Section 1

FUNDAMENTALS OF NOISE, VIBRATION, AND HARSHNESS

Lesson Objectives

1. Introduce the concepts relating to Noise, Vibration and Harshness (NVH).
2. Define NVH terminology.
3. Develop the background necessary for NVH diagnosis and the use of the NVH Analyzer.
4. Introduce the concepts of the transmission of vibration and sound.
5. Introduce the concepts of preventing excessive vibration and noise.
6. Develop skills in associating NVH symptoms to the:
   - Sensation
   - Frequency range
   - Operating conditions
   - Causes
   - Vibrating system

Introduction

Noise and vibration normally exist in the operation of a vehicle. When they become unpleasant to the senses they may be regarded as concerns by the customer. **NVH (Noise, Vibration and Harshness)** is the term used when discussing these conditions.

Noise, Vibration and Harshness

Fig. 1-1

We **experience vibration by our senses of touch and vision**. We experience **sounds by our sense of hearing**. People can perceive the same noise and vibration differently. To some it may be annoying, to others merely unpleasant while others may not notice it until it is pointed out.

Sensing Vibrations

Fig. 1-2

Introduction
Continued

The NVH condition that is a concern does not have to be the strongest vibration or the loudest noise. It could be one that was not there before or one that is not acceptable to the customer. Therefore it is critical that we **verify the customer's concern.**

For example:

Exhaust system noise from a Sport Coupe could be acceptable. A concern on the same vehicle could be much more subtle, caused by a driveline concern.

Because we sense vibration and sound using different senses, we tend to discuss them separately. But **vibration and sound are essentially identical.**

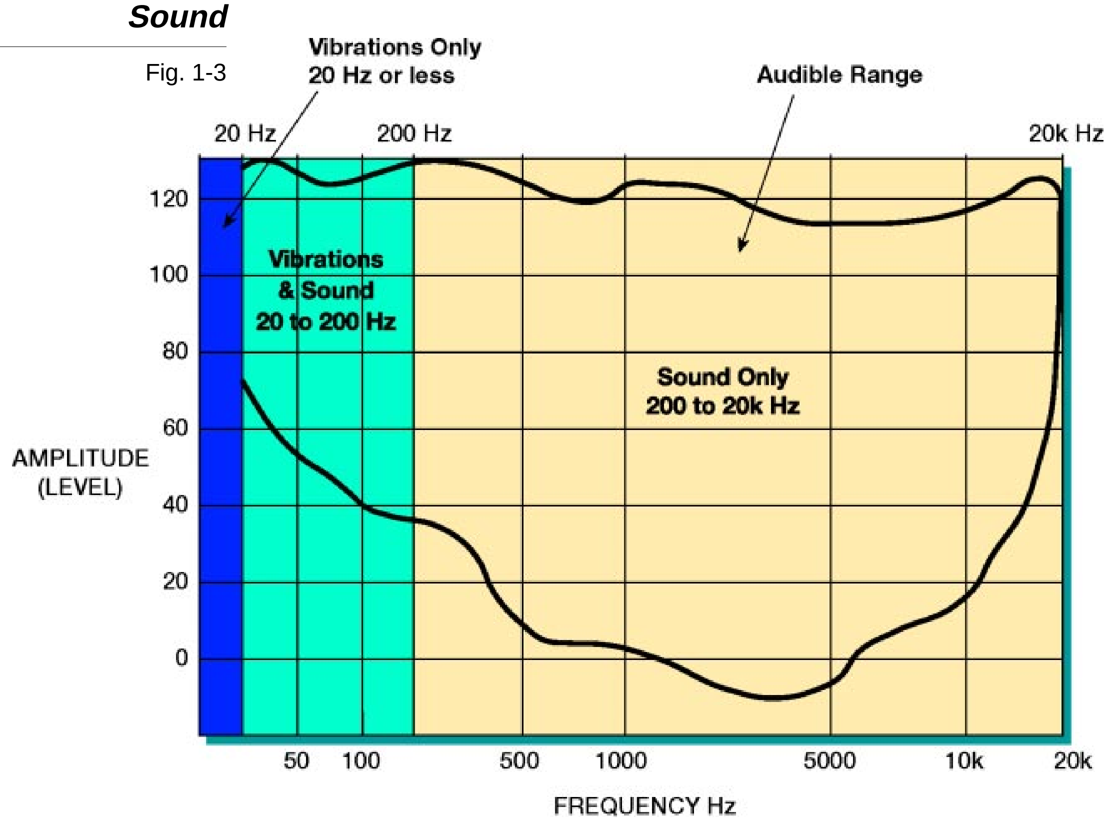
A sound is a vibration (pressure fluctuation) of the air.

Vibrations and sounds are both expressed as **waves per second** called **Hertz (Hz)**, discussed in detail later.

- Vibrations that are felt are under 200Hz
- Vibrations between 20Hz - 20,000Hz are audible by humans
- Vibrations over 20,000Hz are ultrasonic and not audible by humans

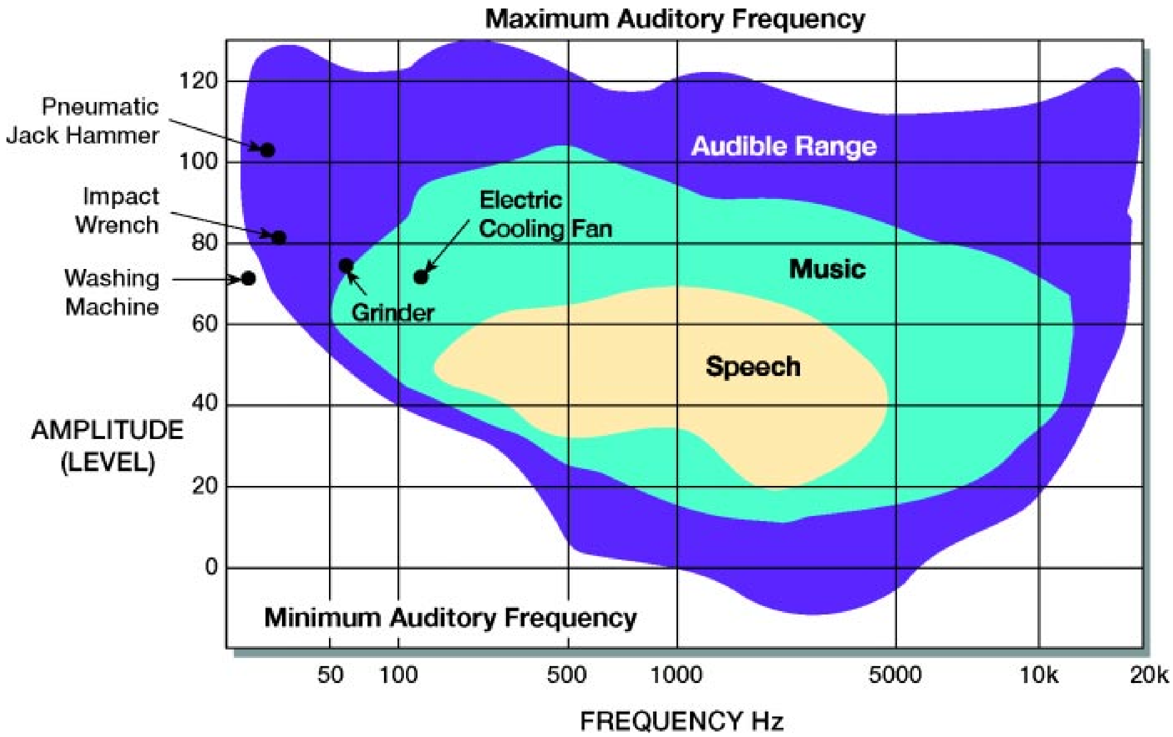
Frequency Ranges of Vibration and Sound

Fig. 1-3



Audible Range

Fig. 1-4



Characteristics of vibration

Introduction

NVH phenomena can be a difficult concept to grasp. It is similar to the concept of electricity, we only experience the results in both cases. We cannot see it as easily as a broken or worn component.

For example:

The light from a light bulb is not electricity, but the result of electricity. The movement felt by a customer is not the source of the vibration. It occurs as a result of a condition such as an imbalance.

Vibrations, like electricity, have **basic characteristics which are always present**. Understanding these characteristics will allow a technician to predict the source of a vibration.

Vibration

The up and down movement of the weight and spring model shown below represents a vibration. This movement or vibration exists as a result of a weight suspended by a spring and an external force.

The factors that determine movement or vibration are:

- The size of the spring
- The size of the weight
- The amount of force pulling on the weight starting it in motion

The model consisting of the suspended weight and spring is called the **vibrating system**.

Anything that vibrates is a vibrating system including:

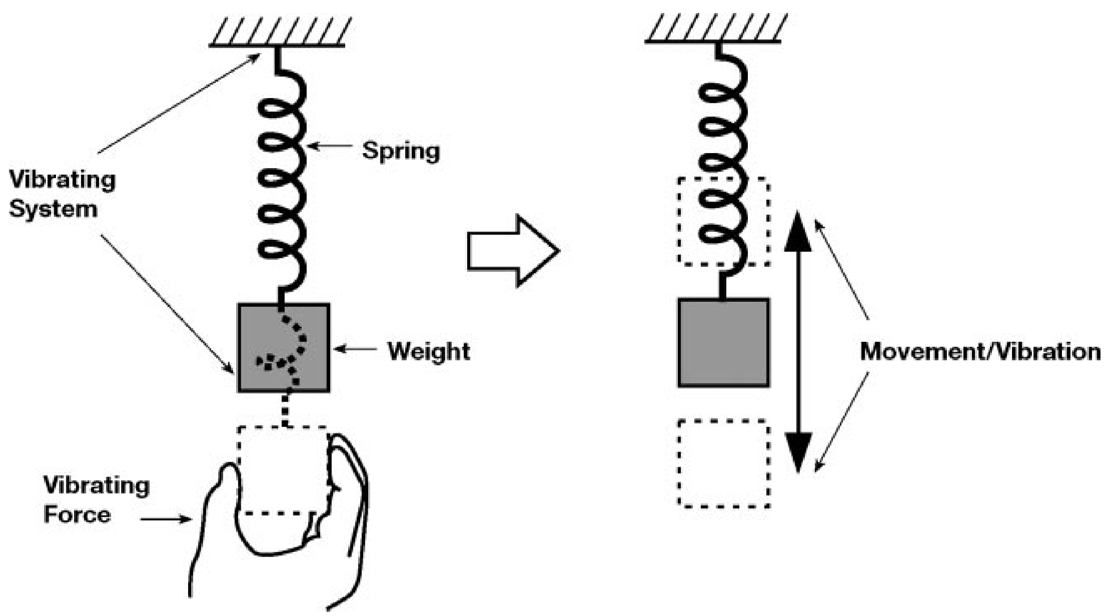
- A string on a musical instrument
- A bell
- A tuning fork

The weight and spring model or vibrating system can be started into motion by pulling on the weight. This action is known as the **vibrating** force. A vibrating force is the external force or energy putting a vibrating system into motion.

Plucking a string on a guitar or striking a bell or tuning fork are the vibrating forces that cause these vibrating systems to vibrate and make noise.

Vibration

Fig. 1-5



Vibration
Continued

For example:

A vibrating system in a vehicle is the suspension.

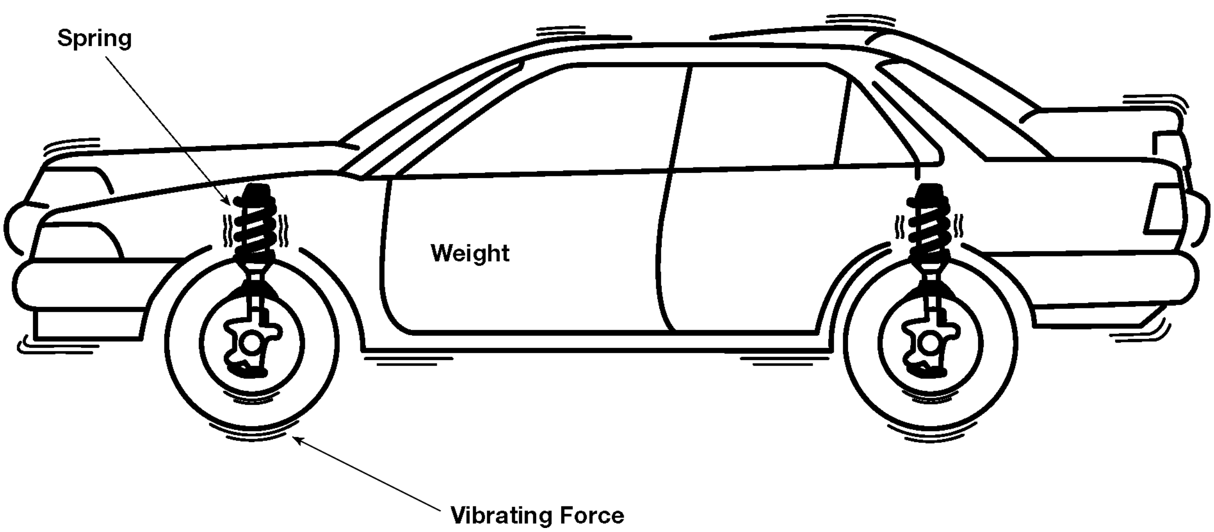
- The spring on the vehicle is similar to the spring on the model.
- The weight of the vehicle is similar to the weight on the model.
- Bumps in the road are the external or vibrating forces that start the vehicle into motion.

If you remove the shock absorbers a vehicle will move or vibrate in a similar manner to the weight and spring model.

A technician can bounce a corner of a vehicle and watch the motion to check for bad shocks. If the shocks are good they will **dampen** the motion quickly.

Vehicle Movement without Shocks

Fig. 1-6



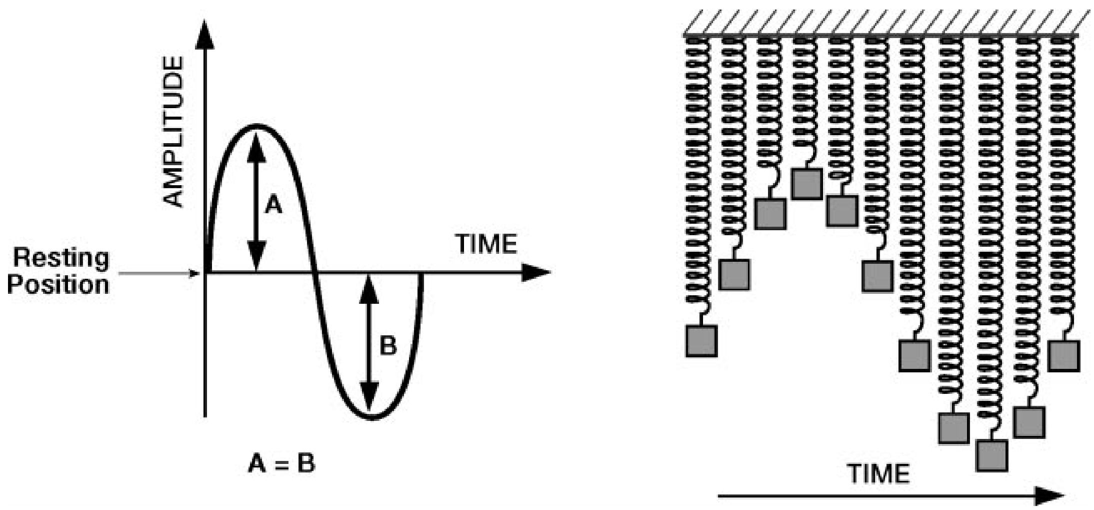
Oscillation is another term used to describe the movement of a vibration. When something oscillates it moves back and forth around a common point.

Cycle If a constant vibration or movement in any vibrating system is plotted over time a pattern appears. This pattern consists of the repetitive movement of the weight.

Tracing this pattern from the resting position through each extreme and back to the resting position will produce **one cycle**.

Cycle

Fig. 1-7



Cycle comes from the word circle. The travel of the weight on either side of the resting position, is half of a circle.

The distance the weight travels from either side of the **resting position** will be the same as long as the vibrating force remains constant.

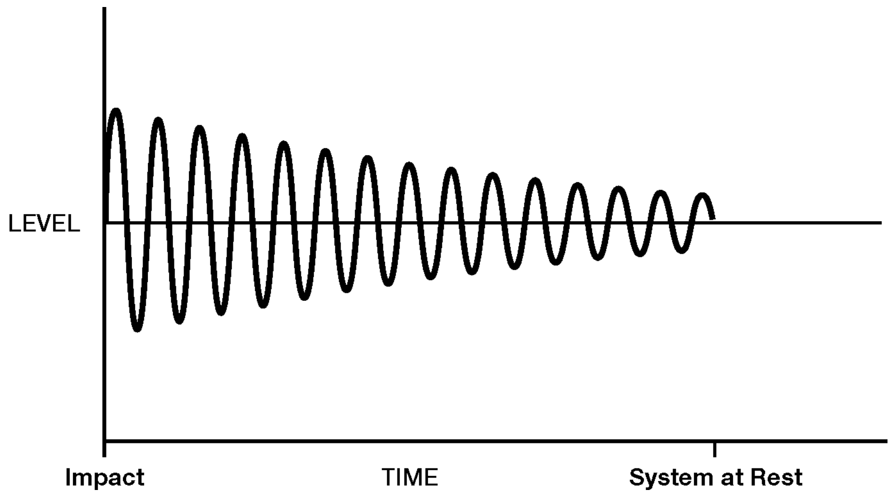
A = B

Cycle
Continued

The movement/vibration will continue until the energy in the system is dissipated and the system is at rest.

Dissipation of Energy from a Single Impact

Fig. 1-8



For example:

Another example of frequency or cycle is rotating a crankshaft 360° starting at TDC. This movement is **one revolution**. We measure the speed of an engine by counting these **revolutions in one minute (RPM).**

Rotating the crankshaft from TDC through 360° and back to TDC is also one cycle of the crankshaft. As defined above the crankshaft starts at a specific point, travels in a circle and returns to the same point.

Plotting the movement of a crankshaft over time will result in a similar pattern to the movement of the spring and weight model. (Fig. 1-7)

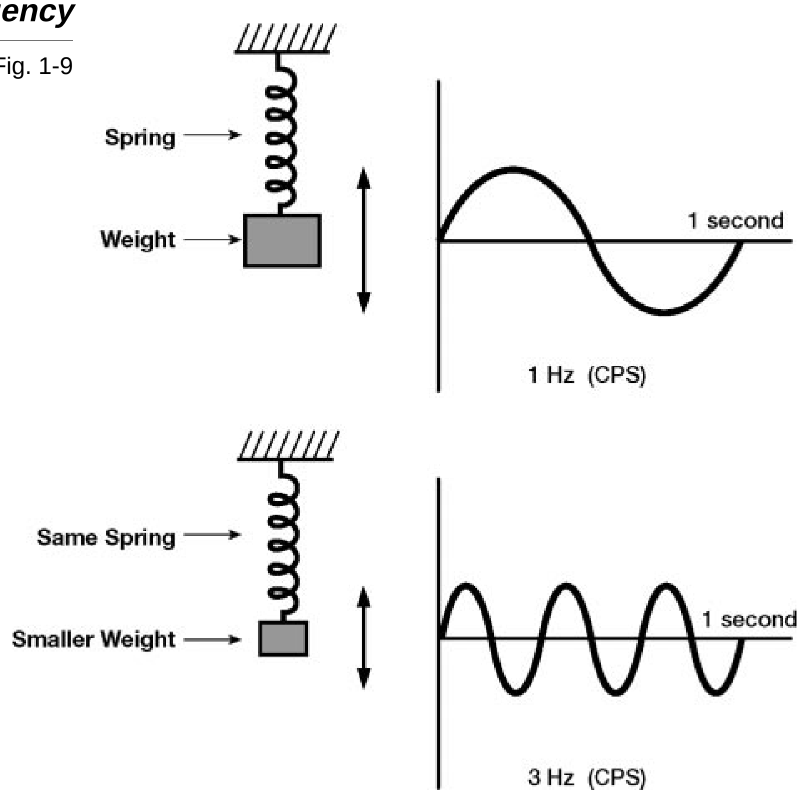
Frequency

The number of **cycles in one second is the frequency** of the vibration.

The unit for frequency is **Hertz (Hz)**.

Frequency

Fig. 1-9

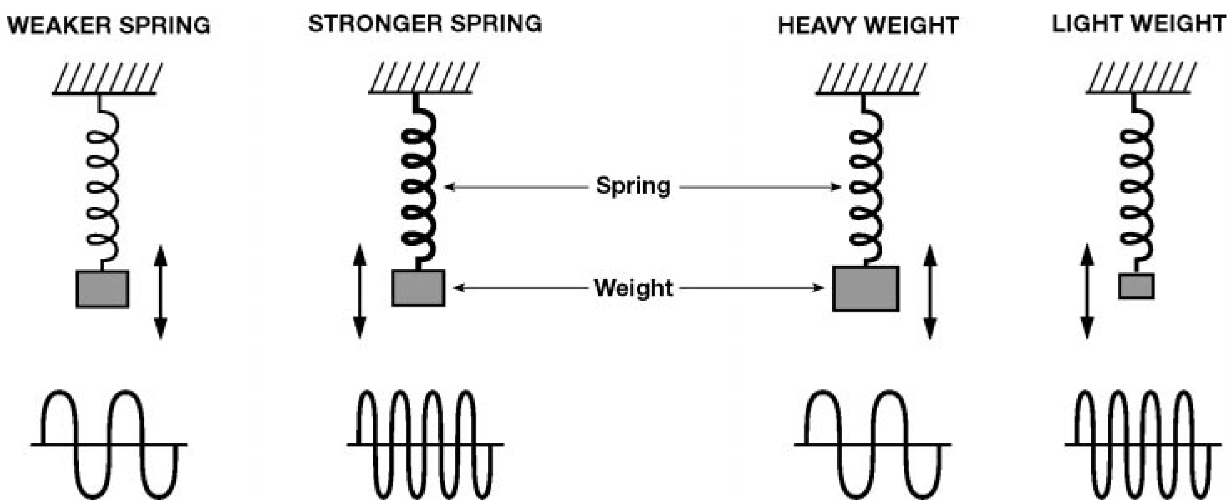


The number of cycles in a second or the frequency (Hz) can be changed by changing the vibrating system. If the strength of the spring is changed or the size of the weight is changed the frequency will change. (All other aspects of the vibrating system unchanged)

- A stronger spring will increase the frequency (Hz)
  - More tension will move the weight at a faster speed
- A weaker spring will decrease the frequency (Hz)
  - Less tension will move the weight at a slower speed
- A heavier weight will decrease the frequency (Hz)
  - More weight will increase the resistance on the spring and it will move at a slower speed
- A lighter weight will increase the frequency (Hz)
  - Less weight will decrease the resistance on the spring and it will move at a faster speed

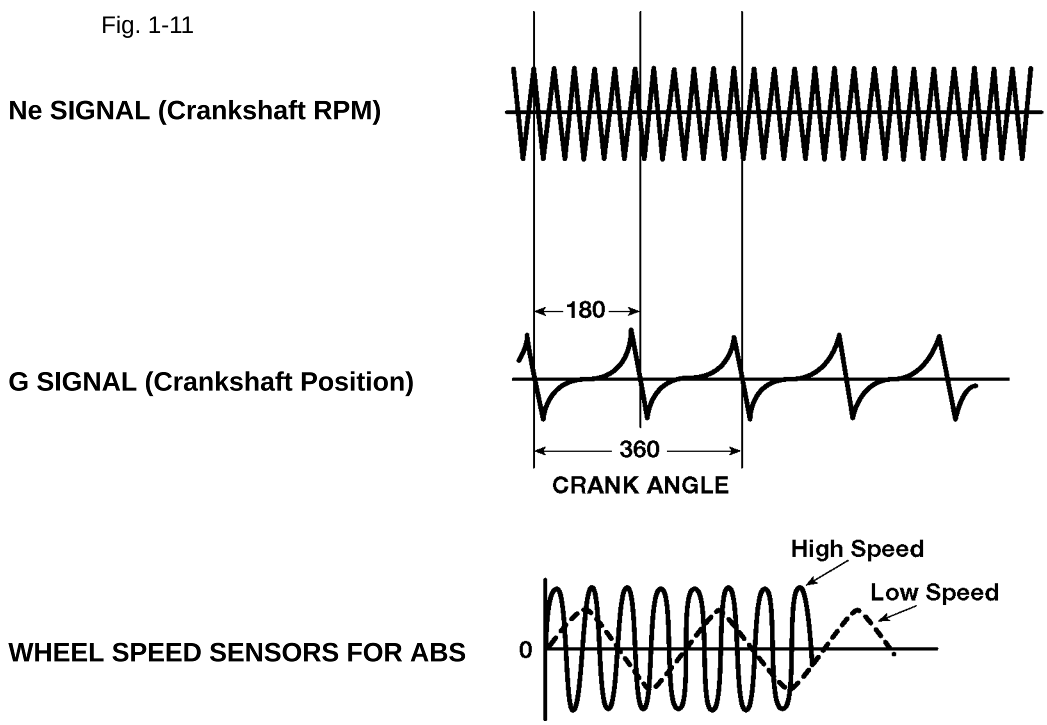
Vibration Characteristics

Fig. 1-10



Sensors Signal

Fig. 1-11



Calculating Component Frequency

Frequency can also be expressed in **Revolutions Per Minute (RPM)**. **RPM** is a common unit for rotating components in the automotive field. RPM can be converted to **Cycles Per Second (CPS) or Hertz (Hz)** by dividing RPM by 60. There are 60 seconds in one minute.

RPM ÷ 60 sec = CPS or Hz

If a crankshaft is rotating at 3000 RPM then it has a frequency (Hz) of 50 CPS or 50 Hz.

3000 RPM ÷ 60 sec = 50 Hz

This formula can also assist the technician in identifying the source of a vibration in a vehicle. If the frequency is known then the RPM can be calculated.

Hz x 60 sec = RPM

A technician can now determine what component is turning at a calculated RPM, during the vehicle conditions at which the concern occurs.

For example:

- Engine RPM can be read from a tachometer **3000 RPM**
- Driveline RPM is the same as engine RPM in fourth gear with a 1:1 gear ratio. (Manual Transmission)

Engine @ **3000 RPM ÷ 1 = 3000 RPM** drivetrain speed

- 3000 RPM = 50 Hz (engine speed and driveshaft speed).

If the gear ratio is other than 1:1, the engine RPM divided by the ratio equals the driveline RPM.

Engine @ **3000 RPM ÷ 0.783 = 3831.42 RPM** driveshaft speed

- 3831.42 RPM = 63.85 Hz (driveline speed)
- Wheel RPM is calculated by dividing the RPM of the driveline by the gear ratio of the differential.

Driveline @ **3831.42 RPM ÷ 4.272 = 896.87 RPM** wheel speed

- 896.87 RPM = 14.95 Hz (wheel speed)

The frequency (Hz) of the vibration or sound can be determined with the use of test equipment. A **vibration analyzer** is able to display the vibrations in a vehicle. An abnormal vibration can be associated with a specific frequency from the display.

For example:

The engine could be determined as the source of a measured 50 Hz vibration with the crankshaft turning at 3000 RPM.

50 Hz x 60 sec = 3000 RPM

Amplitude

The amount of **vertical movement** of the spring and weight (vibrating system) is the **amplitude of the vibration**. The amplitude is determined by the **external force or energy** applied to the vibrating system.

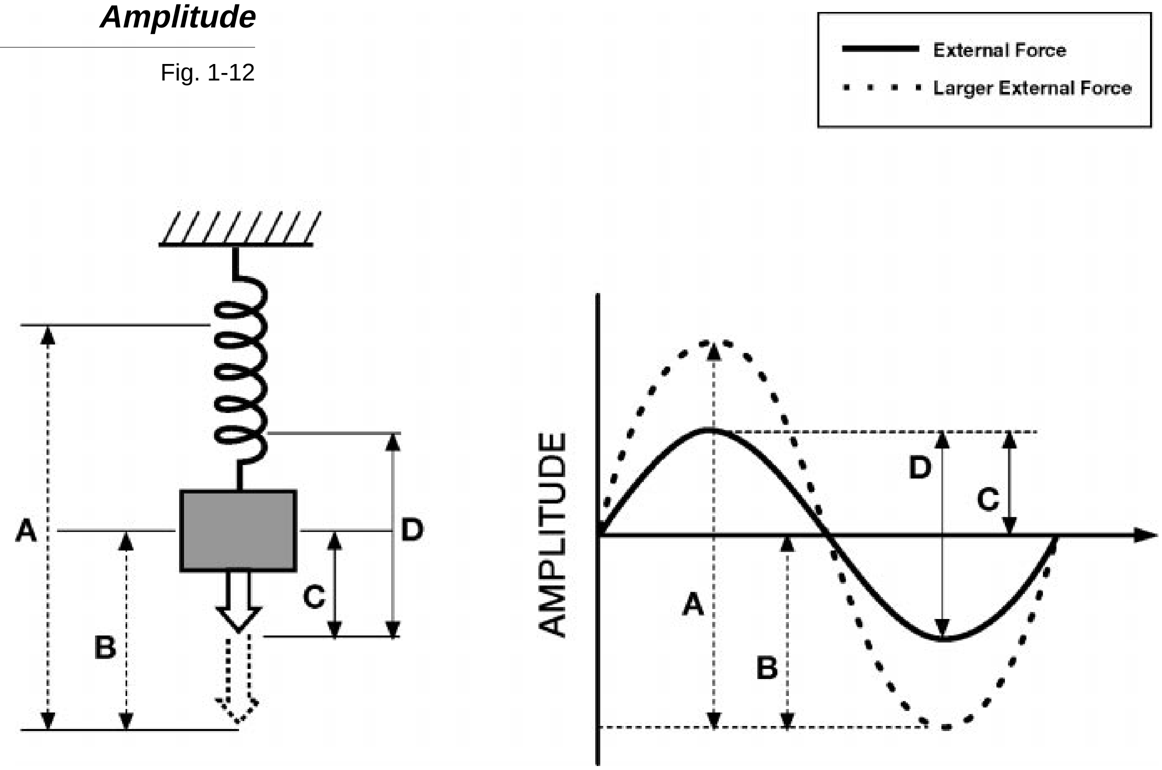
Amplitude is the **size of the wave** and is measured two ways.

- Total amplitude from peak to peak (A)
- Half amplitude from resting position to the peak (B)

The higher the amplitude, the more noticeable the condition.

Amplitude

Fig. 1-12



Vibration Measurement

A vibration is measured in two ways:

- Frequency (Hz)
- Amplitude (dBg)

Frequency is a function of the system design and amplitude is the result of the energy on the system.

Both of these features can be measured with a **vibration analyzer** which senses, processes and displays the vibrations in a vehicle. The information from a vibration analyzer can help the technician determine the:

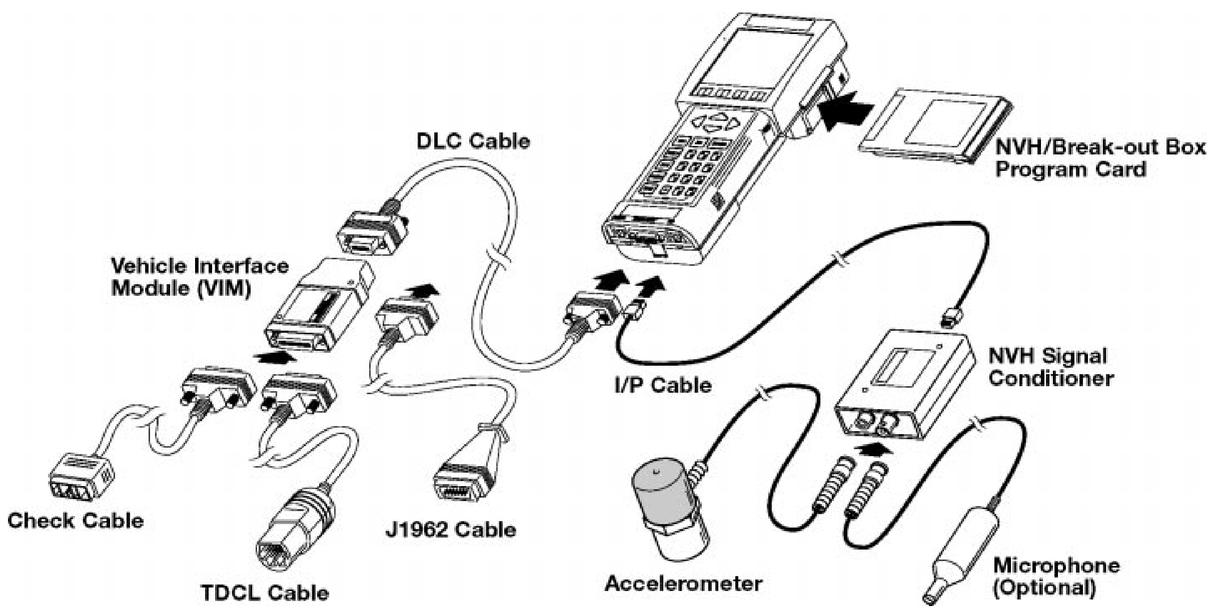
- Frequency of vibration (Hz) - which can indicate the source
- Amount of energy/amplitude(dBg) - which indicates the level of the vibration the customer feels

The vibration analyzer recommended by Lexus is a feature of the **Lexus Diagnostic Tool Set**. The NVH portion of the tool includes:

- An **accelerometer** to sense the vibration
- A **data link** to input RPM and MPH
- A **program card** specific to the NVH function

NVH Analyzer

Fig. 1-13



The tool will display the vibrations occurring in a vehicle and aid the technician in diagnosing an NVH concern.

The unit of measurement used by the NVH Analyzer for:

- **Sound level** is the **dB (decibel)**
- **Vibration level (amplitude) is dBg** (g force related to gravity)

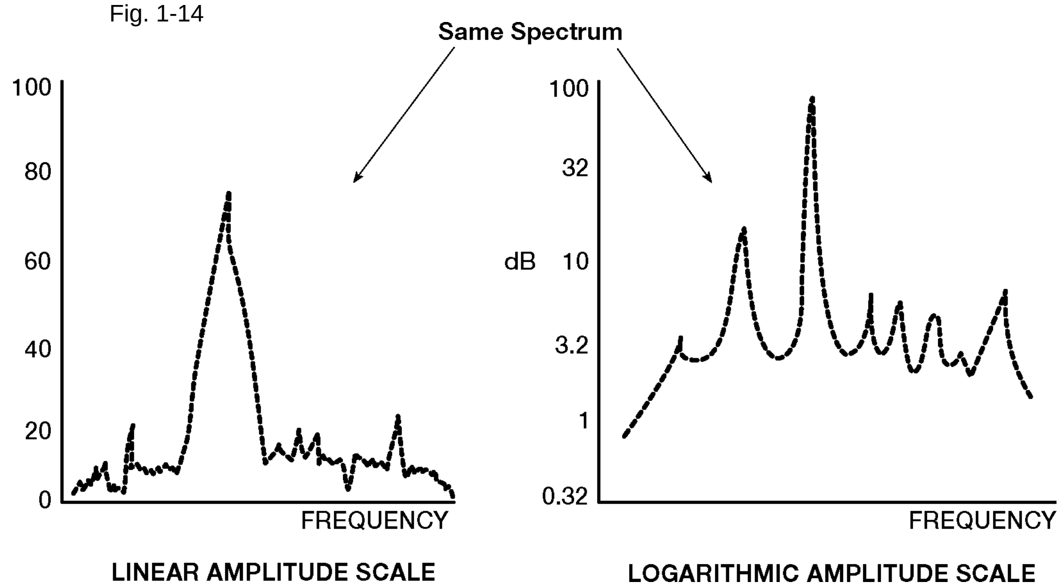
The dB is the unit of measurement related to the level or intensity of what we hear. It is a mathematical calculation (logarithm) of a vibrating force that produces a sound. It is useful to associate the level or amplitude of the vibration to the **level sensed by the customer.**

The dBg is the unit that is related to the level or intensity of what we feel. When measuring the level or amplitude of a vibration without sound the unit **g** is added to associate the force of the vibration to gravity. This is similar to measuring the weight of an object which is also a function of gravity.

Level or amplitude becomes important in determining the success of the repairs performed. If the amplitude of a vibration or sound is measured before and after a repair then a comparison can be made. The results are much more objective than using the senses of touch and hearing.

dB (DECIBEL)

Fig. 1-14



- The graph on the left shows the actual sound level from various sources.
- The graph on the right shows the customer perceived sound level from the same sources and easier to read.

Natural Frequency

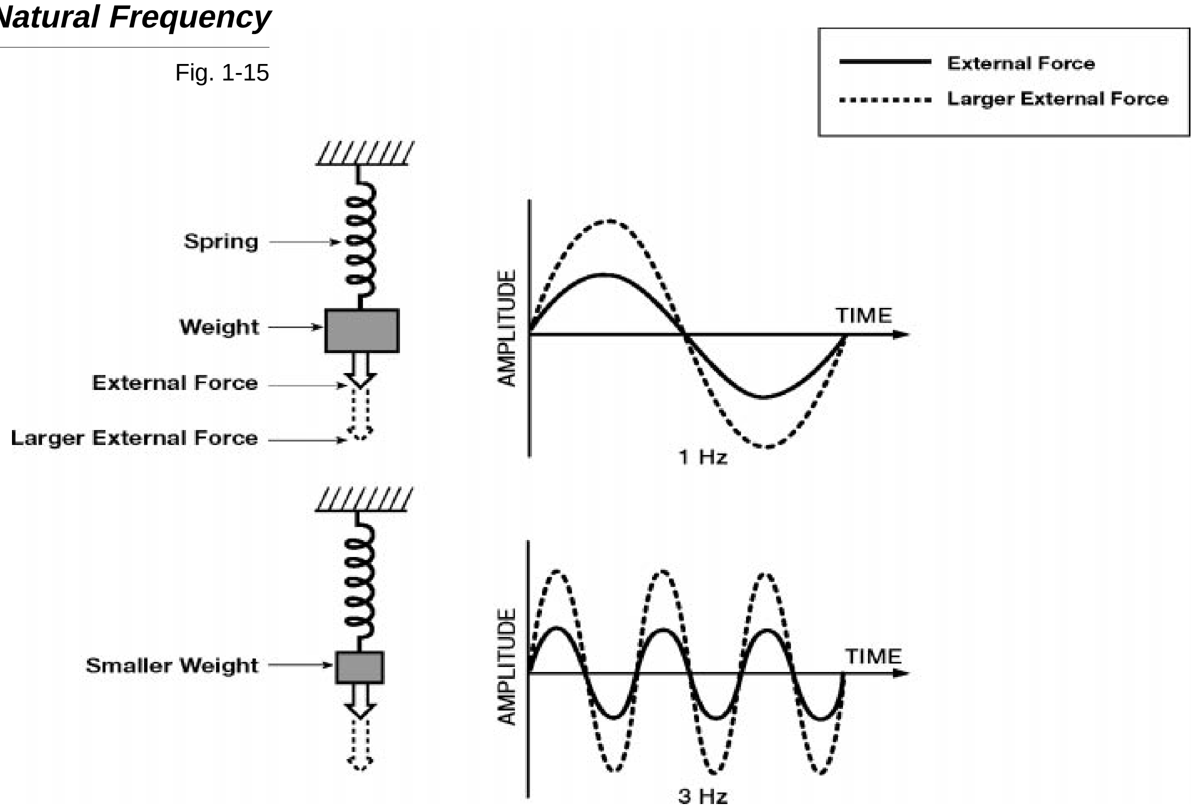
All vibrating systems have a **specific vibrating frequency** unique to that system design. This frequency is called the **natural frequency**.

If any of the characteristics of the vibrating system change then the **natural frequency changes**. (as stated in the section on frequency)

If the **external force** on a vibrating system is changed then the **amplitude changes** but the **natural frequency remains the same**.

Natural Frequency

Fig. 1-15



A vibration or sound that develops in a vehicle may be caused by a change in the status of a component like a bad seal in a strut. The natural frequency of the suspension system is changed due to the loss of dampening in the strut. The suspension system will now vibrate noticeably over the same road conditions which had not previously caused a customer concern.

In this example the technician can resolve the customer concern by restoring the suspension system to the original condition and natural frequency.

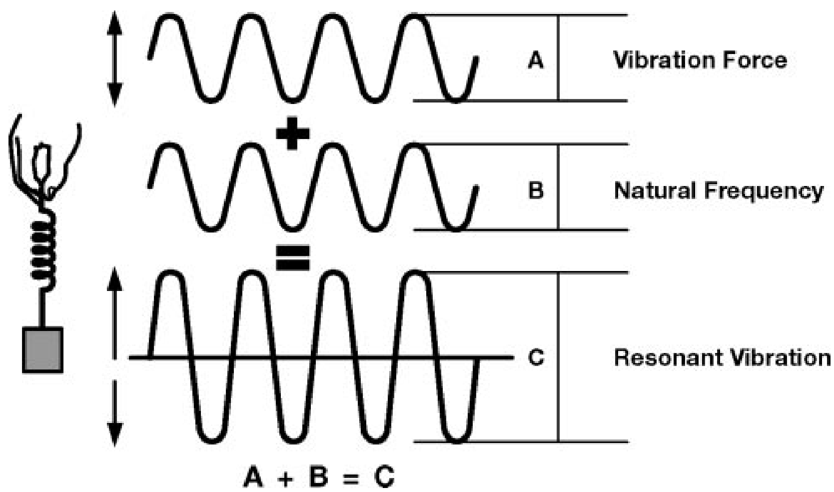
Resonance

Resonance occurs when the **vibrating force** (external force) on a vibrating system is moving at the **same frequency (Hz)** as the **natural frequency** of that vibrating system. Fig. **1-15** shows the wave form of the natural frequency of the system and the wave of the vibrating force at the same frequency. The resulting wave that occurs is at the same frequency but with much greater amplitude.

This is a significant phenomenon in a vehicle because the increased level is sensed by the customer and perceived to be a problem.

Resonance

Fig. 1-16

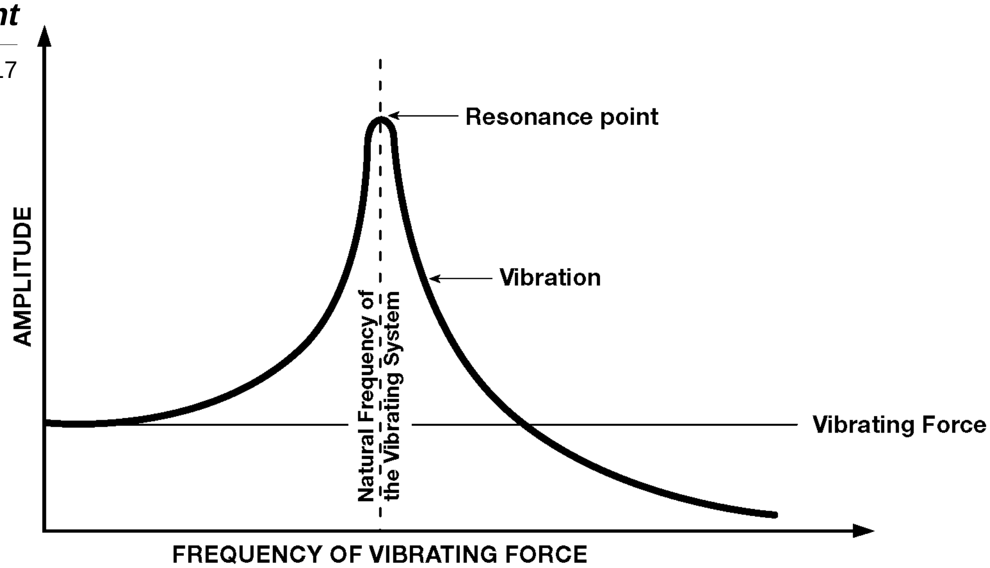


The frequency (Hz) at which this occurs is the **"resonance point"**.

The amplitude (dBg) of the vibrating system increases dramatically when the resonance point is reached.

Resonance Point

Fig. 1-17



Resonance
Continued

In the above example with the suspension system vibration (caused by the leaking strut), the vibration the customer feels is amplified when:

- The new natural frequency of the suspension system and the frequency of the tire on a rough road are the same
- When the frequencies are the same they resonate increasing the level or amplitude

When the leaking strut is repaired the original natural frequency of the suspension system is restored. The suspension system frequency will not be the same as or resonate with the frequency of the tire on a rough road during normal operating conditions.

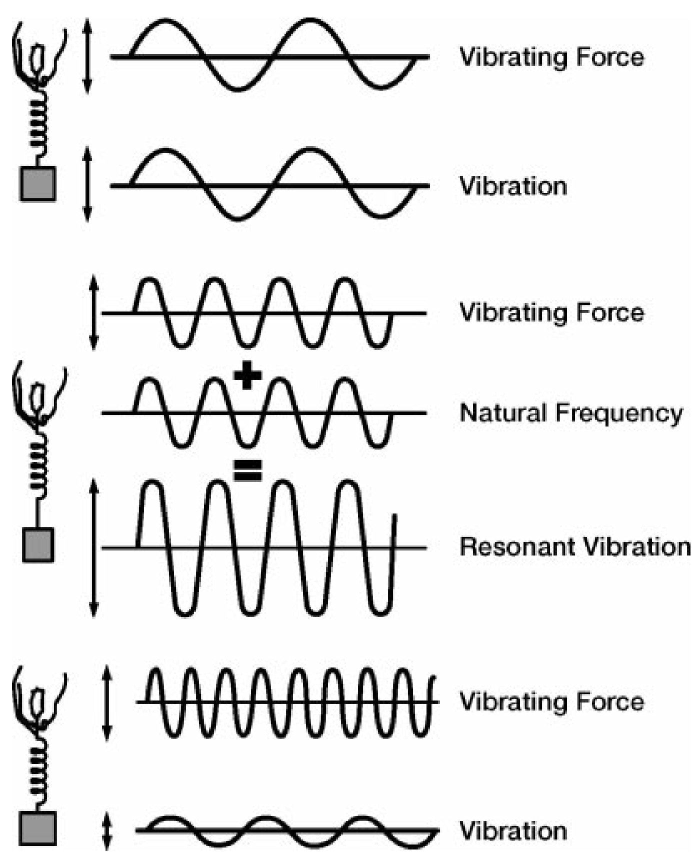
Fig. 1-16 shows that moving the vibrating force frequency to either side of the resonance point will **lower the amplitude**.

If the vibrating force cannot be changed then changing the natural frequency of the vibrating system will also lower the amplitude.

The shock absorber, in the suspension system example, changes the natural frequency of the suspension system. The technique is called **dampening**. The shocks change the resonance point of the system and reduce the vibration felt by the customer.

Varying the Frequency to Modify Resonance

Fig. 1-18



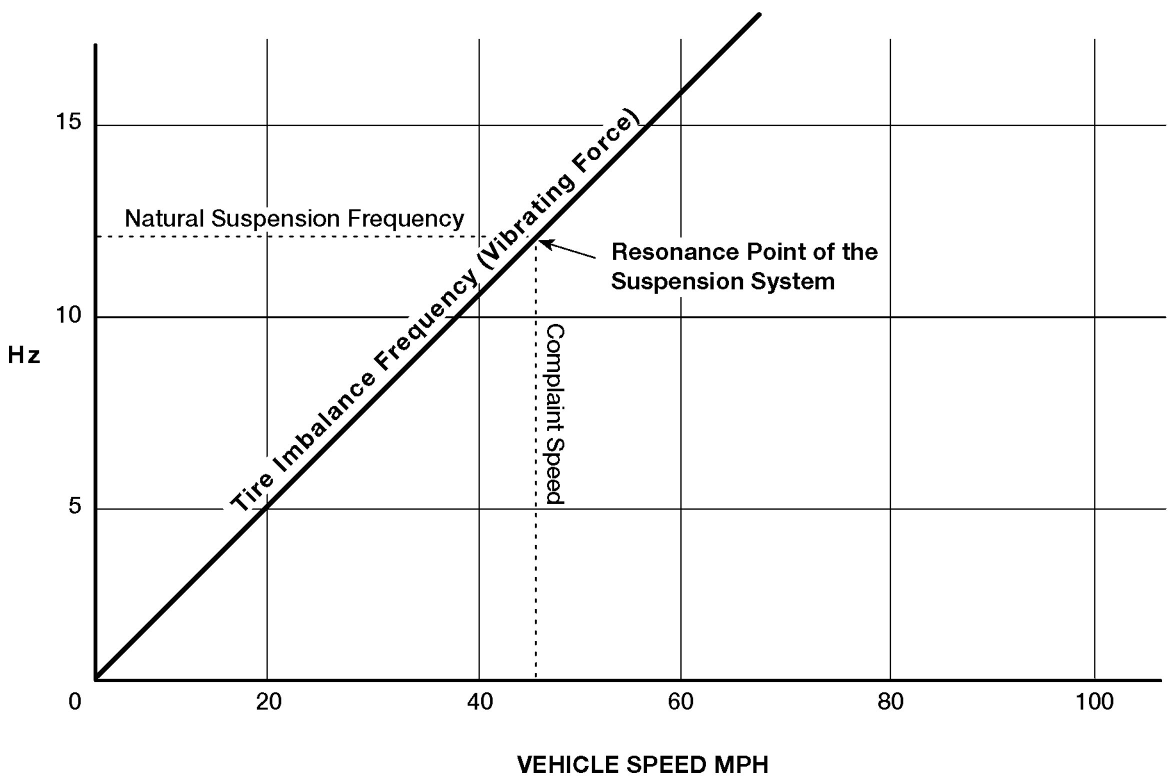
Resonance
Continued

Another example of resonance is an unbalanced tire as it reacts with a suspension system. The vibration is usually more noticeable at a specific speed range. This is the point when the vibrating force (unbalanced tire) and the natural frequency of the suspension system resonate. The customer feels a strong vibration when this occurs due to the significant increase in the vibration level (amplitude).

In this case, balancing the tire will return the system back to the original design and move the resonance point out of the normal operating range. The customer will no longer feel a vibration.

Resonance Graph

Fig. 1-19



Resonance
Continued

Resonance is not always a negative condition. Engineers use the phenomenon of resonance in the design of a number of products including the **knock sensor**. The knock sensor is monitored by the ECM to modify timing.

The vibration generated by a detonation or a knock is transmitted through the cylinder block to the knock sensor. The natural frequency of the piezoelectric element in the sensor is designed to match the frequency of the vibration caused by the knock. When the knock occurs, its frequency and the natural frequency of the sensor are the same, and they resonate.

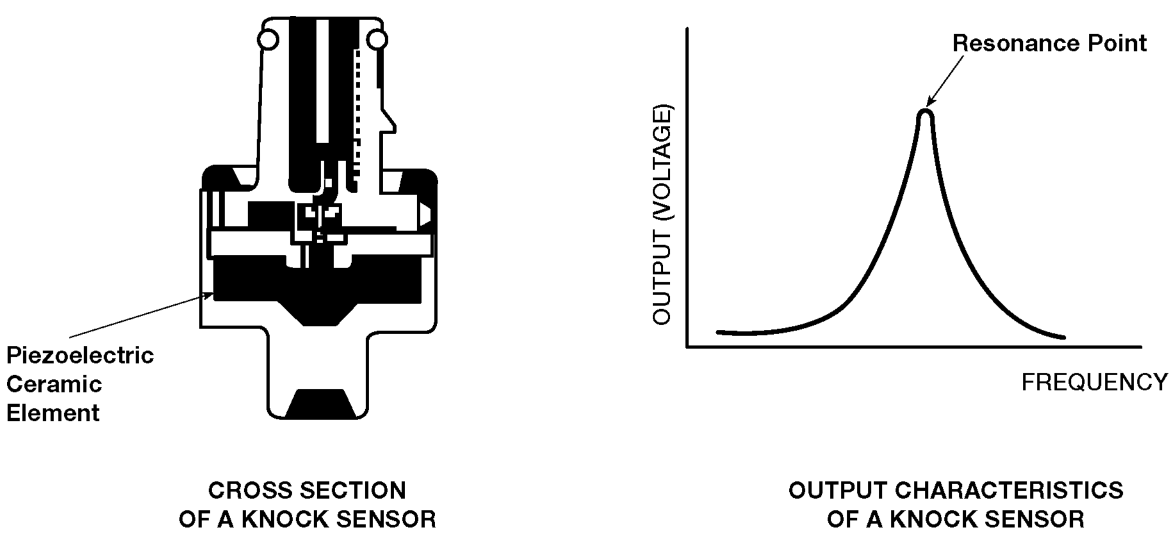
The amplitude of the vibration sensed increases sharply due to the resonance of the element.

At the same time the voltage generated by the piezoelectric element in the sensor increases in proportion with the amplitude. The computer monitors the voltage and makes corrections to engine timing to eliminate the detonation or knock.

The vibrating force, in this case, is the explosive force created by an abnormal combustion of the fuel.

Knock Sensor

Fig. 1-20



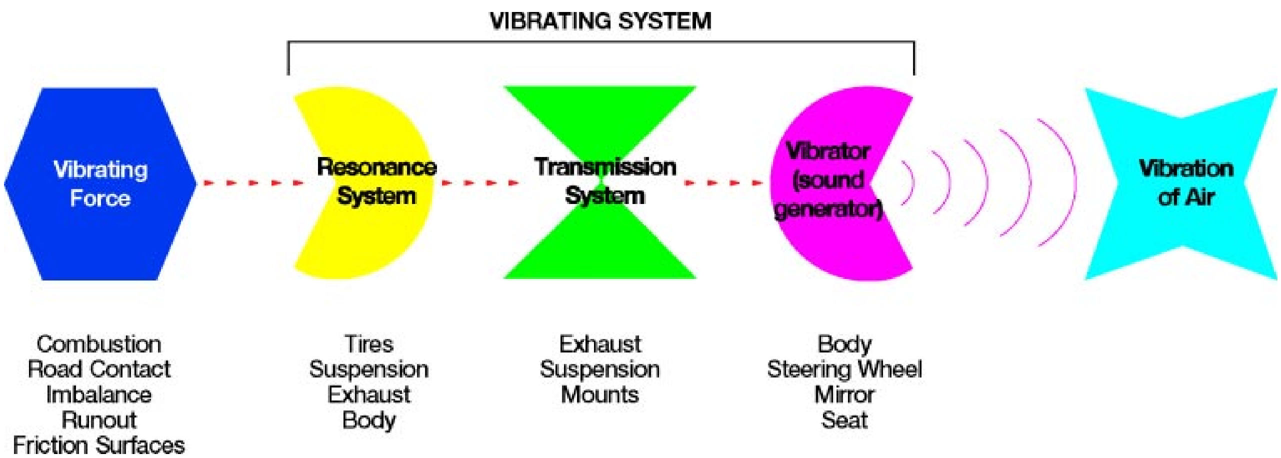
Transmission of Vibrations and Sounds

Vibrations and sounds are transmitted the same way. There has to be a:

- Vibrating force
- Resonating system
- Transmission system (path)
- Vibrating element (vibration)
- Vibration of air (sound)

Transmission of Vibrations and Sound

Fig. 1-21



Transmission of Vibrations and Sounds
Continued

Examples of **vibrating forces** in automobiles are:

- Combustion (engine firing)
- Tires contacting a rough road
- Imbalance or run-out of a rotating component
- Fluctuation of friction surfaces

A **Resonance System** is any component on the vehicle that resonates when it receives a vibrating force. All components will resonate if the vibrating force matches the natural frequency.

The most common examples are:

- Tires resonate when vibrated by the road
- Suspension systems will resonate with an out of balance tire
- An exhaust system will resonate when vibrated by the engine

The **Transmission System** is the path in the vehicle that carries the vibration from the resonance system to the vibrator (sound generator).

Examples of a transmission system or path are the:

- Exhaust system
- Engine mounts

These components carry engine vibrations through the vehicle.

The following are examples of methods used to minimize the level of vibration felt by the customer through modifying the transmission path:

- Rubber O ring exhaust hangers
- Liquid filled mounts

The **Vibrator** (sound generator) is the component that generates the vibration or sound that the customer senses.

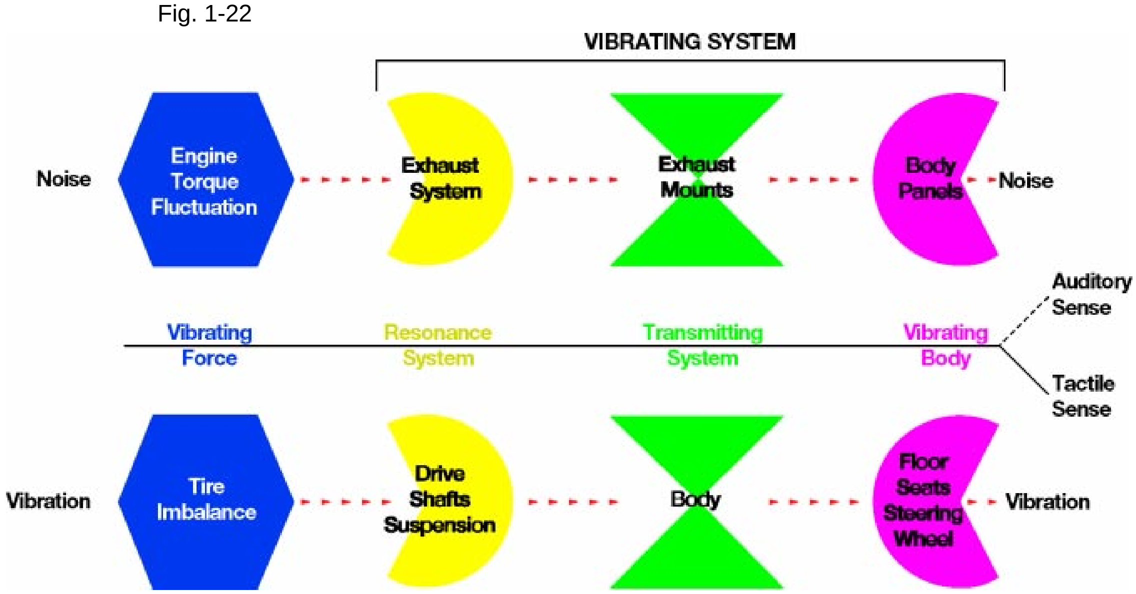
Examples of a vibrator (sound generator) are:

- Body
- Steering wheel
- Seat
- Shifter
- Mirror

Asphalt sheeting on a body panel is an example of a **modification** to the vibrator to insulate the passenger compartment from a vibration or sound.

Examples of Transmission Paths

Fig. 1-22

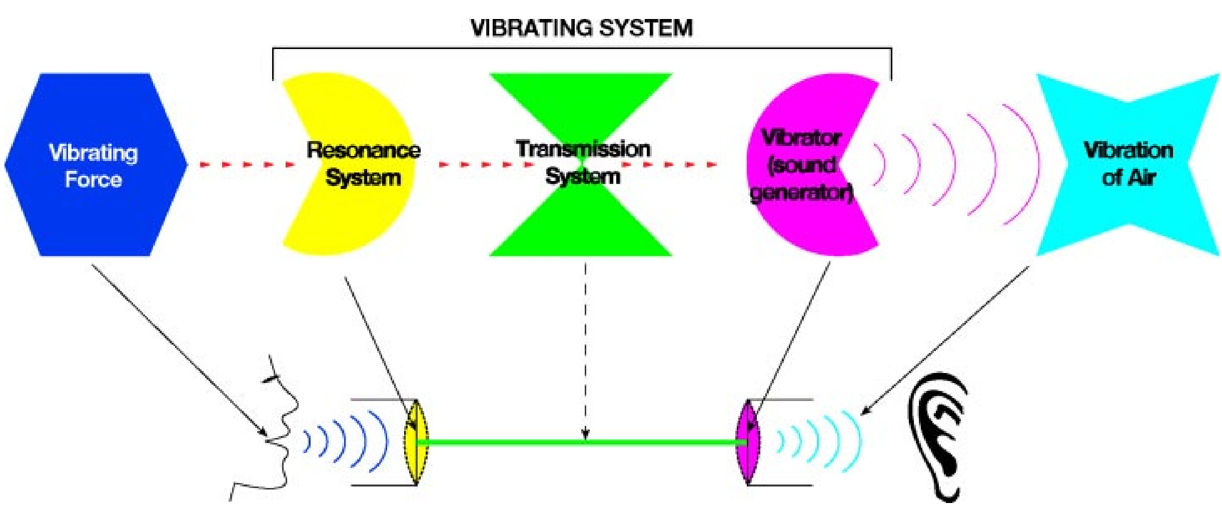


Preventing Vibrations and Sounds

Diagnosing and repairing NVH concerns can be easily understood by looking at the vibrating force and the transmission of vibrations and sounds.

Transmission of Sound

Fig. 1-23



Preventing Vibrations and Sounds
Continued

The vibrating force is usually the **first** area a technician considers in troubleshooting. This is especially true if something has changed with the source such as an imbalance, run-out or a worn component.

In some cases the vibrating force may **not** have changed or may **not** be the easiest area to repair. Changing **any part** of the **vibrating system** will also change the vibration or sound the customer senses.

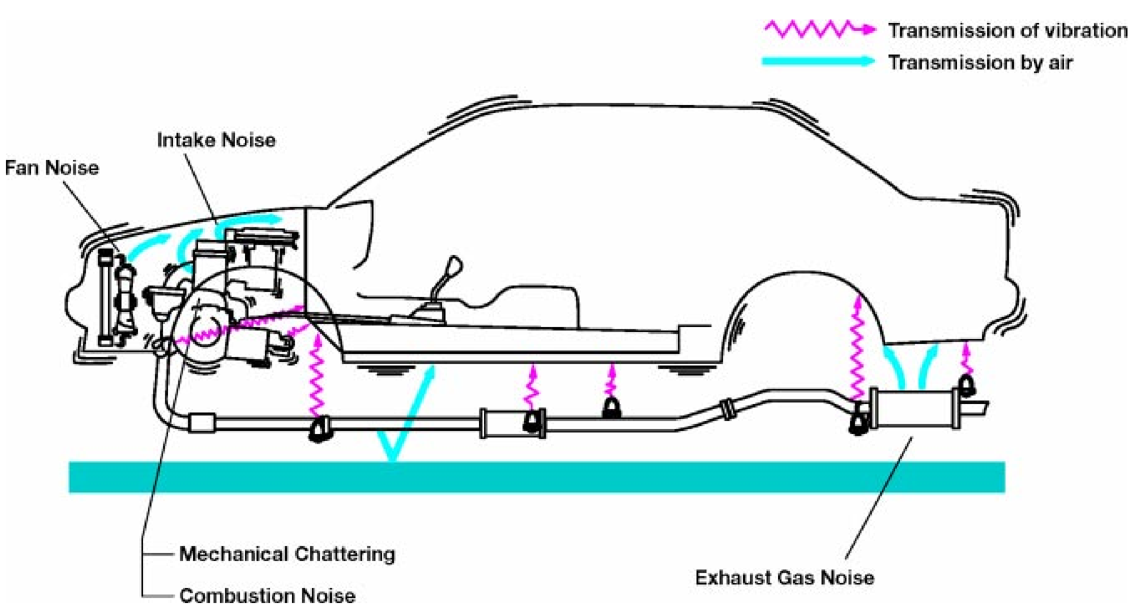
For example:

A vibration that is a result of an exhaust system that is in contact with the body.

- Vibrating force is the engine
- Resonating system is the exhaust system
- Transmission system is the contact of the exhaust to the body
- Vibrating element is the body panels

Engine Vibration/ Noise Transmission

Fig. 1-24



The repair would involve eliminating the **contact** of the exhaust system to the body (transmission path). This is the most likely area where the vehicle condition has changed causing the concern. Careful **examination** of the system should identify the cause of the grounded exhaust. The repair may involve a hanger or replacement of bent exhaust components.

Dampers

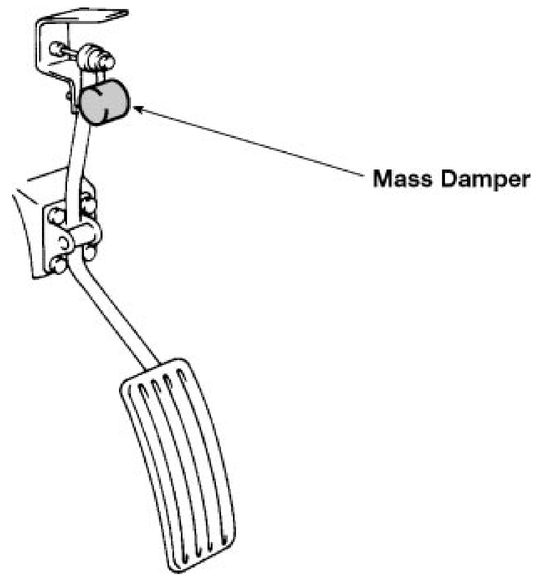
Engineers can modify a vibrating system during the design of a vehicle with the use of **mass or dynamic dampers**.

A **mass damper** is an extra weight attached to a resonance system to **lower** its natural frequency. It does two things:

- Moves the vibration or noise outside the normal operating speed range
- Reduces the vibration level or sound pressure level

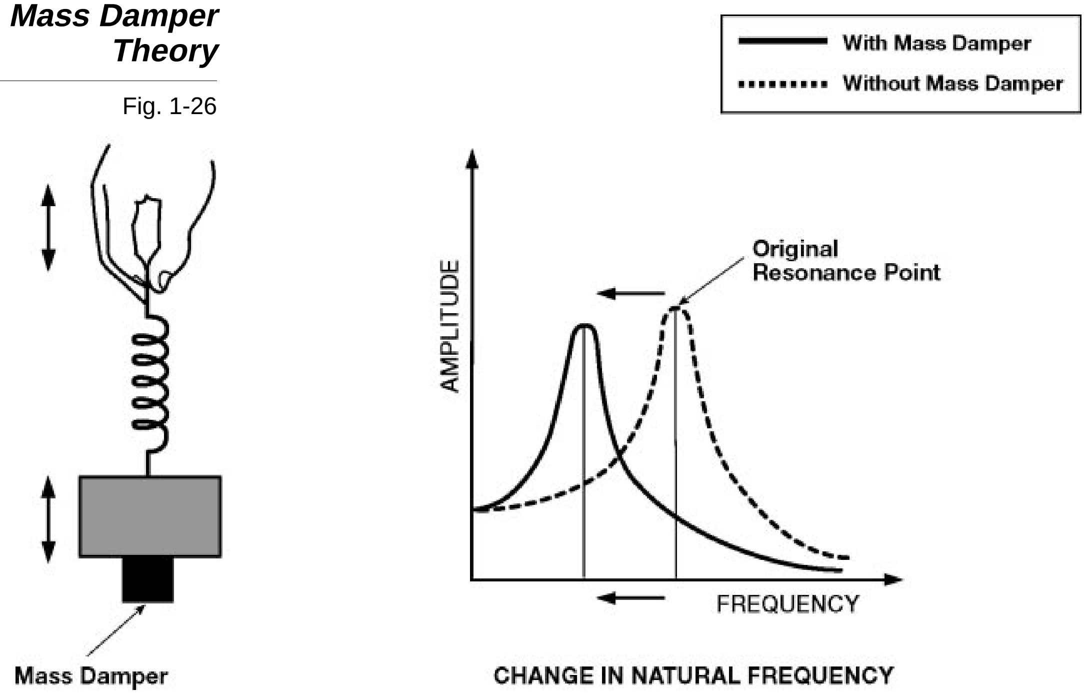
Mass Damper

Fig. 1-25



Mass Damper Theory

Fig. 1-26



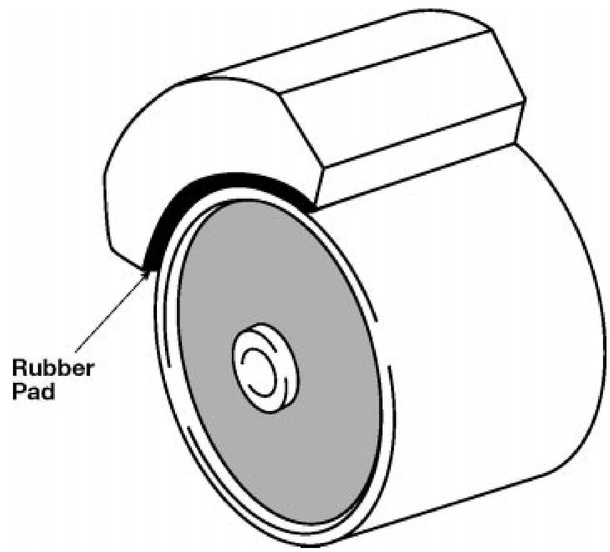
Dampers
Continued

A **dynamic damper** consists of springs (rubber) and a plumb weight that are fitted to a resonance system. When a dynamic damper is added, a large vibration having a single natural frequency is divided into **two vibrations** having **two smaller natural frequencies**.

The vibration level and sound pressure level are **reduced** as a result.

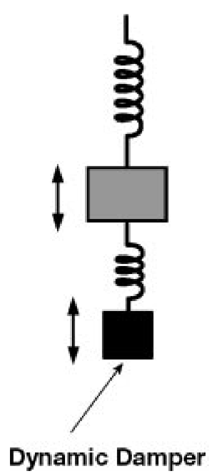
Dynamic Damper

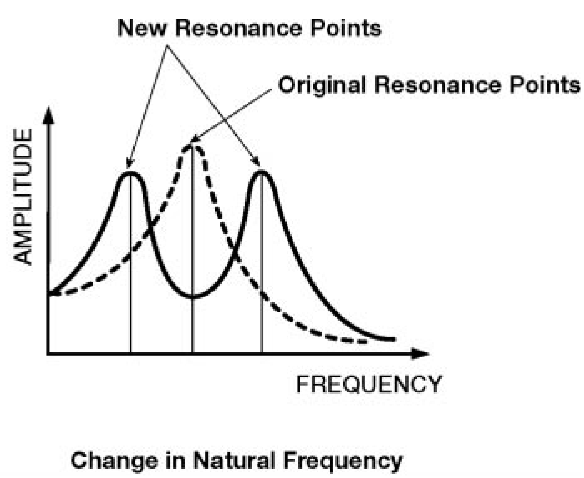
Fig. 1-27



Dynamic Damper Theory

Fig. 1-28





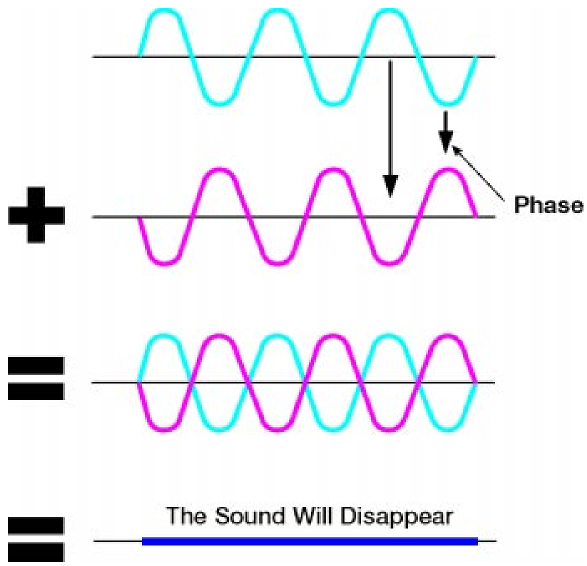
Additional NVH Phenomena

Phase is the **lateral shift** of a wave as it relates to **another wave**. For phase to have an impact on the vibrations sensed in a vehicle, there has to be **two vibrations** of the same frequency. The lateral shift determines how the high and low peaks of the waves line up and create the conditions, such as beating, explained below.

Phase

The same sounds with opposed phases will cancel each other.

Fig. 1-29



Beating/ Phasing/ Growl

Beating or phasing occurs when two similar vibrations or sounds with **slightly different frequencies** exist in the same area or vehicle.

Over a period of time the phase of the two waves will **change** due to the **slight difference in frequencies**. At times:

- The two higher points overlap and create an even higher peak which raises the level or amplitude.
- The two low points overlap to make an even lower point which lowers the level or amplitude.

This change in intensity or amplitude occurs in a **repetitive manner** at a constant vehicle speed as the phase of the wave changes over time.

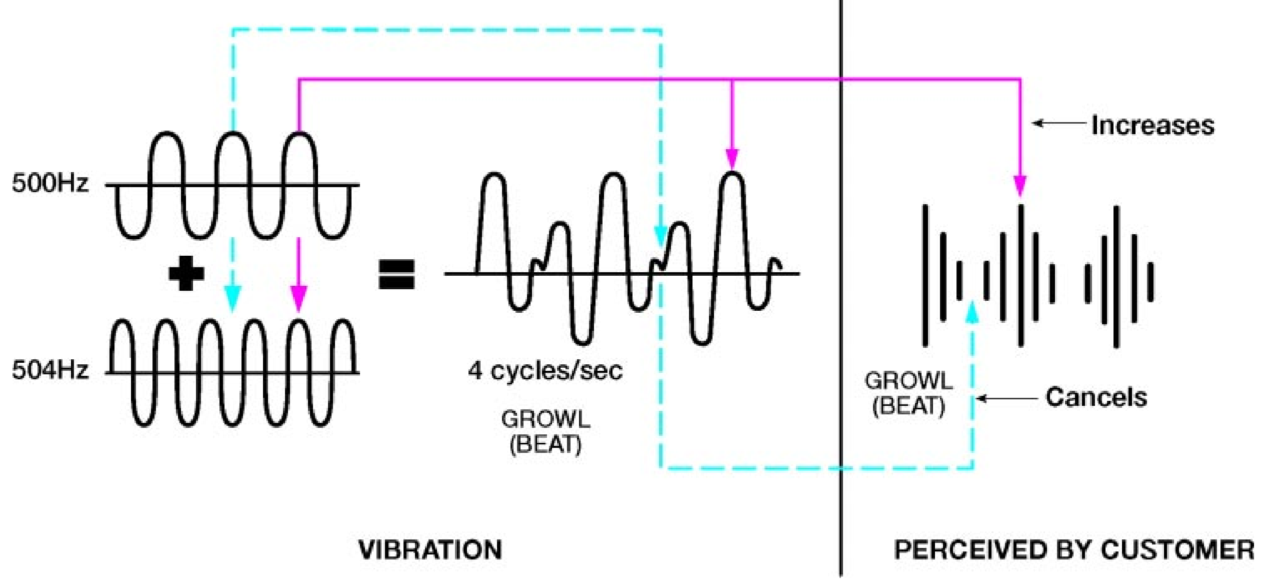
The resulting wave creates a sound called **beating**, which is associated with a vehicle having more than one tire out of balance. Tires are not always the same size and will rotate at slightly different speeds (Hz).

This condition can be corrected by **eliminating either one of the vibrations**. If one tire is balanced then the beating noise will be eliminated leaving the constant vibration from the remaining out of balanced tire. Correcting the second tire will return the vehicle to its original condition and ensure customer satisfaction.

You may have noticed a beating condition in a **twin engine boat or airplane**. If the engines are out of “sync” there is a strong cyclic vibration and sound. When the pilot adjusts the RPM on the engines, the beating vibration and cyclic sound goes away.

Growl/Beat Wave Form

Fig. 1-30



Notes

Order A **single** vibrating force may generate **more than one** vibration.

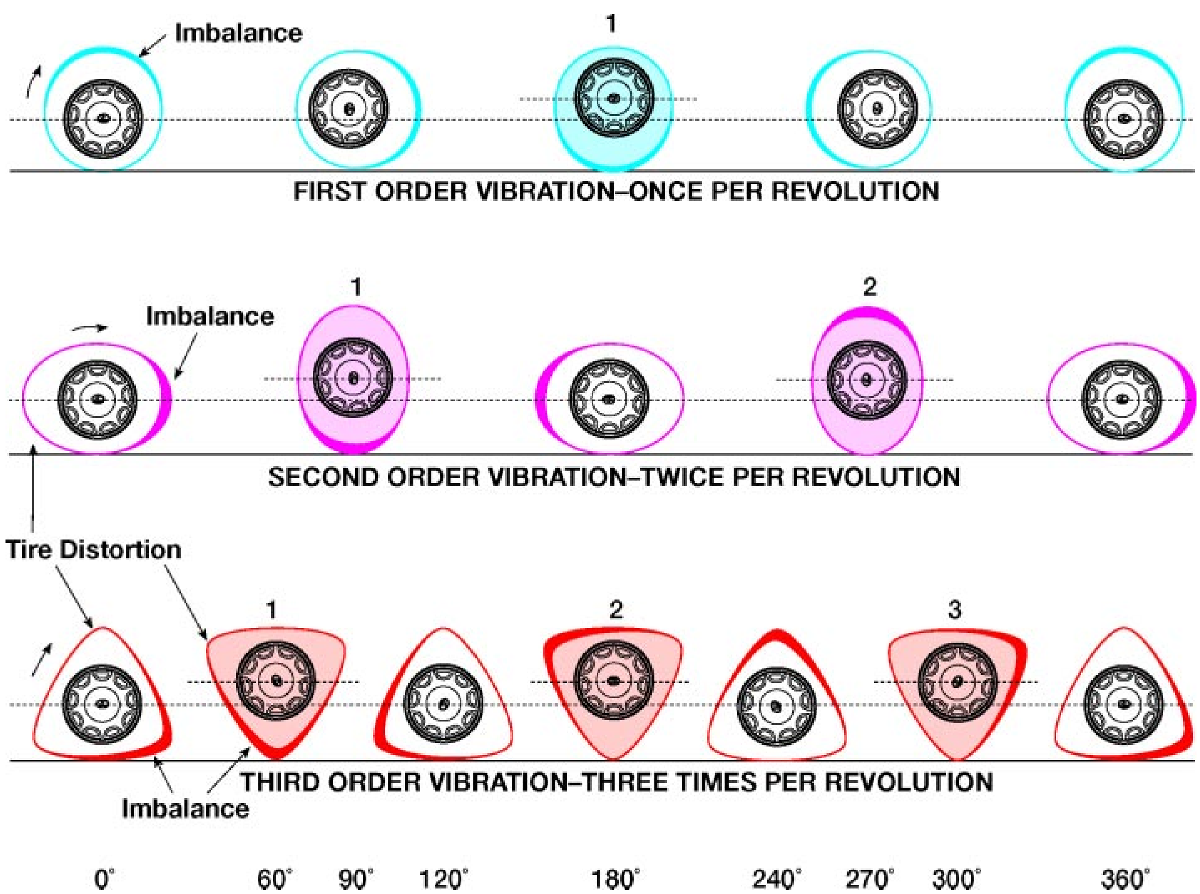
For example:

> An out of balance tire can develop multiple vibrations due to the distortion of the tire as it rotates. This is a characteristic of radial tires. The tire is no longer round and bumps rise on the tire causing the additional vibrations.

The distortion of the tire is caused by **centrifugal force** as the tire rotates. Centrifugal force is similar to swinging a yo-yo in a circle. The faster you swing it, the more the pull. This **pulling force** is what causes the tire to change shape.

Tire Frequencies

Fig. 1-31



As the tire rotates, the heavy spot on the tire causes an **up and down motion** as it contacts the road. This will induce a vibration into the suspension and steering system which will be felt by the driver. The centrifugal force of the rotating heavy spot also contributes to the up and down movement.

Order
Continued

The vibration caused by the heavy spot is a **first order** vibration. It occurs **once every revolution** of the tire.

A first order vibration can be the largest amplitude vibration of the vibrations caused by the imbalance.

Due to centrifugal force and the heavy spot, the tire changes shape raising **additional high spots** on the tire. As these spots contact the road they also cause an up and down motion that is induced into the suspension and steering systems.

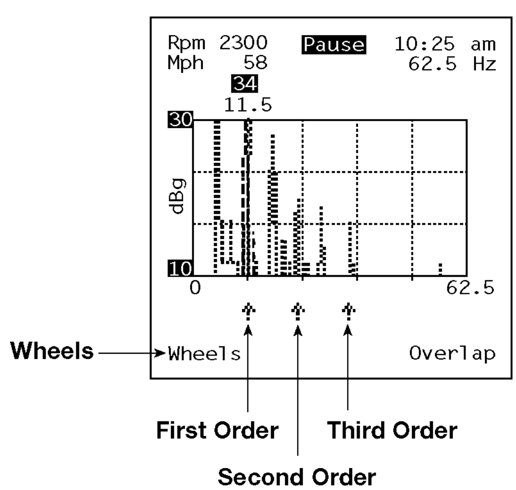
This second vibration is caused by a second bump in the tire as a result of the change in shape. It is usually smaller in amplitude than the first order vibration. This is called the **second order** or second component vibration.

Because there are **two vibrations in one rotation** of the tire, the second order vibration will be approximately **twice the frequency of the first order** and a spike on a frequency analyzer will appear at that frequency.

The third vibration is caused by a third bump as a result of the change in shape. It is generally smaller in amplitude than the second order vibration though there are some applications and speeds where it may be greater in amplitude than a first order vibration. This vibration is called the **third order or tertiary component** vibration. It will appear as a spike on a frequency analyzer at three times the first order vibration due to the **three vibrations in one revolution** of the tire.

Multiple Order Tire Vibrations

Fig. 1-32



Order
Continued

Driveline vibrations are caused by:

- Imbalance
- Runout
- U-joint condition

The force from a driveline imbalance or runout will usually cause a first order vibration because it occurs once per revolution of the shaft.

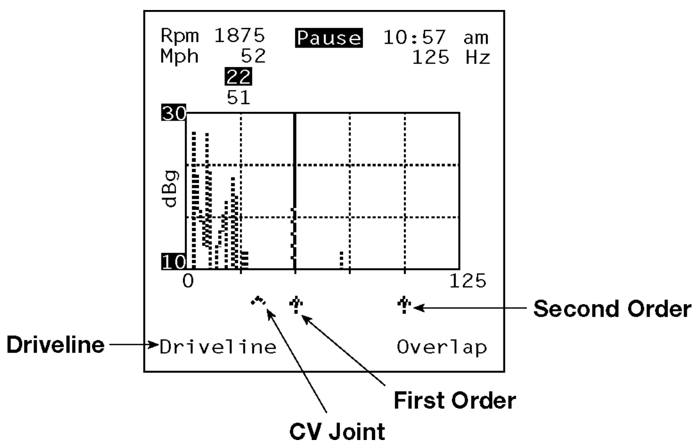
Driveline concerns relating to U-joints are caused by:

- Phase
- Joint condition i.e.: tight/loose
- Working angle/inclination

As a U-joint rotates it accelerates and decelerates **twice per revolution**. Therefore conditions relating to U-joints will generate second order vibrations.

Driveline Vibrations

Fig. 1-33

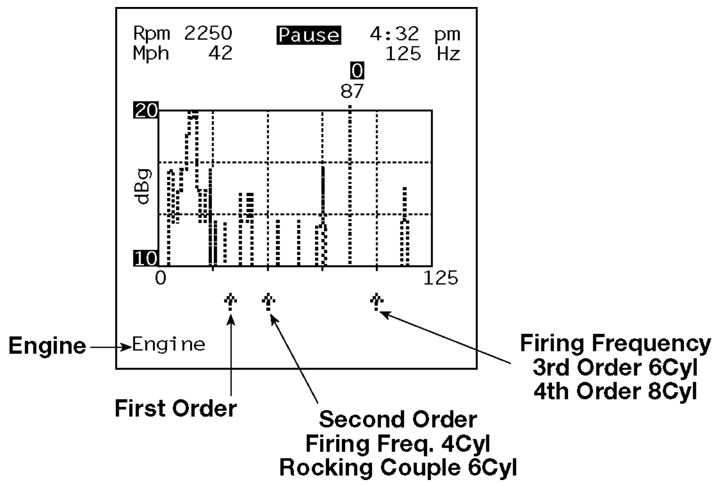


Order
Continued

Engines will also generate multiple vibrations. A first order engine vibration is associated with the **rotational force or torque**. It is usually associated with imbalance or runout conditions such as in a flywheel, torque converter or harmonic balancer.

Engine Vibrations

Fig. 1-34



Engine firing or combustion will produce **vibrations relative to the number of cylinders** in the engine. The order will be **one half the number of cylinders.** A four-stroke engine requires two complete revolutions of the crankshaft to fire all the cylinders.

For example:

A four cylinder engine fires cylinders 1 and 3 in the first revolution and 2 and 4 in the second revolution. Two pulses per revolution are generated which is a second order vibration. (Second order of crankshaft frequency)

Order
Continued

A six cylinder engine fires three cylinders in the first revolution and three in the second causing three pulses per revolution or a third order vibration.

Firing Frequency

Fig. 1-35

FIRST ORDER ENGINE		FIRING FREQUENCY		
RPM	Hz	4CYL 2nd Order	6CYL 3rd Order	8CYL 4th Order
500	8.3	16.6	24.9	33.2
750	12.5	25	37.5	50
1000	16.6	33.3	49.8	66.4
1500	25	50	75	100
2000	33.3	66.6	99.9	133.2
2500	41.6	83.2	124.8	166.4
3000	50	100	150	200
3500	58.3	110.6	174.9	233.2
4000	66.6	132.4	199.8	266.4

Fourth, fifth and greater order vibrations can exist but the first three are most common, noticeable and useful for diagnosis. If the technician identifies and repairs any of the first three vibrations the remaining vibrations will also be reduced.

The NVH Analyzer will display **all of the most common vibrations** in an operating vehicle. It also uses **arrows** to point to various order vibrations of the engine, driveline and wheels. The arrows aid in the diagnosis of vibrations by pointing to the **frequencies associated with these sources**.

If a technician notes a large spike over one of the arrows, then a **pinpoint diagnosis** can begin in the area indicated by the arrow.

Harshness

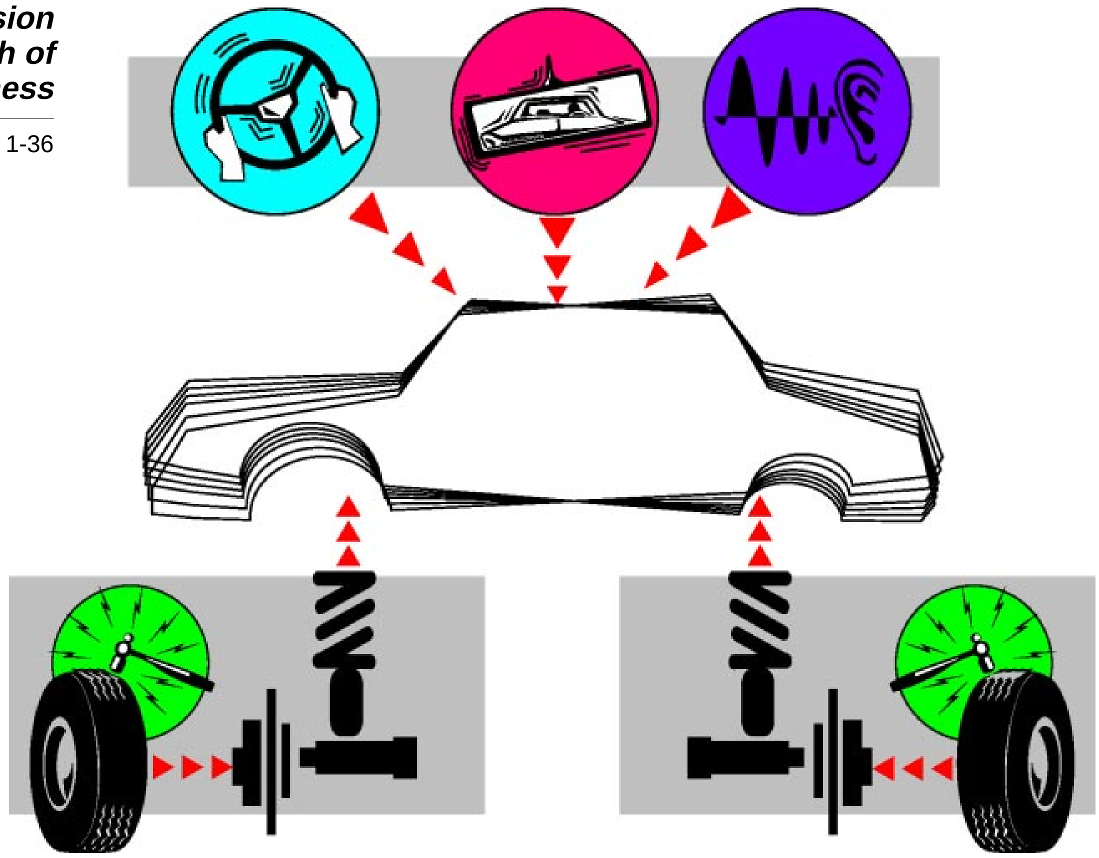
Harshness is the condition a customer senses when a vehicle contacts a **single impact** such as road irregularities, railroad tracks or speed bumps.

The level of impact that the customer senses depends on the **type of suspension** used on a vehicle. A sports car suspension system is designed for handling and to give the driver a good "feel of the road". A luxury vehicle is designed to provide the most comfortable ride possible, insulating the driver from unpleasant sensations.

A harshness concern is relative to the type of vehicle involved and should be compared to other vehicles of the **same type**.

Transmission Path of Harshness

Fig. 1-36



A vibration analyzer will **not** be the primary tool used to diagnose a harshness concern because the incident is **momentary and difficult to isolate**. In addition, the source causing the disturbance is already known and **cannot** be controlled. What has usually changed, causing the concern, **is the transmission system or path**.

A good **visual inspection** starting at the location in the vehicle where the symptom seems to originate, will usually identify the component that has changed or deteriorated.

NVH in Automobiles

There are **three major sources** of vibration in an operating vehicle.

- Engine/Accessories
- Driveline
- Wheels and tires

Each of these sources usually rotate at **different speeds or frequencies** in an operating vehicle. This is useful in diagnosis. A component generating a vibration can be associated with one of the source groups if the frequency of the vibration can be determined (discussed in Section 2).

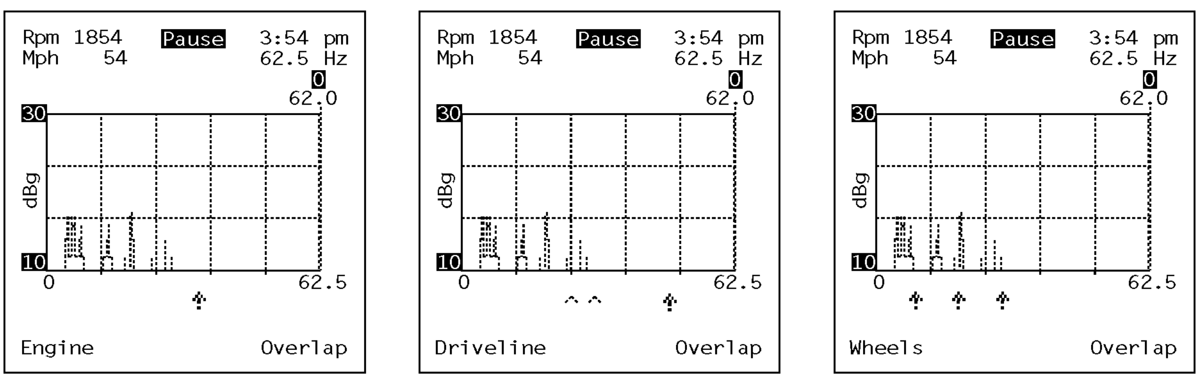
For example:

A V8 LS400, traveling at 54 MPH, in OD, will have:

- An engine speed of 1854 RPM/30.9 Hz
- A driveline speed of 44 Hz
- Wheel speed of 12 Hz

LS400

Fig 1-37



ENGINE **DRIVELINE** **WHEELS**

The different speeds of these component groups above, are determined by the **gear ratios of the transmission and differential**. Therefore, the speeds will be different for vehicles with different tire sizes, transmissions and differentials.

Shifting gears will also change engine speed at the same MPH. This will be useful for diagnosis during a road test where **modifying the symptoms** can help **isolate** the source (discussed in Section 2).

Section 2 provides the diagnostic procedures to **classify the symptom** and identify one of the three major source groups generating the condition.

Section 3 deals with pinpoint diagnostic procedures to **isolate the condition** causing the vibration or noise.

NVH in Automobiles
Continued

In addition to a frequency analyzer, **our everyday experience** with common vibrations and noises can be helpful in diagnosis. As a technician you have become accustomed to how many vibrations feel. This experience can be applied to troubleshooting a vibration in a vehicle.

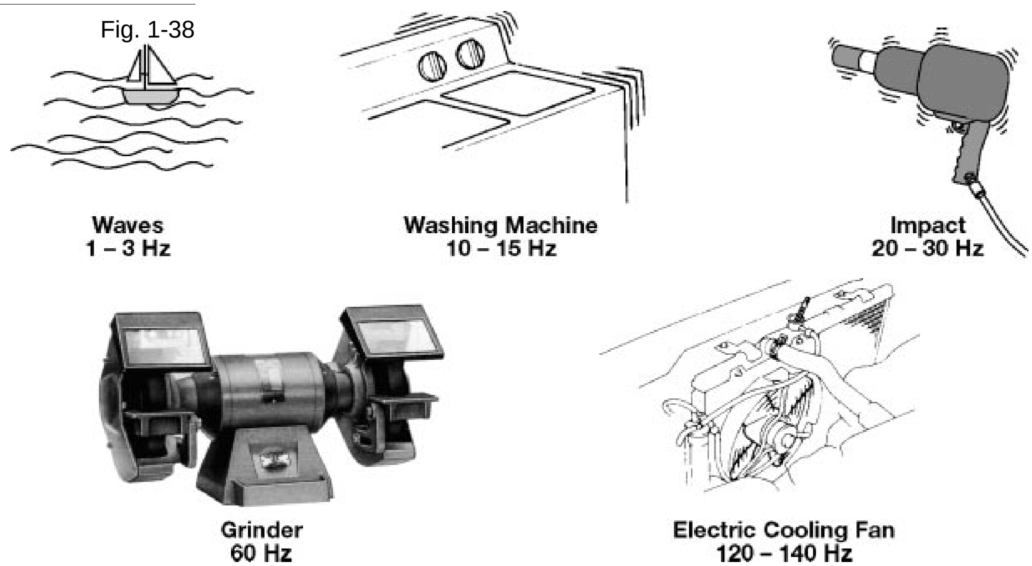
If a symptom feels like one of the examples in fig. **1-38** then the **frequency is the same** as noted. This frequency or speed can now be associated with a component group and pinpoint diagnosis can be conducted in that component area.

For example:

> A vehicle traveling between 40-50 MPH has a vibration that feels like a spinning washing machine (10-15 Hz). It is likely to have a wheel condition causing the vibration. At 40-50 MPH the wheel frequency is approximately 10-15 Hz depending on the tire/wheel diameter.

Example Vibrations

Fig. 1-38



Common NVH Symptoms

In order to help **standardize** and define the terms used to describe NVH symptoms, the following chart has been developed as a reference. It will be used extensively throughout this course.

The chart covers the common NVH conditions that occur in an operating vehicle. It includes:

- A description of the NVH condition
  - What the customer senses
  - Under what circumstances the NVH condition occurs
- Associated frequency range
- Vibrating force
- Vibrating system of the vibration or sound
- Other characteristics specific to the condition

SYMPTOM	SENSATION	CONDITIONS
Body Shake	1. A major vertical and/or lateral vibration of the body, seats and steering wheel. 2. Frequency 10-30 Hz	1. The vibration occurs at a specific speed when driving at a moderate or high speed.
Steering Flutter and Shimmy	1. Rotational steering wheel vibration 2. Shimmy has a relatively low frequency 5-15 Hz 3. Flutter is a higher frequency than shimmy	1. Flutter vibration is usually constant and generated at a limited range of speed during moderate to high speed driving. 2. Shimmy is generated when driving over a rough road or when the brakes are applied. It occurs at a lower speed than flutter and increases with vehicle speed.
Accelerator pedal vibration	1. A vibration of a small amplitude, transmitted from the accelerator pedal to the driver's foot. (it never vibrates along the stroke direction of the pedal). 2. Frequency 20-200 Hz (4cyl)	1. The vibration occurs at a high engine RPM 2. Vehicle speed has no impact on the vibration.
Shift lever vibration	1. A vibration of a small amplitude felt at the shift lever. 2. Frequency 100-200 Hz	1. The vibration occurs at a specific RPM at high engine speed.
Riding comfort	1. Refers to a slow swaying motion of the entire vehicle rather than a vibration. 2. It also refers to impacts from road irregularities being transmitted directly to the vehicle body. 3. Frequency 1-15 Hz	1. Generated when going over large bumps or dips in the road surface. 2. It is also generated when driving on irregular roads at a specific speed.
Harshness	1. A momentary heavy impact that resembles hitting the tire with a hammer. The vibration is felt in the steering wheel, seats, and floor. 2. It may be accompanied by a high-pitched impact sound. 3. Frequency 30-60 Hz	1. When going over road joints and gaps, the tire is deformed locally by an impact in the front-to-rear direction. 2. The impact is transmitted to the suspension system and body.

CAUSES	VIBRATING SYSTEM	REMARKS
Vibrating forces 1. Tire runout, imbalance or a uniformity problem 2. Rotor or Drum Imbalance 3. Axle hub eccentricity, runout or imbalance Resonators 1. Suspension 2. Engine 3. Body 4. Seat 5. Steering Linkage	1. The vibrating force of the tire condition causes a vibration that is transmitted from the axle through the suspension system. 2. The vibration will resonate with the body or engine which will cause the body to shake heavily. 3. The vibration of the body is transmitted to the steering wheel and seat.	1. The vertical and lateral shake may occur alternately every ten seconds, approximately. This is a result of a slight difference in the tire radius. A constant speed for at least ten seconds is required to attain this condition. 2. Correcting the tire causing the vibration is usually the most effective method of resolving a body shake.
Vibrating force Flutter 1. Tire runout, imbalance and uniformity condition 2. Rotor imbalance 3. Axle hub eccentricity, runout or imbalance Shimmy 1. Kick-back from a rough road 2. Tire deformation 3. Radical vertical movement during braking Resonators 1. Tires - worn or low air pressure 2. Steering linkage - loose, worn components 3. Suspension - misalignment, lack of shock absorber dampening	Flutter 1. A vibrating force is generated by a tire imbalance. 2. The vibration occurs around the steering axis causing the tire to vibrate to the left and right. This induces a vibration in the steering linkage. 3. When the vehicle reaches a particular speed, the lateral vibration of the tire resonates with the steering system. The steering wheel vibrates rotationally as a result. Shimmy 1. Shimmy is similar to flutter except it is generated by road kick-back, tire deformation, or a vertical vibration from braking. The transmission path is the same as flutter.	1. In modern cars, flutter is more common than shimmy. 2. Flutter and shimmy give similar sensations to the driver, but their mechanisms are not the same. 3. Flutter is a forced vibration caused by the resonance of the vibrating force from the tires and the steering system. 4. Shimmy is a direct vibration generated by the road irregularities or braking.
Vibrating force 1. Engine Vibration Resonators 1. Throttle linkage 2. Cable 3. Pedal	1. The engine vibration causes the throttle linkage and cable to vibrate. 2. The vibration is transmitted to the accelerator pedal.	
Vibrating forces 1. Engine torque fluctuation 2. Imbalance of revolving or reciprocating engine components Resonators 1. Engine and transmission 2. Driveline 3. Shift lever	FR models 1. The engine torque fluctuation or imbalance causes a bending vibration in the driveline. It can be amplified if there is also a propeller shaft condition like imbalance or joint angle. 2. The vibration causes the extension housing to vibrate which in turn causes the shifter to vibrate. The vibration is more noticeable if the shifter is worn. FF models 1. An engine imbalance causes a vibration in the shift lever.	
Vibrating forces 1. Road irregularities Resonators 1. Tires - air pressure 2. Suspension - shock absorber dampening, spring modules of the suspension bushings or springs, rigidity of the stabilizer	1. Road conditions cause the tires to move up and down inducing a vibration in the suspension system. 2. The vibration in the suspension system causes the vehicle to bound and rebound which is felt as swaying by the passenger.	
Vibrating force 1. Pavement joints, gaps, rail road tracks and speed bumps Resonators 1. Tire characteristics 2. Suspension 3. Body	1. Harshness is greatly effected by tire characteristics. New low-aspect ratio tires have contributed to harshness concerns. 2. Suspension system bushing design has been modified to include slits which help improve the ride.	

SYMPTOM	SENSATION	CONDITIONS
Road noise	1. A continuous blasting or rumbling sound at a constant pitch. It increases with the vehicle speed. 2. It also accompanies a very fine vibration seen on a vibration analyzer but difficult to feel. 3. Frequency ranges from 30-60 Hz and from 80-300 Hz	1. It changes with the surface of the road. The rougher the road, the more noise.
Tire pattern noise	1. A high pitched whining and roaring noise. 2. The noise may change from roaring to whining as the vehicle speed increases. 3. Frequency 100-5k Hz	1. Occurs on pavement with tires having blocked or lug pattern tread. 2. The noise is more noticeable on flat, well paved roads.
Body Booming noise	1. A heavy droning sound that is oppressive to the ear and difficult to tell where it is coming from. 2. Sometimes accompanies vibration in the body, seat and floor. 3. The frequency increases as the vehicle speed increases. Frequency 30-100 Hz at low to medium speed and 100-200 Hz at high speed. (4cyl)	Booming noise is heard at a specific engine or vehicle speed. The range is very narrow. 1. When affected by vehicle speed ± 6 MPH of peak speed 2. When affected by the engine RPM ± 50 RPM of peak RPM
Engine noise	1. A continuous sound heard in the passenger compartment that increases with engine RPM. 2. Frequency 200-2k Hz	1. It is heard when the engine is running at a high speed or under load.
Wind noise	1. The hissing or whistle of air heard near a window. 2. Wind noise increases with vehicle speed and can change with wind direction. 3. Frequency 500-5000 Hz	1. It occurs at approximately 40-50 MPH with the windows shut.

CAUSES	VIBRATING SYSTEM	REMARKS
Vibrating force 1. Small road surface irregularities Resonators 1. Tires 2. Suspension system 3. Body	1. When driving on rough pavement, a fine vibration occurs in the tire which causes the tire to resonate and the vibration is amplified. 2. The vibration is transmitted through the suspension system to a body panel that vibrates generating the noise.	1. Suspension bushings are also designed to provide a good balance between road noise and handling.
1. Pumping of air by the tire tread.	1. Air is trapped and compressed between the grooves of the tire and the road as it rotates. 2. As the section of the tire leaves the ground, the compressed air is released and expands creating the sound.	1. Pattern noise is greater if the area to trap air is larger such as truck tires. It is more noticeable if the grooves are perpendicular to the car's body.
Vibrating force 1. Imbalance of rotating and reciprocating engine components, torque fluctuation 4cyl twice per revolution, 2nd order/secondary engine component 6cyl three times per revolution, 3rd order/tertiary engine component 2. Torque fluctuation due to propeller shaft joint angle twice per revolution, 2nd order/secondary driveline component 3. Propeller shaft imbalance once per revolution, 1st order/primary driveline component 4. Clutch assembly imbalance 5. Exhaust noise 6. Intake noise 7. Tire uniformity condition Resonators 1. Twisting of the driveline 2. Bending of the driveline 3. Exhaust pipe 4. Rear suspension system 5. Outer body panels	Due to propeller shaft joint angles 1. A propeller shaft joint accelerates and decelerates twice per revolution and generates a torque fluctuation twice per revolution. The vibration is greater the greater the angle. 2. The torque fluctuation starts to vibrate the driveline at a specific speed. The vibration is transmitted via the rear suspension arm bushings and springs to the body panels which generate the booming noise. Due to propeller shaft imbalance 1. An unbalanced propeller shaft generates a vibration once per revolution. 2. The vibrating force bends the driveline and the vibration is transmitted via the rear engine mount, center bearing, rear suspension bushings, to the body panels which generate the booming noise. Due to the transmission of exhaust noise 1. Exhaust noise can be transmitted to the body panels through the floor with direct contact or through the vibration of the air.	1. The body booming noise can be engine related or vehicle speed related 2. Check to see if the condition exists when the engine reaches a specific RPM or if it occurs while coasting which indicates vehicle speed related. 3. Knowing the frequency and order is very helpful in diagnosing which component is generating the vibration.
Vibrating force 1. Mechanical noise - valve train, timing chain, piston, connecting rod, crankshaft, accessories 2. Combustion noise 3. Fan noise 4. Intake air noise 5. Exhaust noise Resonators 1. Engine 2. Accelerator cable 3. Body panels	1. The sound is transmitted through the air or through the body via engine or exhaust mounts.	1. Engine noise can be improved by reducing the noise from the source or insulting against the noise. 2. The following are examples: Holes plugged with grommets Asphalt sheets Sealer Sandwich steel sheets with insulators inside Pad for engine hood Specially designed engine mounts
Vibrating force 1. Swirls of air generated by protrusions and steps in the body surface. 2. Leakage of air through gaps in the body.	1. Wind noise is generated when air hits or is swirled by an object. The sound enters through a door or window. 2. Wind noise is also caused by leakage through a gap. When the vehicle is moving, the pressure outside the vehicle is lower than inside and the noise is created when the air escapes.	1. Refer to the Interior Noise and Wind Noise programs for detailed procedures on repairs.

SYMPTOM	SENSATION	CONDITIONS
Body Beating noise	1. The level of the sound changes cyclically. 2. The cycle becomes shorter as the vibrating force speed increases. 3. The cyclical sensation is more apparent when it occurs between 2-6 times per second.	1. It occurs at a specific engine or vehicle speed. 2. When two sounds having slightly different frequencies are present, the level of the combined sound changes cyclically and is felt as a beating noise. 3. When the two high points of the wave coincide, the level of the sound is amplified. When the two low points line up, the level is much less noticeable.
Transmission gear whine	1. A high pitched clear sound that is noticed from the front seats. 2. Frequency 400-3k Hz	1. It is specific to a particular gear position and is not heard when the gear is connected directly with the engine.
Differential gear whine	1. A high pitched, clear sound heard from the front of FF vehicles and the rear of FR vehicles. 2. Frequency 400-1500 Hz	1. It occurs at medium speed 25-30 MPH regardless of gear position. 2. When it occurs during acceleration, it will disappear when the pedal is released. When it occurs during deceleration, it will disappear when the pedal is engaged.
Clutch judder	1. The forward and backward shocks to the body when the clutch is engaged. It stops when the clutch is completely engaged. 2. Frequency 10-20 Hz	1. It occurs when the clutch is partially engaged, starting from a stop, especially under a load such as an incline. 2. It usually does not occur when the vehicle is in motion.

CAUSES	VIBRATING SYSTEM	REMARKS
1. Two vibrations are required and could be a combination of the following: Engine imbalance - 1st order Torque fluctuation - 2nd order 4cyl, 3rd order 6cyl Torque converter imbalance Propeller shaft imbalance - 1st order driveline Flange runout - 2nd order driveline Joint condition or angle - 2nd order driveline Tire vibration Cooling fan imbalance Alternator vibration A/C compressor vibration Power steering pump vibration	1. Torque converter imbalance will generate a beating with another vibration such as a propeller shaft vibration when the conditions are as described. Slippage of the torque converter can contribute to the difference in frequencies creating the beating. 2. The vibrations are transmitted to the body through the engine mounts from the torque converter and the rear suspension from the propeller shaft. 3. Correcting the propeller shaft may be the easiest repair. 4. Depending on the gear ratio of the transmission a beating can occur between an engine vibration and a driveline vibration if the frequencies of each are only slightly different. 5. Engine vibrations and accessory vibration can match to cause a beating noise. Removal of belts will help identify the accessory causing the vibration. 6. Depending on differential gear ratio tire vibration and propeller shaft or engine vibrations can cause a beating noise. 7. Two imbalanced tires with a different radius can cause a beating noise.	1. Beating noise due to torque converter slippage can be identified by checking it during lock-up or fluctuating the accelerator pedal. 2. A constant speed is necessary to allow the beating noise to cycle. 3. Due to the fact that a beating noise requires two vibrations, if one is eliminated the beating noise will stop leaving the remaining vibration.
Vibrating force 1. Gear meshing error - nicked, worn or damaged tooth, incorrect teeth contact, gear runout and backlash, gear supporting rigidity Resonators 1. Gear vibration 2. Transmission case 3. Engine supports and mounts 4. Propeller shaft 5. Rear suspension 6. Body panels	FR 1. Inaccurate meshing of the transmission gears causes the gears to vibrate. 2. Gear vibration vibrates the transmission case, which vibrates the body panels via the rear engine support members. 3. Gear vibration is also amplified by the resonance of the propeller shaft and the rear suspension. FF 1. Sound is transmitted from the transaxle case to the body via the engine mounting and shifter.	1. Gear selection is the key to diagnosis between transmission and differential gear whine. 2. Familiarity with the transmission power flow will assist in determining which gear is 1:1 and the gears that could be in question. 3. Bearing noise is similar to gear whine and must be considered during disassembly.
Vibrating force 1. Same as transmission gear whine Resonators 1. Same as transmission gear whine	FR 1. Inaccurate meshing of the differential gears causes the gears to vibrate. 2. The vibration is transmitted to the differential carrier and amplified by the resonance of the propeller shaft and the rear suspension. It is then transmitted to the body. FF 1. The noise is transmitted directly to the passenger compartment via the case, mounts, cables, and the air.	
Vibrating force 1. Friction characteristics of the facing material and runout of the clutch disc 2. Unequal height of the diaphragm spring fingers 3. Binding of the clutch cable or linkage Resonators 1. Driveline	1. Intermittent slippage occurs when partially engaging the clutch, transmitting engine torque vibrations. 2. Induces a torsional vibration in the driveline. If resonance occurs, the vibration is amplified. 3. Amplified torque fluctuation is transmitted to the tires and rocks the vehicle back and forth.	1. Foreign material such as oil or grease will contribute to the condition.

SYMPTOM	SENSATION	CONDITIONS
Take-off vibration	1. A slow and weak vibration of the body and steering wheel during initial acceleration. 2. Frequency 15-30 Hz	1. It occurs when the clutch is slightly engaged with the engine at idle or when engaged abruptly at 800-900 RPM. 2. A load such as an uphill grade can also contribute to the vibration.
Cranking vibration	1. A very slow vibration felt in the body and seat during cranking. 2. Frequency 5-15 Hz	1. The vibration begins when the starter is activated and stops when the engine starts.
Idle vibration	1. A slow vibration of the body, steering wheel and seats. 2. Frequency 10-50 Hz.	1. Engine idle, not moving, in gear or A/C on.
Brake vibration	1. A vibration of the dashboard, steering wheel and seats when the brakes are applied. 2. It is felt at the pedal at the same frequency as the vibration. 3. Frequency 10-30 Hz	1. Occurs when the brakes are applied at medium to high speeds.
Brake squeak	1. A very high pitched squeaking noise or low solid groan. 2. More common from disc than drum brakes. 3. Frequency 5-20 Hz.	1. Occurs when brake is applied lightly or heavily.

CAUSES	VIBRATING SYSTEM	REMARKS
Vibrating force 1. Torque fluctuation of the engine Resonators 1. Engine mounts 2. Body 3. Steering wheel	1. When the clutch is partially engaged during initial vehicle movement, the engine RPM drops momentarily and results in a major torque fluctuation. This causes a rolling vibration of the engine. 2. The vibration is transmitted via the engine mounts to the body. The engine sometimes hits the mounting stops. The instrument panel and steering wheel shake as a result.	1. Take-off vibration is also caused by coupling created by a joint angle of the three joint propeller shaft on FR vehicles. In this case, the vibration is transmitted to the floor by the center carrier, causing the shifter and floor to vibrate. 2. It is also caused by a wind-up on vehicles with rear leaf springs.
Vibrating force 1. Torque fluctuation during starting of the engine Resonators 1. Engine mounts 2. Body	1. Engine rolls due to the fluctuation in compression. 2. This movement acts on the mounts causing the body to shake.	1. A heavy hitting noise could be associated with this condition if components such as the exhaust contact the body.
Vibrating force 1. Torque fluctuation of the engine Resonators 1. Engine mount 2. Exhaust pipe and supports 3. Body	1. Torque fluctuation causes a rolling vibration which is worse if under a load or in poor operating condition. 2. The engine vibration is transmitted to the body through the mounts. 3. The exhaust system will also vibrate and will be transmitted to the body by the O-rings. 4. The body vibration will cause the steering wheel and seat to vibrate.	1. Transverse mounted engines are more prone to this type of vibration and have specially designed mounts and exhaust systems
Vibrating force 1. Rust or runout, in the rotor 2. Runout of the rear axle flange 3. Runout of the rotor and rim mating surface Resonators 1. Pad 2. Brake pedal 3. Steering knuckle, axle hub or shaft 4. Suspension 5. Body	1. Runout of the rotor causes the pad to vibrate during braking. 2. The pad vibration is transmitted along the brake hydraulic circuit and causes the pad to vibrate. 3. It is also transmitted to the rotor, steering knuckle, axle shaft or hub, causing an up and down or front to back vibration. 4. The vibrations are transmitted to the body via the suspension system causing a shake.	1. Lug nut torque is important to minimize the chance of the unequal strain contributing to the condition. 2. If it occurs at high speed the tires should also be checked for runout which could contribute to a brake vibration.
Vibrating force 1. Fluctuation and friction of the pads Resonators 1. Pads 2. Rotor	1. The friction surface between the brake components causes a vibration which resonates with the rotor.	1. It is important that the anti-squeal components are in place during installation.

Notes