted on graph paper. The motion of the vibration is depicted as a wave form (known mathematically as a sine wave form).

Figure 3—Graphic Representation of a Vibrating Object



The graph in Figure 3 describes two vibration characteristics:

Displacement—is the distance the vibrating metal rod moves from its neutral position. The graph shows the maximum displacement as *peak amplitude*. *Peak-to-peak amplitude* on the graph indicates the maximum distance the rod moves from one extreme position to the other extreme position. Displacement is measured in mils (one mil is equal to 0.001 inch) or in micrometers (one micrometer is equal to 0.001 millimeters). When there is an increase in the rod's displacement, the vibration becomes more severe.

Frequency—is the number of vibration cycles that the rod experiences in one second. The graph in Figure 3 shows one cycle of the rod's vibration and the *period* of time required to complete that cycle. Mathematically, the frequency of the vibration is calculated by using the following formula:

$$\text{Frequency} = \frac{1}{\text{period}} = \text{cycles per second, or hertz} \qquad f = \frac{1}{t} \quad t = \frac{1}{f}$$

or

$$\text{Frequency} = \frac{\text{number of cycles}}{\text{time}} \qquad f = \frac{\text{cycles}}{t}$$

Several important vibration analysis concepts are associated with frequency:

- All objects have a *natural* vibrating frequency. If an object is struck (e.g., with a hammer), the object will vibrate at its *natural* frequency. Most equipment has more than one natural vibration frequency. The natural frequency of the equipment changes when the equipment is weighted or when bracing is added.

- An increase in vibration frequency results in an increase in vibration severity (the degree to which the vibration contributes to component failure). Each time the metal completes one cycle of vibration, the metal experiences stress. As the frequency increases, the metal flexes more often. If the vibration stress is above the metal fatigue limit, the increased frequency of flexing reduces the time for the metal to fail due to fatigue.

- The severity of vibration in equipment tends to remain constant (reaches a steady state) because the materials making up the equipment absorb the energy created by the vibrating forces. However, if the forced vibration is at the same frequency as the equipment's natural vibration frequency, the vibration is amplified. Amplification of the vibration occurs because the motion of the forced vibration is in time with the natural vibration. An example of this condition, known as *resonance,* would be pushing a child on a swing. If timed correctly, each push adds to the *amplitude* of the swing's motion.

- The motion of a point on a rotating shaft can be described in terms of a sine wave, as shown in Figure 4. The graph shows the *vertical* position of the point on the shaft as the shaft rotates. In this graph, time is measured in terms of degrees.

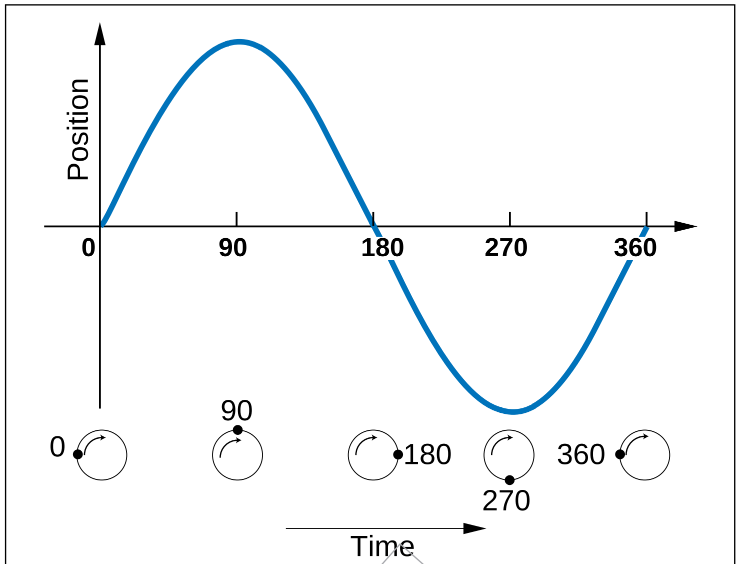


Figure 4— Graphic Representation of a Rotating Point

- The ability to describe rotation in terms of a sine wave is fundamental to vibration analysis. For example, an imbalanced shaft exerts a force that produces a vibration which matches the rotational speed of the shaft.

- If the rotational speed of the shaft matches the natural frequency of the equipment, severe vibration occurs because resonance is created. The term *critical speed* is used to identify the rotational speed which matches the equipment's natural vibration. Manufacturers attempt to design equipment so that the critical speed is outside the operating range of the equipment. However, some turbines have a critical speed which is below the operating speed of the turbine. During startup, the turbine must pass through the critical speed to reach the operating speed. When this situation occurs, the manufacturer recommends that the turbine be brought up to the operating speed as quickly as possible. This startup strategy minimizes the length of time at which the turbine's rotation speed is near the critical speed.

- In vibration analysis, the fundamental frequency equals the equipment's rotational speed. The fundamental frequency can be represented as revolutions per second:

1 Hz (frequency) = 1 rps (revolution per second)

Some vibration instrument manufacturers refer to the rotational speed in terms of rpm (revolutions per minute). To convert units:

rpm = 60 rps = 60 Hz

rpm = 60 x rps   rpm = 60 x Hz

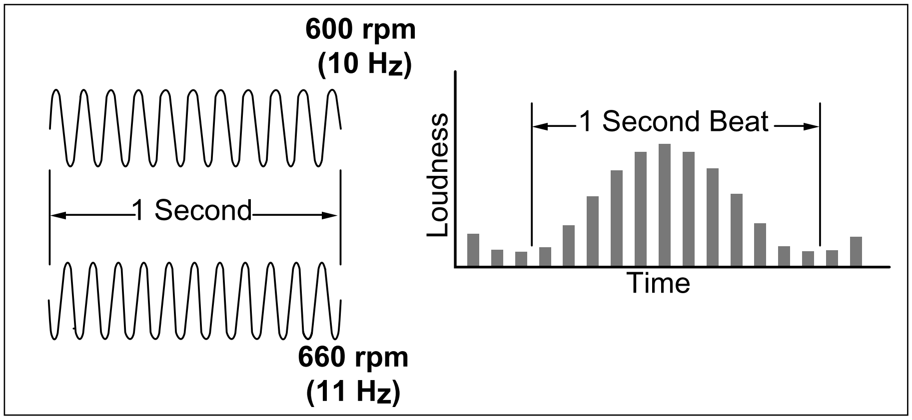
$$\text{rps} = \frac{\text{rpm}}{60} \qquad \text{Hz} = \frac{\text{rpm}}{60}$$

- *Harmonics* are vibration frequencies which are exact multiples of the fundamental frequency. To calculate a harmonic frequency, multiply the fundamental frequency by any whole number (times 1, times 2, etc.). For example, if the fundamental frequency is 1000 Hz, the next two harmonic frequencies would be 2000 Hz and 3000 Hz. Since the fundamental frequency equals rotational speed, harmonics can then be calculated as multiples of the rps (example, 1 x rps, 2 x rps, etc.). Some vibration instrument manufacturers express the harmonic frequencies in terms of rpm (example, 1 x rpm, 2 x rpm, etc.).

  Often the presence of harmonic frequencies is an indication of the source of the vibration. The training kit *Perform Vibration Analysis* provides a detailed description of the relationships between vibration characteristics and the source of the vibration.

- When two adjacent machines are operating close to the same rpm, a sound which alternately builds up and then falls in amplitude can sometimes be heard. This sound is called a *beat* frequency. The beat frequency is equal to the difference between the two rpms of the machines. For example, one machine is operating at 600 rpm (10 Hz) and another machine is operating at 660 rpm (11 Hz). The difference in rotational speed between the two machines is 60 rpm (1 Hz). In this example, the amplitude of the sound rises and falls once per second. A beat frequency can sometimes cause difficulties in balancing equipment because the beat frequency can cause a continuous shift in vibration phase. Vibration phase is explained in section 3.4 of this module.

Figure 5— Beat Frequency



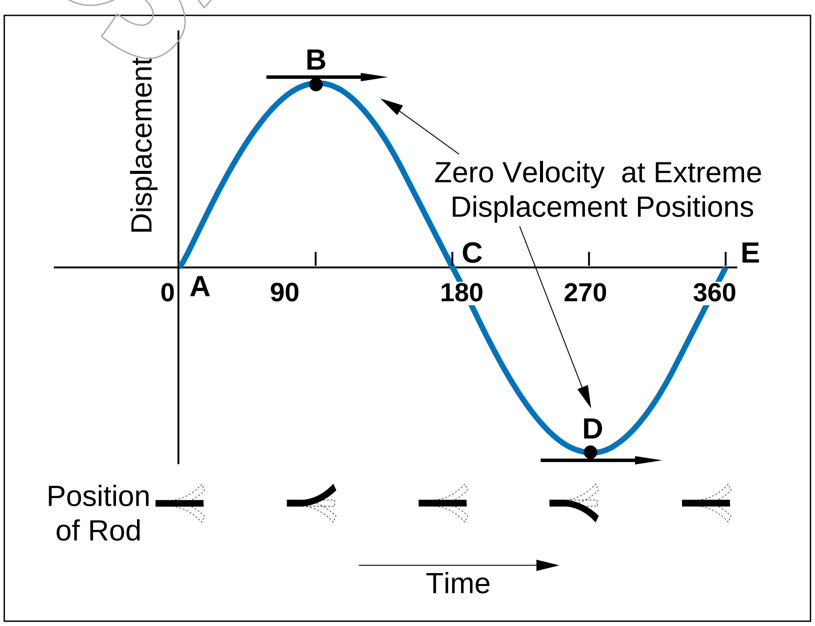
3.2 Vibration Velocity

Velocity is the measure of the speed of the vibrating object. Velocity is defined as distance divided by time. For example, the distance between two cities is 300 kilometers. If it takes 3 hours to drive the 300 kilometers, the velocity is 100 km/hr

$$\text{velocity} = \frac{\text{distance}}{\text{time}} = \frac{300\text{ km}}{3\text{ h}} = \frac{100\text{ km}}{\text{h}}$$

In Figure 6 below, the instantaneous velocity of the vibrating rod at the extreme positions of its motion (identified by points B and D on the graph) is zero because the rod has to stop momentarily and then reverse direction.

Figure 6— Velocity at Extreme Displacement Positions

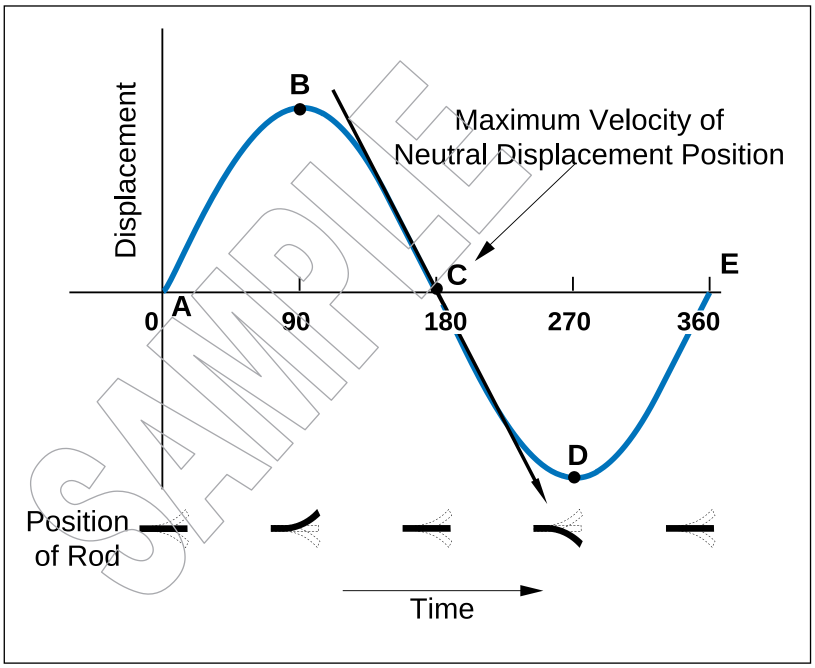


At the extreme displacement positions, B and D:

$$\text{instantaneous velocity} = \frac{\text{0 displacement}}{\text{time}} = \text{0 velocity}$$

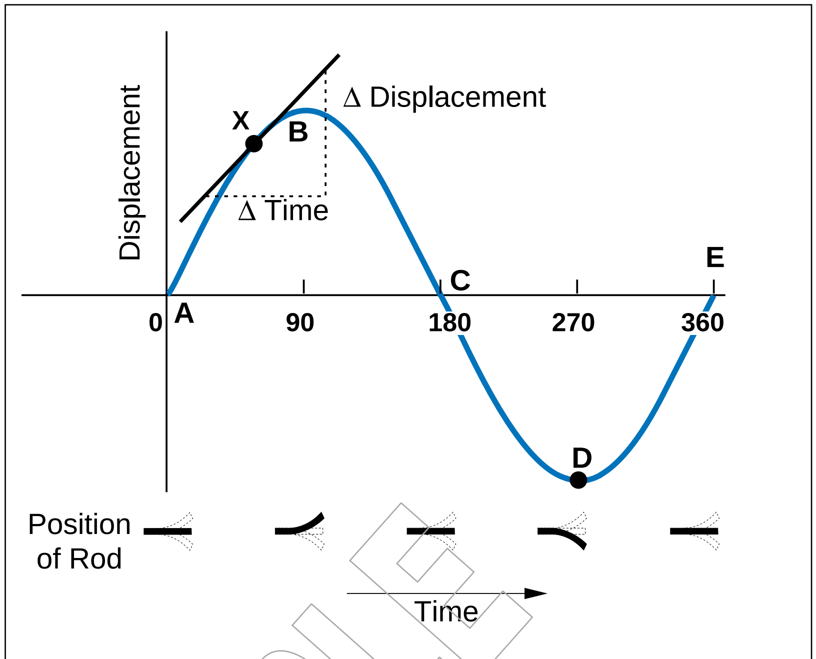
Starting at position B on the graph in Figure 7, the rod speeds up until it reaches the neutral displacement position (point C on the graph) and then begins to slow down until it reaches the other extreme position (position D). At the neutral position, the rod is traveling at its maximum velocity.

Figure 7— Velocity at Neutral Position



Since velocity is defined as distance divided by time, the velocity at any point on the displacement graph can be represented by drawing a tangent (sloped line) to the curve at that point (see Figure 8).

Figure 8— Velocity as a Tangent to the Displacement Curve



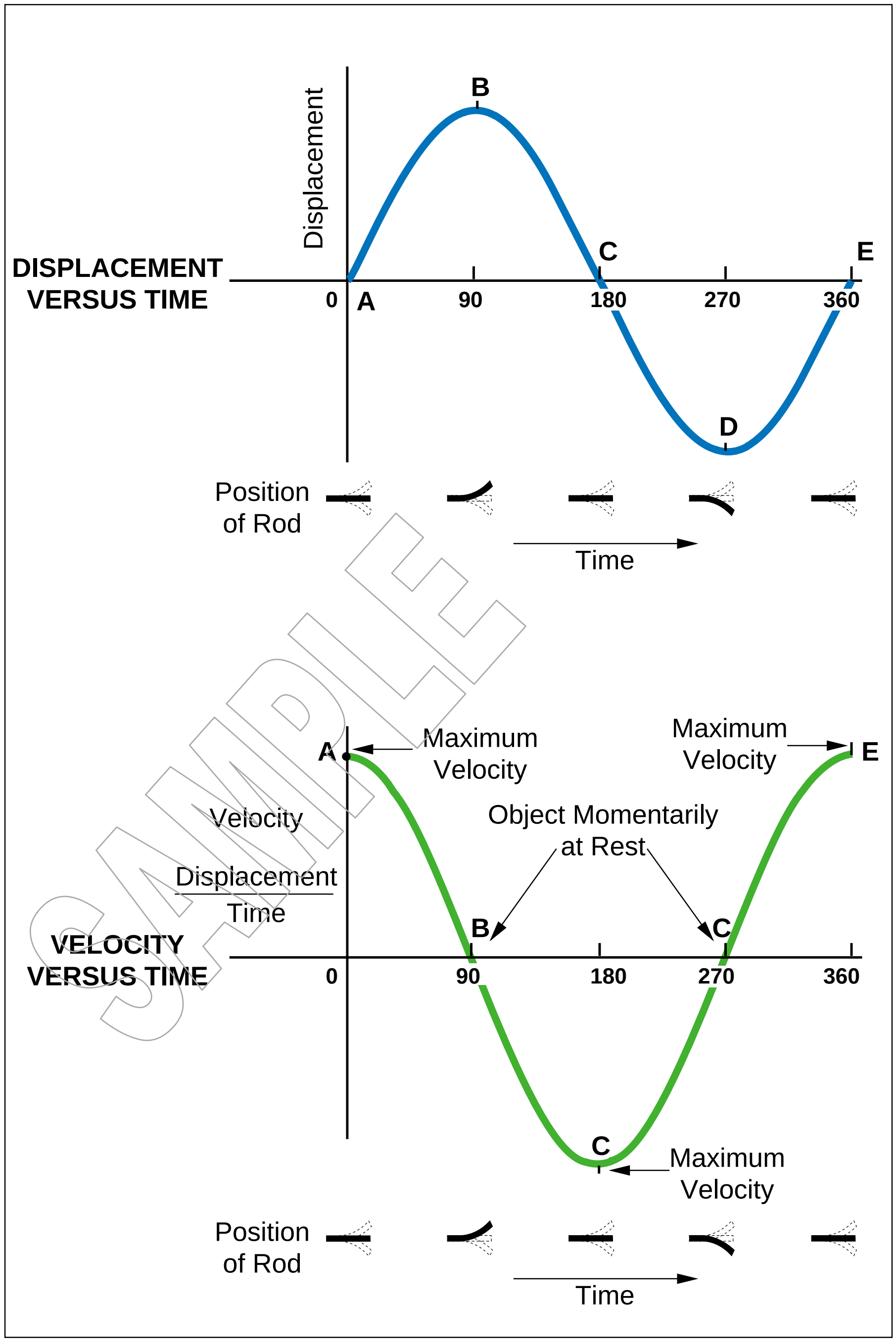
The velocity at point X in Figure 8 is determined by the slope of the tangent:

$$\text{velocity} = \frac{\Delta\,\text{displacement}}{\Delta\,\text{time}} \qquad \text{where } \Delta \text{ means change}$$

The velocity of the rod can be calculated for all points on the displacement graph and the results graphed as shown in Figure 9.

The velocity of the vibration is directly related to displacement and frequency. An increase in displacement or an increase in frequency results in an increase in the velocity of the vibration. Since both displacement and frequency are also indicators of the severity of vibration, vibration velocity is often used as a direct measure of vibration severity. On large rotating equipment, the fixed vibration protective devices often use vibration velocity as the parameter for measuring vibration severity.

Figure 9—
Velocity Graph



Vibration velocity is normally measured in millimeters per second, or inches per second. As an example, a protective device for an electrically driven centrifugal pump may be set to shut down the pump when the pump's vibration exceeds 5 mm/s (five millimeters per second) which is equivalent to 0.2 in/s (inches per second).

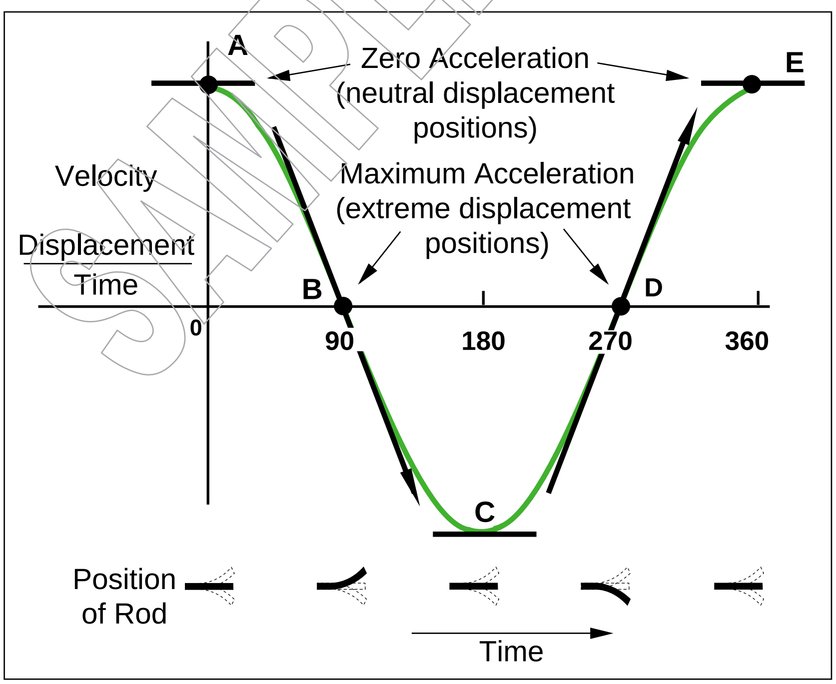
3.3 Vibration Acceleration

Acceleration is defined as the rate of change of velocity. As examples:

1. To win a race, a race car accelerates rapidly to reach the maximum velocity in the shortest time possible.
2. A passenger car accelerates slowly to reach the maximum allowable velocity to ensure passenger comfort and fuel economy. Vibrating objects also experience acceleration. At the extreme positions of vibration, the object experiences maximum acceleration because it has to change direction.

At the neutral position, the vibrating rod momentarily reaches its maximum velocity, and no acceleration takes place. Figure 10 uses the velocity graphic (from Figure 9) to identify the rod's acceleration at the rod's extreme and neutral positions.

Figure 10— Acceleration at Extreme and Neutral Displacement Positions



At neutral displacement positions A, C, and E the acceleration is zero. At extreme displacement positions B and D the acceleration is at maximum. Since acceleration is defined as a change in velocity divided by time, the acceleration at any point on the velocity graphic can be represented by drawing a tangent to the curve at that point (refer to Figure 11).

End of Sample

A full licensed copy of this kit includes:

• Training Module and Self-Check
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• Performance Check