Welcome to Vibrationdata

Acoustics • Shock • Vibration • Signal Processing

August 2006 Newsletter

Greetings

Fingernails scraping against a blackboard, a crying baby, dental drills, and other high-frequency sounds can be very annoying to most people. The squeal of automobile disc brakes can be added to this list.

The squeal may or may not be a symptom of a problem requiring service, but the brake system should be inspected if the sound is persistent. Vibration during braking can be a sign of a serious problem such as a warped rotor. The first article discusses both sound and vibration for disc brake systems.

The image of the brake rotor on the right is courtesy of the University of Huddersfield. It is a VW disc brake with a superimposed holographic pattern resulting from the modal response of the disc to sinusoidal excitation at the corresponding modal frequency.

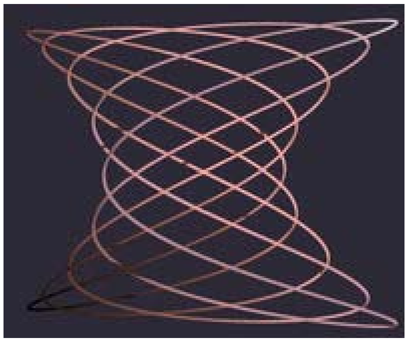
The second article describes Lissajous patterns, which can be used to study the vibration of tuning forks, pendulums, and other objects. Electronics engineers use Lissajous patterns to measure radio signal frequencies by analyzing the type of pattern an unknown signal makes when it is combined with a signal of known frequency.

Sincerely,

Tom Irvine

Tom Irvine
Email: tomirvine@aol.com

Feature Articles



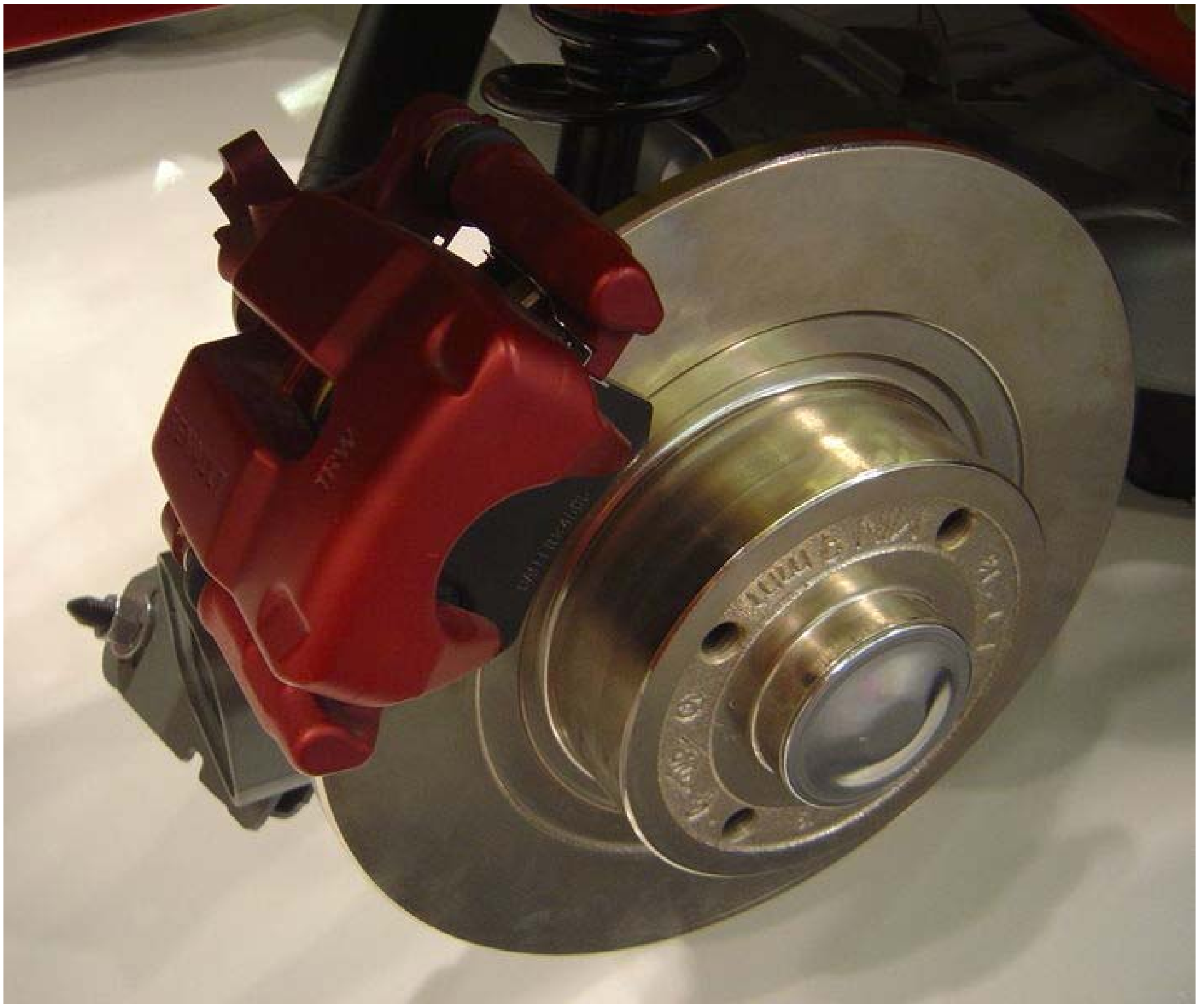


Figure 1. Close-up of a Disc Brake (Image Courtesy of Wikipedia)

Disc Brake Sound and Vibration

By Tom Irvine

Introduction

Consider an automobile with disc brakes. As the brakes are applied, hydraulic pressure causes the calipers to press two pads against each rotor. There is one pad on each side of the rotor. Brake pads have two main parts, the steel backing, and the actual friction material.

Each rotor has a disc shape, and each rotates with its attached wheel.

The vehicle is slowed as friction between the brake pads and rotors converts the vehicle's kinetic energy to heat.

Some of the vehicle's kinetic energy is transmitted into sound and vibration, which are unwanted byproducts.

A squealing sound may indicate a problem or may be simply be a nuisance. Vibration may be a symptom of a warped rotor or some other defect.

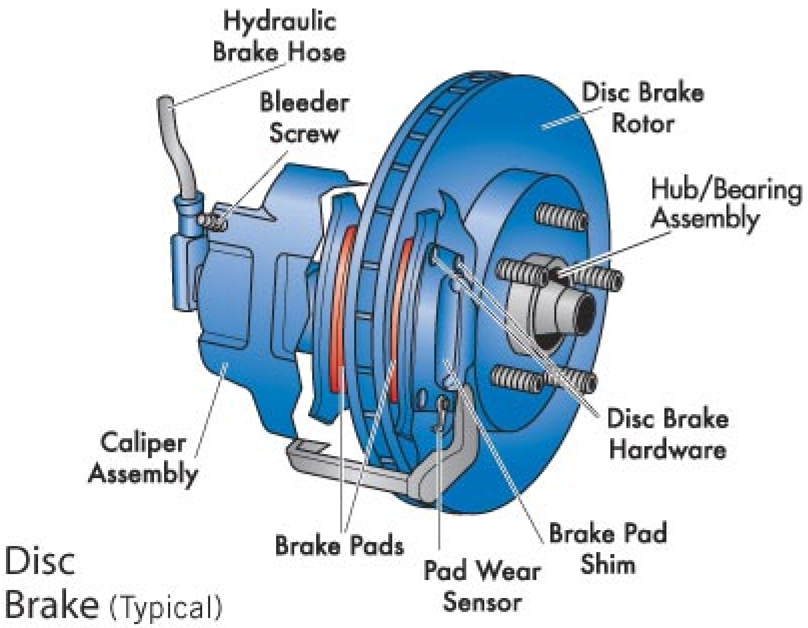


Figure 2. Disc Brake Assembly (Image courtesy of Midas)

Vibration due to Warped Rotors or Uneven Wear

The surfaces of a warped rotor are not parallel. The caliper pistons are rapidly pushed in and out as the pads contact high and low spots. These pulsations will cause the entire wheel to vibrate.

This "shimmy vibration" is transmitted to the driver's foot via the brake pedal and to his hand's via the steering system. The shimmy may be accompanied by a groaning or grinding noise.

Rotors can become warped due to normal wearing, especially if the brake pads are worn to the point that there is metal-to-metal contact between the pad's metal backing plate and the rotor.

Warping can also occur if the brake pads become very hot during a long trip and then exposed to cool water as the vehicle drives through a puddle.

An overheated disc may also develop an oxide layer, or glazing.

Furthermore, the shimmy may start after a tire has been changed if there is dirt, corrosion or rust on the inner surface of the new wheel. This can cause uneven clamping, leading to rotor warping. Uneven clamping may also occur from improper tightening of the lug nuts.

The pulsations and resulting shimmy may cause improper operation of the anti-lock braking system. In addition, severe vibration can cause premature wear or damage to the brake system.

Warped rotors can be repaired in some cases. The surface layer can be milled off so that the surface is smooth and even.

However, the remaining thickness must be within manufacturer's specifications for proper strength and heat dissipation. The specified thickness is usually stamped into the rotor itself. Further recommendations regarding resurfacing are given later in this article.

Brake Fluid Concern

Overheating has already been mentioned as a source of rotor warping.

As an aside, brake fluid has a tendency to absorb water over time. Brakes generate a tremendous amount of heat during braking. Any water in the brake fluid is likely to boil. The resulting bubble or bubbles contain compressible air which leads to a loss of pressure on the brake pads for that wheel.

Thus, the brake fluid should be replaced at regular intervals.

Brake Squeal Sources

High-frequency vibration in the brakes generates an annoying squeal sound.

The vibration in disc brakes can occur due to:

1. Loose or corroded pads
2. Metal-to-metal contact between the pads and rotor
3. Loose or worn caliper
4. Glazed rotors or pads
5. Rough or hard spots on the rotor
6. Missing anti-rattle springs (if used in the design)
7. Contamination such as grease, oil, or rust on the pads or rotor

Furthermore, some manufacturers have a metal wear indicator that touches the rotor and squeals as a warning when the brake pads are worn out.

Friction between the pad and rotors is a particularly common source for brake squeal. This can occur due to rough spots or bump on either the pads or rotor.

Pad Replacement

The pads may need replacement if they are worn or corroded in order to attenuate the brake squeal.

The brake pad material may be semi-metallic, metallic, or ceramic. Metallic pads are used almost exclusively on race cars. The most common material for the last several years is semi-metallic.

Complaints about brake squeal became a problem when front-wheel drive and semi-metallic brakes appeared in the 1980s. Semi-metallic pads are required on many applications to handle high brake temperatures.

Semi-metallic pads are harder than asbestos pads. Asbestos is no longer used due to health and environmental concerns.

The semi-metallic pads are thus more likely to produce squeal if there are any irregularities or roughness on the rotor surface, or if there is any looseness between the pads and calipers. A certain amount of high-pitched brake noise is even considered "normal" for semi-metallic pads.

Shim Replacement

Shims dampen sound and vibration. These shims are also referred to as “brake noise insulators.”

The shim is mounted with an adhesive or is mechanically fastened on the back plate of the brake pad.

The two most common types of shims are a woven fiberglass cloth impregnated with rubber or a thin wafer of steel coated with plastic. A new type of shim has a nitrile phenolic dampening layer sandwiched in between two thin wafers of steel.

RTV Silicone Compound

In some cases, an RTV silicone compound may be applied on the back of the brake pad to dampen vibration in place of a shim. The silicone must be fully cured prior to installing the pads in the caliper. The silicone serves as a cushion between the brake pad and the caliper.

Lubrication

Furthermore, a high temperature brake lubricant may be applied to the backs of the pads and to the points where the pads contact the caliper. The lubrication helps reduce noise.

Resurfacing Rotors

In addition to replacing the pads, the rotors may need to be resurfaced provided the minimum thickness can be maintained. Otherwise, the rotor may need to be replaced.

The rotor may be made from cast iron or composite material. Note that the rotor rings like a cymbal at its natural frequencies.

Replacing a composite rotor with a solid cast rotor changes the natural frequencies and harmonics of the brake system, which may increase brake noise on some applications.

Cast iron rotors are easier to resurface because they are more rigid than composite rotors. Special care must be taken when resurfacing composite rotors.

The rotor should have a smooth, non-directional finish. The recommended rotor finish for most applications is 60 to 80 microinches. A smaller value may be needed in some cases.

New Brake Squeal

New brakes may squeal due to one of two reasons.

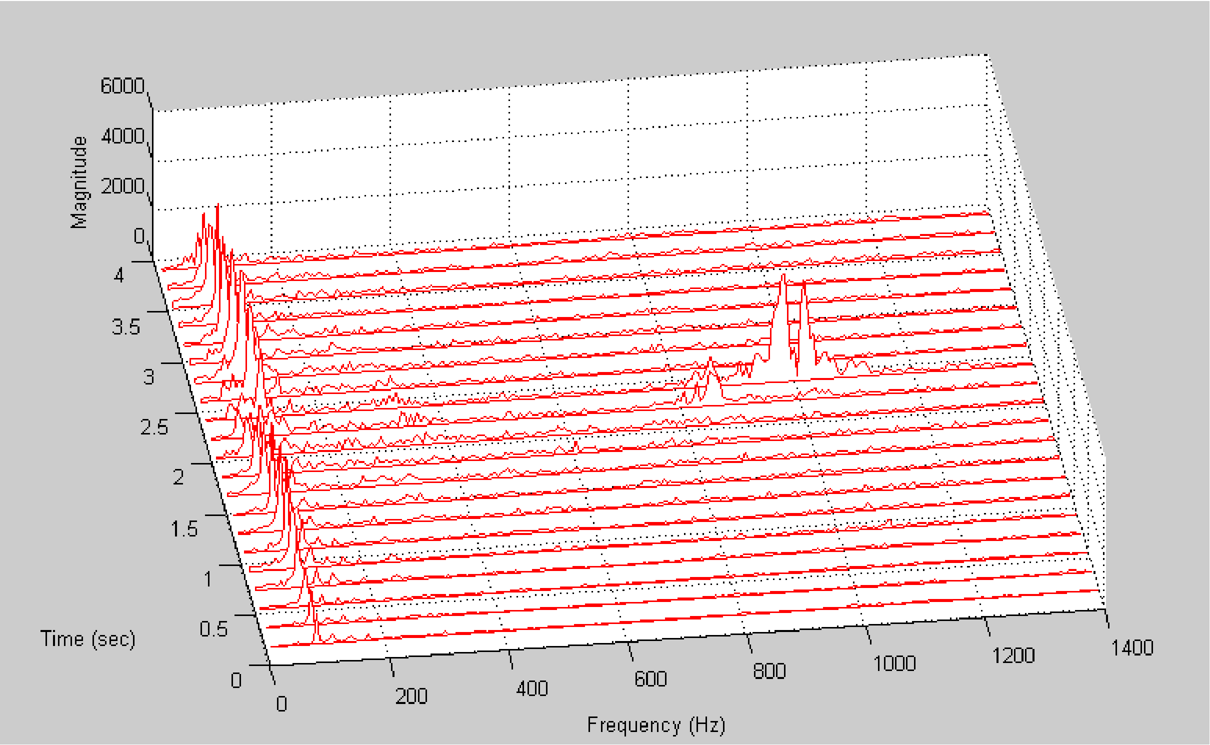
First, new pads need to conform to the rotor surface, preferably through gentle driving and stopping. This is called “bedding in.” The squealing will gradually stop as this process occurs.

On the other hand, there is a risk of over-heating and carbonizing the surface of the pad if the brakes are applied hard before they bed-in. This means performance will suffer dramatically and a glazed surface will likely result.

Second, the pads may have become covered with some grease or oil. Also, new rotors usually have a thin film of oil on them to prevent them from rusting up while sitting on the shelf.

The resulting squeal will also slowly stop as the surface of the pads wear down a little, thereby removing the contaminant.

A similar problem may occur if a car has been sitting after being exposed to rain, snow, or even a simple car wash. The moisture can cause a thin layer of rust to develop on the brake rotors. The pads pressing on the rust-covered rotors may cause a squeal for a few stops until the rust wears off. The sound will then go away.



FFT MAGNITUDE 1995 PORSCHE CARRERA BRAKE SQUEAL

Figure 3.

Measured Squeal Data

A brake squeal sound file was obtained from:

http://www.sounddogs.com

The sound file was described as:

> Cars - 1995 Porsche Carrera 2 993 Turbo RWD - Exterior - Corner By at 40 Mph, Peak at 0:18, Good Brake Squeal.

A waterfall FFT of the sound pressure time history is shown in Figure 3. The FFT magnitude for the entire duration is shown in Figure 4,

The spectral peak at 82 Hz corresponds to 4920 rpm. This represents the engine speed. The spectral peaks at 854, 976 and 1011 Hz correspond to brake system frequencies. One or more of these peaks may represent the rotor natural frequency or frequencies.

The exact cause of the squeal is unknown. It may have been due to loose or warn pads or to any of the other previously mentioned sources.

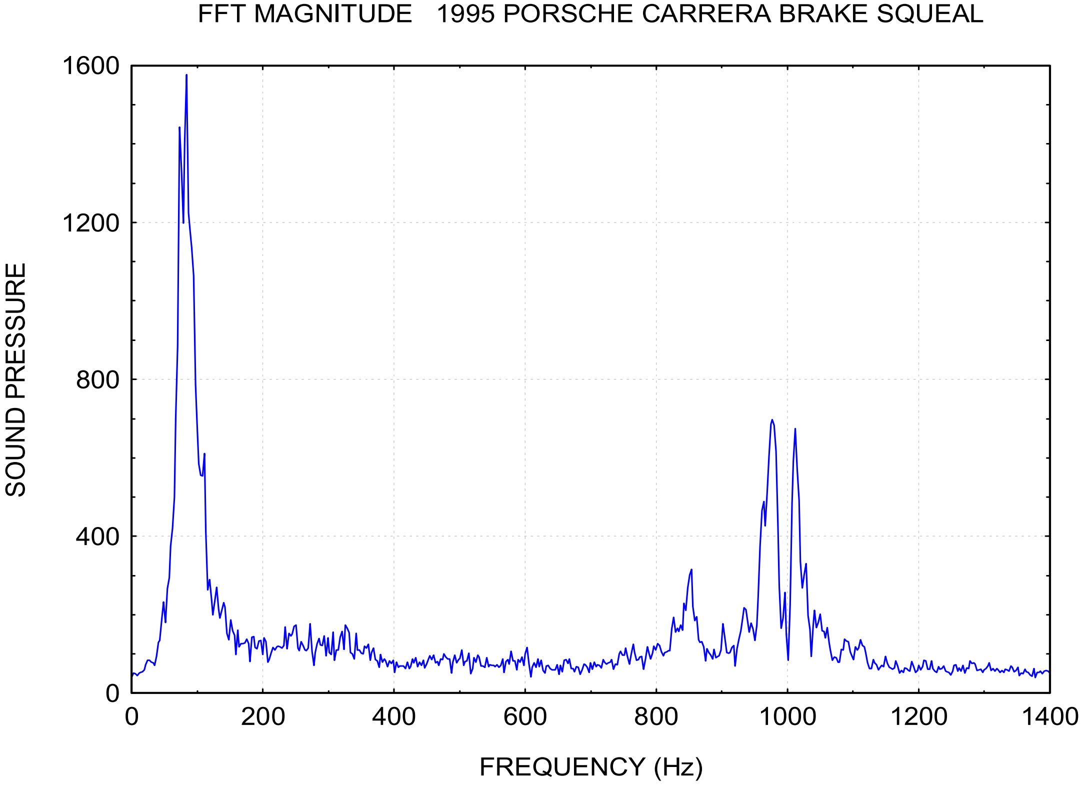

FFT MAGNITUDE 1995 PORSCHE CARRERA BRAKE SQUEAL
SOUND PRESSURE
1600
1200
800
400
0
0
200
400
600
800
1000
1200
1400
FREQUENCY (Hz)

Figure 4.

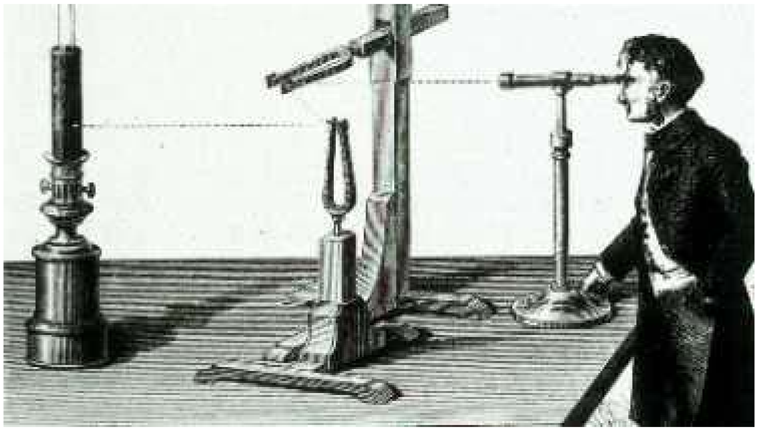


Figure 1.

Lissajous Patterns

by Tom Irvine

Jules Antoine Lissajous

Jules Antoine Lissajous (1822–1880) was a French physicist who studied the mechanical oscillations of objects. As an example, he stood tuning forks in water and watched the ripple patterns.

His most famous experiments involved tuning forks and mirrors. He attached a mirror to a tuning fork and shone a light onto it. He observed, via additional mirrors, the reflected light twisting and turning on the screen in time to the vibrations of the tuning fork.

Lissajous performed a similar experiment using two tuning forks, with one vibrating at twice the frequency of the other. He found that the curved lines on the screen would combine to make a figure eight pattern when he set up the two tuning forks at right angles. This pattern is shown in Figure 9, assuming zero phase difference.

Nathaniel Bowditch

Nathaniel Bowditch (1773-1838) also analyzed the curves resulting from similar oscillations, but Lissajous studied the corresponding equations in more detail.

Equations

Consider a two-degree-of-freedom system with harmonic motion in two orthogonal axes. The displacement in the X and Y-axis can be represented by two parametric equations:

$$x(t) = a \sin\left(\omega_1 t + \phi_1\right) \tag{1}$$

$$y(t) = b \sin\left(\omega_2 t + \phi_2\right) \tag{2}$$

where

a and b	are the respective amplitudes
ω_1 and ω_2	are the respective angular frequencies (rad/sec)
ϕ_1 and ϕ_2	are the respective phase angles (rad)
t	is time

The two equations contain six constants and one independent variable, which is t. A single equation can thus be formed by solving one equation for t and then by substituting into the other original equation.

The resulting curve is very sensitive to the ratio of the angular frequencies. The curve will be an ellipse if the frequencies are equal. Note that a circle and a line are each special cases of an ellipse.

Furthermore, the curve will be closed provided that the frequency ratio is rational.

Examples

Some examples are shown in the following figures where the phase angle is represented in degrees. The figures are grouped according to frequency ratio.

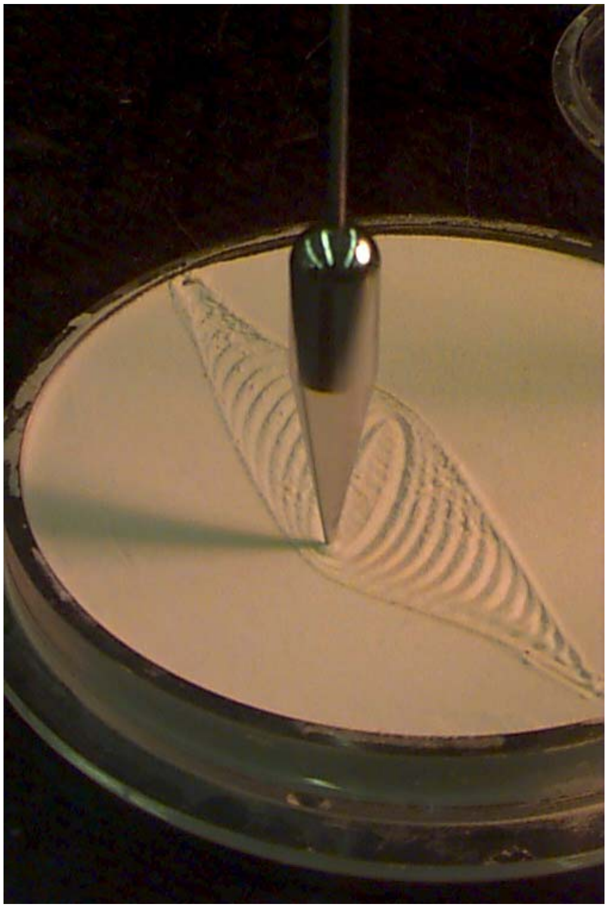


Figure 2. Sand Pendulum Tracing Lissajous Ellipses

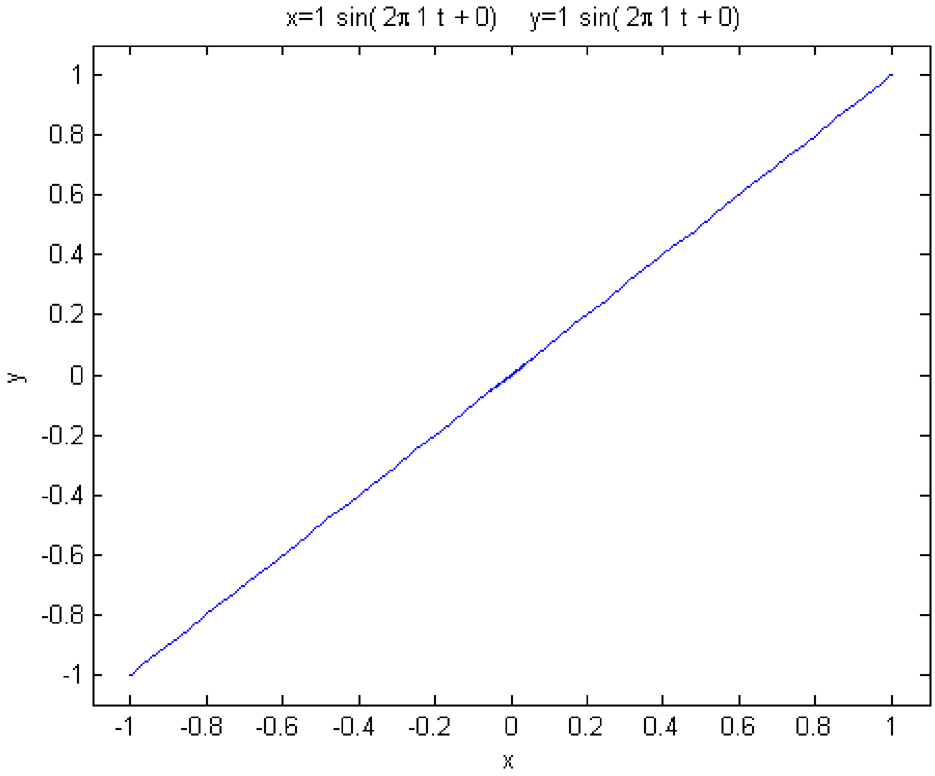


Figure 3.

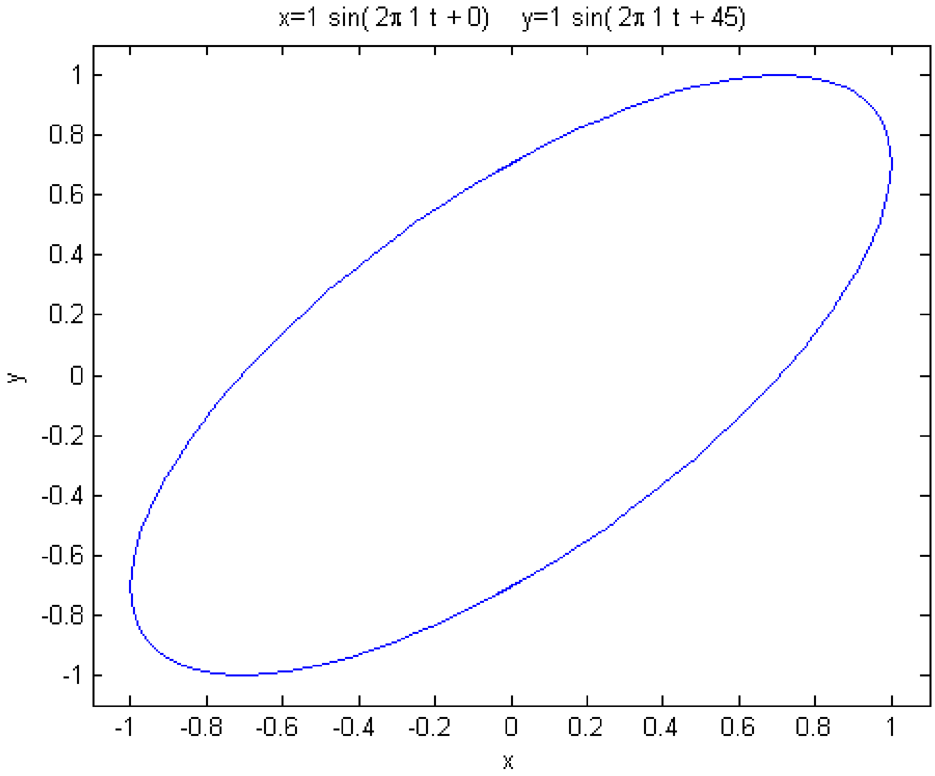


Figure 4.

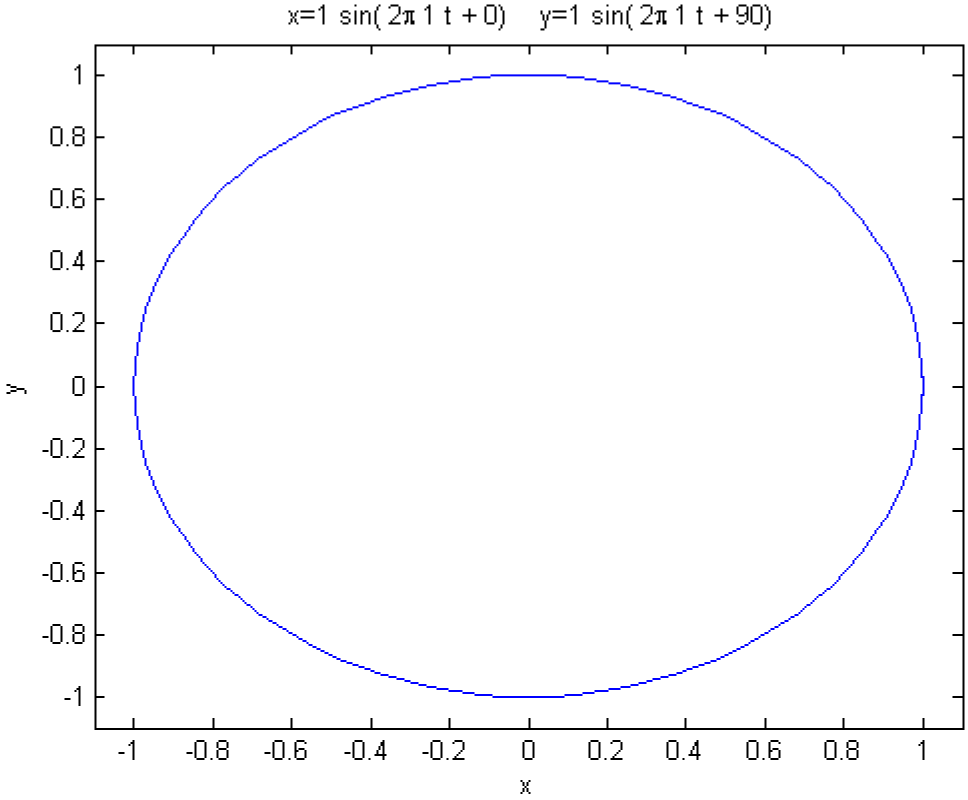


Figure 5.

The shape in Figure 5 would be a circle if each axis had the same divisions per inch scale.

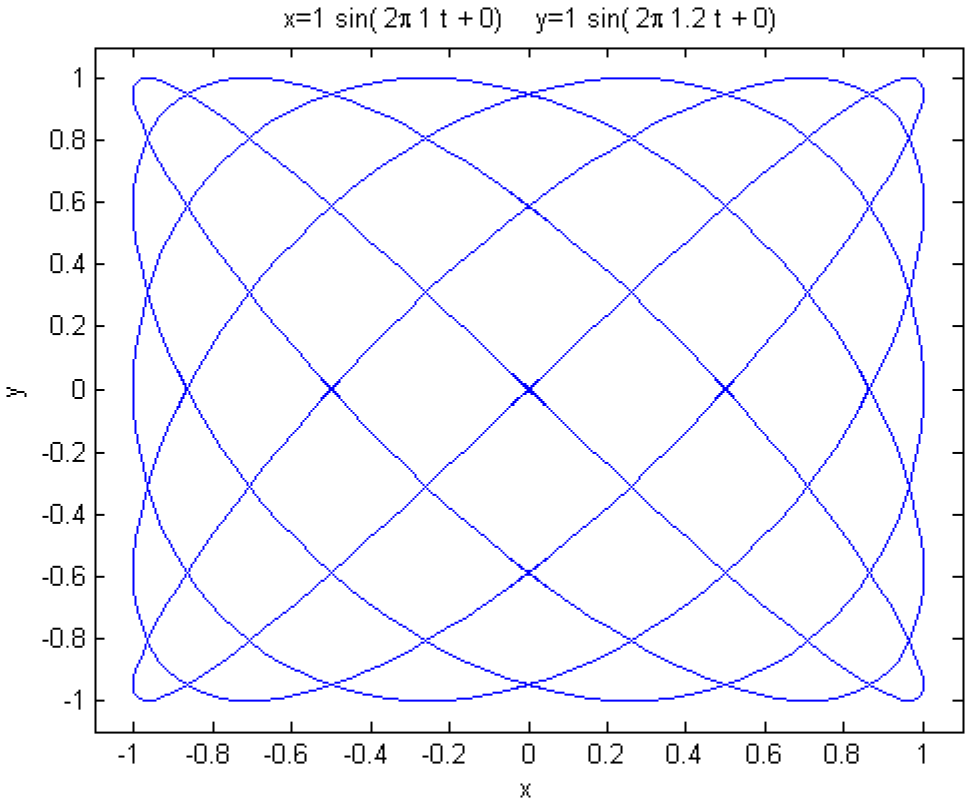

x=1 sin(2π 1 t + 0)   y=1 sin(2π 1.2 t + 0)
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
y
-1
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1
x

Figure 6.

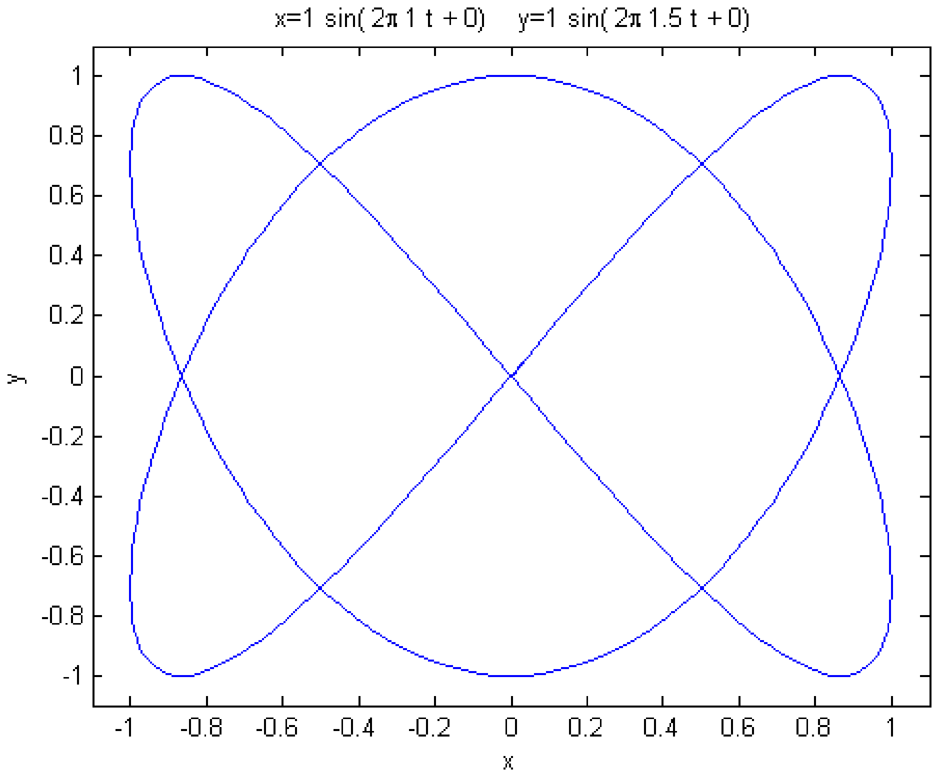


Figure 7.

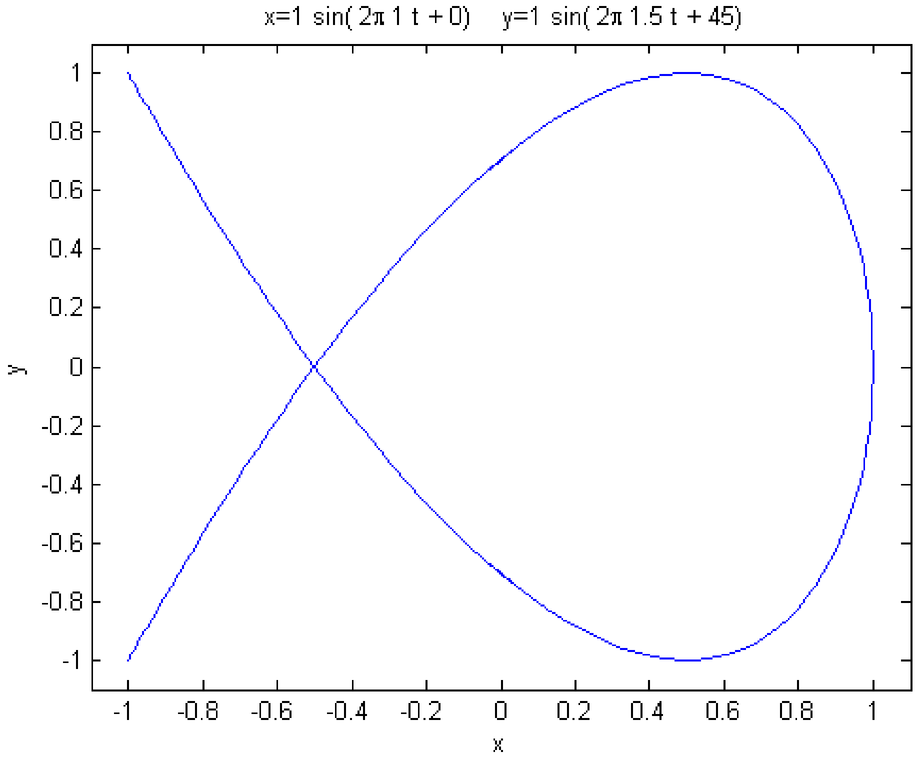


Figure 8.

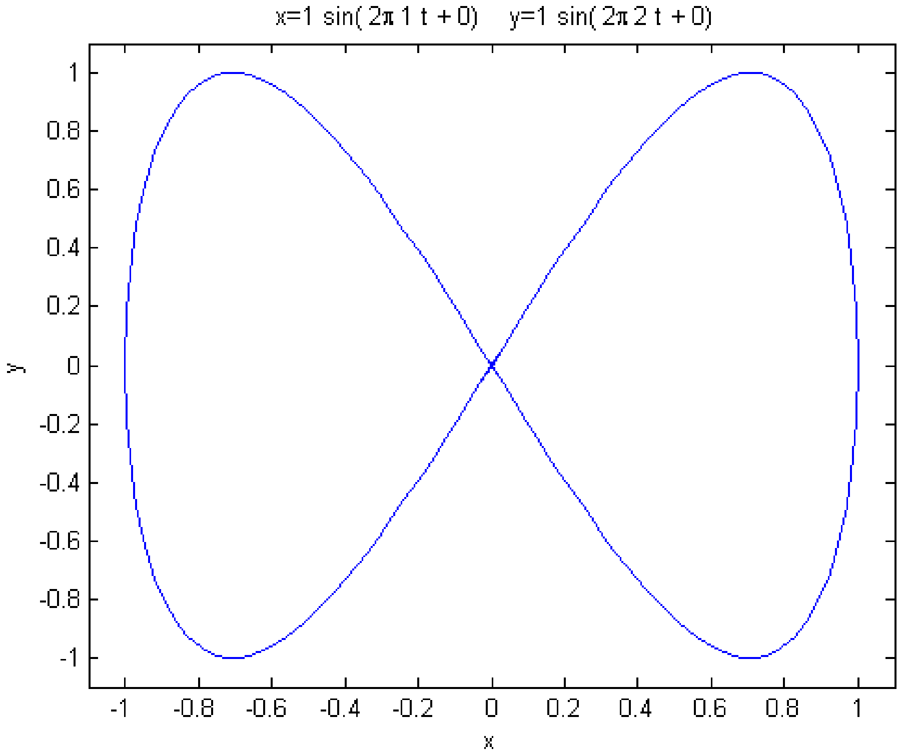


Figure 9.

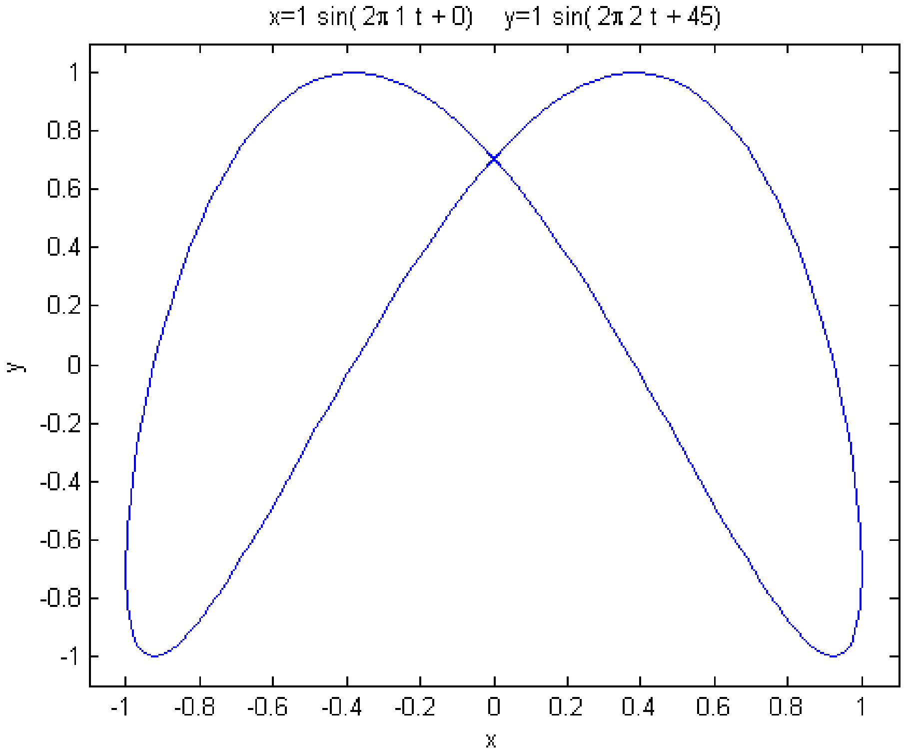


Figure 10.

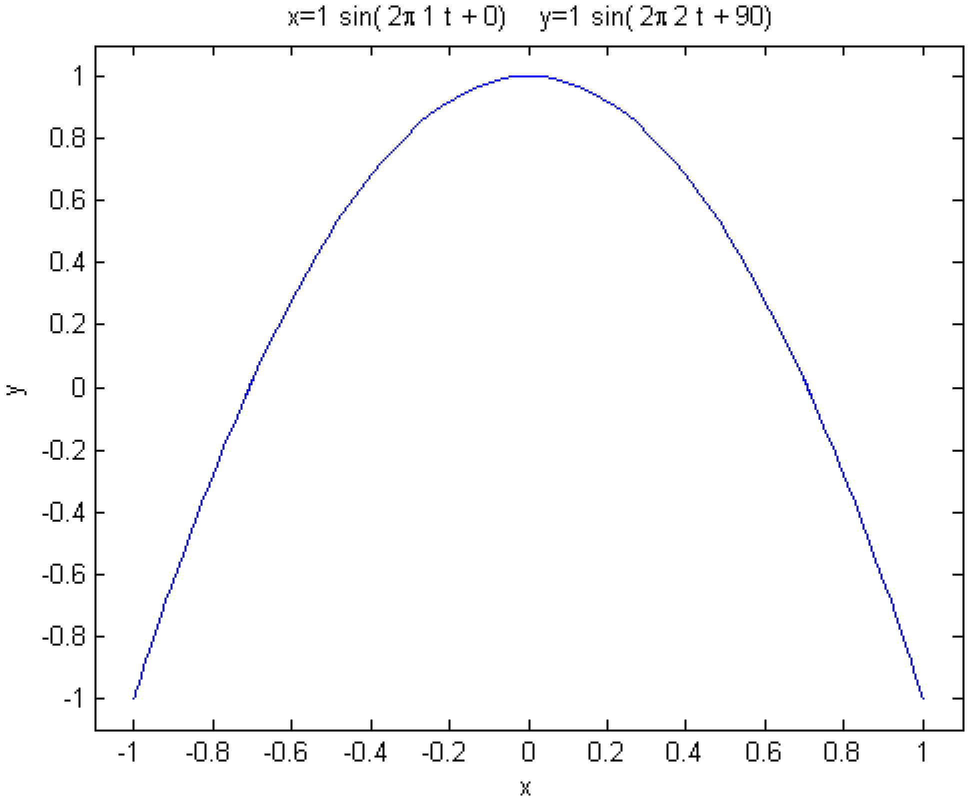


Figure 11.

The curve is a parabola.

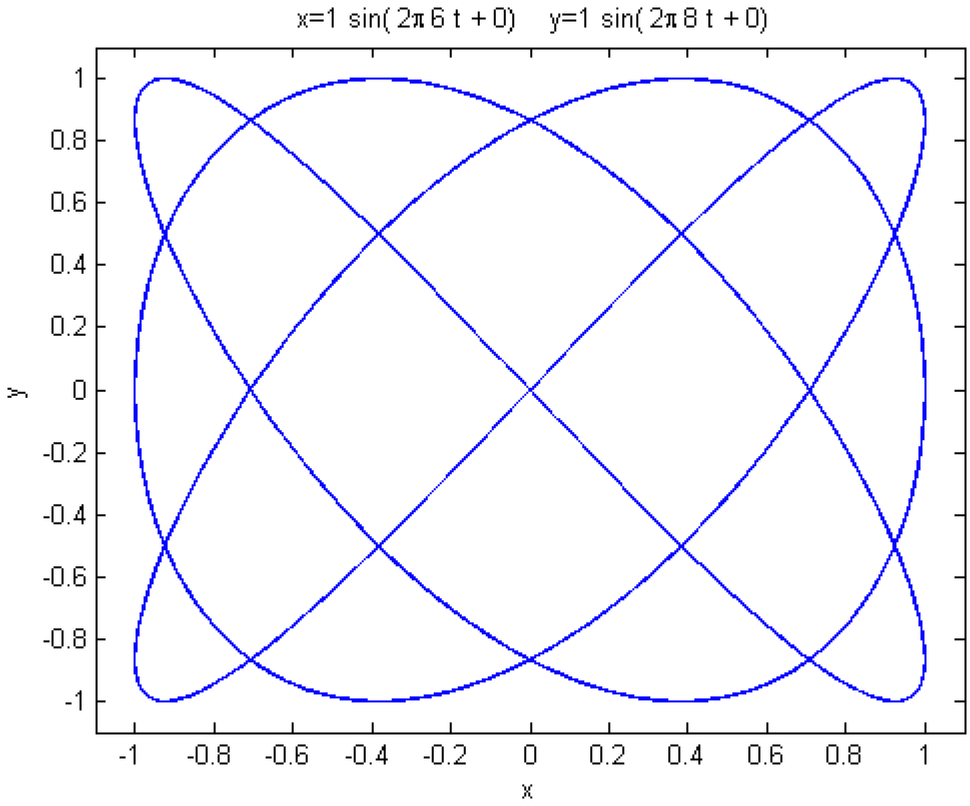


Figure 12.

This pattern is incorporated in the MIT Lincoln Labs logo, rotated 90 degrees.

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MASSACHUSETTS INSTITUTE OF TECHNOLOGY