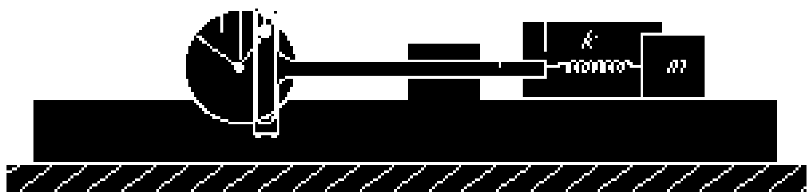
Building a Crankshaft Oscillator with Working Model

In this tutorial you will build the system below in Working Model. The tutorial assumes a basic familiarity with Working Model, which can be achieved by working through the Simple Tutorial.



Our goal will be to determine the rate (ω) at which the crankshaft must rotate so that resonance occurs. The crankshaft's radius R is 0.5 meters and the slider pin's position is a distance r = 0.2 meters from the crankshaft's center. The spring constant k is 50 N/m and the 0.6 meter square block's mass m is 1 kg. All other masses are negligible. We'll assume that there is no friction.

If you haven't already done so, start Working Model and create a New document (and close any others you might have opened). It is also strongly recommended you work through the Simple Tutorial first, and in particular read the section titled ***What is Working Model?***

Setting Up the Workspace

For this exercise three changes in the workspace are necessary. For clarity, the x-y axes will be displayed. The number of digits displayed after the decimal point will be changed to 1, from the default 3, to match the significant figures of the problem. Third, gravity will be turned off.

1. **Choose Workspace from the View menu and select X,Y Axis from the Workspace submenu.**

   The x-y axis will appear on the workspace.

2. **Choose Number and Units from the View menu.**

3. **Enter 1 into the Digits field.**

   The number of digits displayed to the right of the decimal will be set to 1.

4. **Choose Gravity from the World menu.**

5. **Click the None box.**

   Gravity will be turned off. This step eliminates both the need for the "floor" and the force calculations between the floor and the block.

6. **Click OK.**

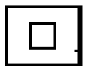
Creating the Components

This exercise has three mass objects, a 0.5 meter radius circle, a 2 meter long connecting rod and a 0.6 meter square block with a mass of 1 kg. The objects will be created, sized and initialized in the following steps. For clarity we will place the components along the x-axis. The block will be placed at the origin. All other positions will be referenced from the block.

Creating the Block

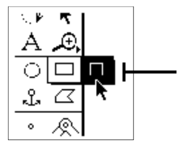
The block will be modeled by a square mass object. The square will be drawn with the Square tool. Its size, 0.6 meters, will be set with the Geometry utility window. It will be positioned at the origin using the Properties utility window.

To draw the block:



1. Choose the Square tool.

Figure 2-1
The Square pop-up menu



2. Drag out a square.

To size the block:

1. Select the square if it is not already selected.

2. Choose Geometry from the Window menu.

3. Click in the Height or Width field and enter 0.6. Press Return.

Either field will change both the height and the width of the object so that it remains square.

To set the block's mass:

1. Choose Properties form the Window menu.

2. Click in the Mass field and enter 1.0.

To position the block:

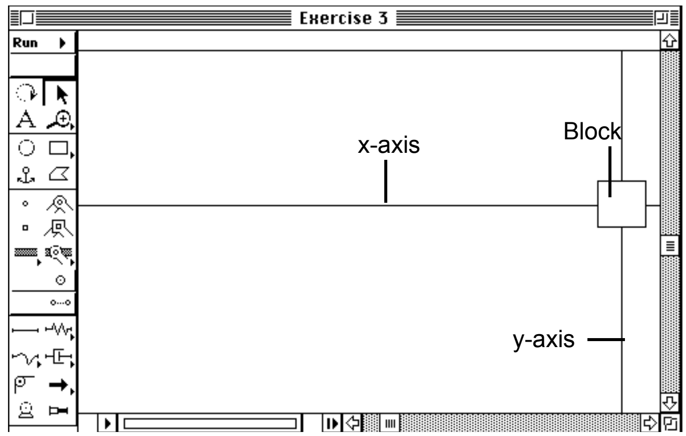
1. Select the square.

2. Choose Properties from the Window menu.

3. **Enter 0 for the X and Y fields.**

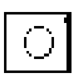
The square is now at the origin (see figure 2-2 below).

Figure 2-2
The block at the origin



Creating the Driver Crankshaft

The crankshaft will be modeled by a circle. The circle will be drawn with the Circle tool. Its radius, 0.5 meters, will be set using the Geometry utility window. Its position, 6.5 meters to left of the block, will be set with the Properties utility window. To draw the crankshaft:



1. **Click the Circle tool on the toolbar.**
2. **Drag out a circle.**

To size the crankshaft:

1. **Select the circle.**

2. **Choose Geometry from the Window menu.**

3. **Click in the Radius field and enter 0.5.**

It is important to keep everything aligned vertically. To position the crankshaft:

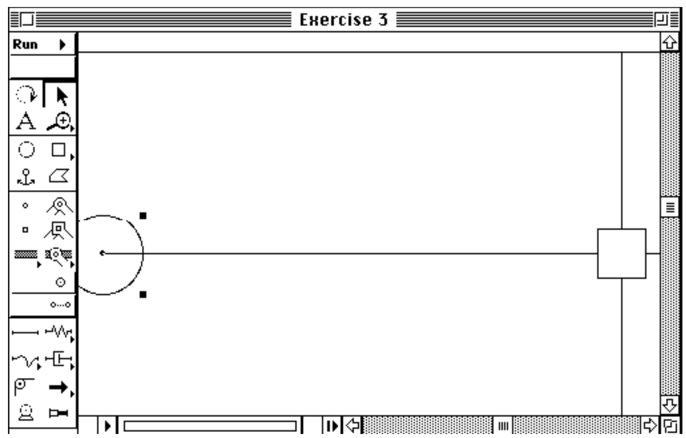
1. **Select the circle.**

2. **Choose Properties from the Window menu.**

3. **Enter -6.5 and 0 into the X and Y fields, respectively.**

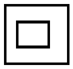
   Your screen should resemble figure 2-3 below.

Figure 2-3
The crankshaft in position



Creating the Connecting Rod

The connecting rod will be modeled as a rectangle. It will be drawn using the Rectangle tool. Though its height could be any value, it will be set at 0.35 meters to resemble the connecting rod in the problem. To set the rectangle size, the Geometry utility window will be used. Its position, 2.5 meters to the left of the block, will be set using the Properties utility window. To draw the connecting rod:



1. **Choose the Rectangle tool from the Rectangle pop-up menu.**

2. **Drag out a thin rectangle.**

To size the rectangle:

1. **Choose Geometry from the Window menu.**

2. **Enter 0.35 and 2 into the Height and Width fields, respectively.**

To position the rectangle:

1. **Select the rectangle.**

2. **Choose Properties from the Window menu.**

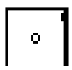
3. **Enter -4 and 0 in the X and Y fields, respectively.**

Creating the Elements for Joining

In this exercise, many points will be created. Most points will be created automatically when the tools for the spring, slot, and motor are used. Only the point and slot from the crankshaft-to-connecting rod joint will be created with element tools.

Creating a Point on the Crankshaft

The crankshaft is attached to the connecting rod. The connection will be made using a point on the crankshaft and joining it to a slot on the connecting rod. The point on the crankshaft is positioned 0.2 meters from the crankshaft's center. To draw the point on the crankshaft:



1. **Click the Point tool on the toolbar.**

2. **Click on the crankshaft.**

To position the point:

1. **Select the point if is not already selected.**

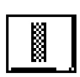
2. **Choose Properties from the Window menu.**

3. **Click in the X field and enter the value 0.2. Press the Return key.**

4. **Click in the Y field and enter the value 0.**

Creating a Slot on the Connecting Rod

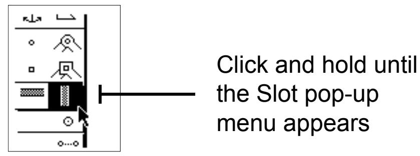
In the exercise the connecting rod has a slot on which the crankshaft slides. To model this, a slot will be placed on the connecting rod. To create the slot:



1. **Choose the Vertical Slot tool.**

   Choose the slot by placing the pointer over the Horizontal slot tool on the toolbar, clicking and holding until the Slot tool pop-up menu appears (see figure 2-4 below). Choose the Vertical Slot tool.

Figure 2-4
The Slot pop-up menu



2. Click on the connecting rod.

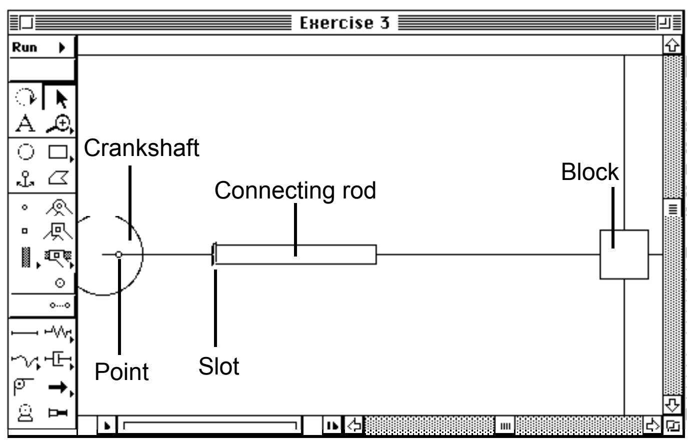
3. Choose Properties from the Window menu.

4. Click in the X field and enter -1.

This will locate the slot on the left end of the connecting rod rectangle.

Your screen should look like figure 2-5 below.

Figure 2-5
The connecting rod with the slot on it

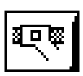


Creating the Constraints

Exercise 2 requires four constraints: a keyed slot, a variable speed motor, a 50 N/m spring, and a slot on the connecting rod. The following steps will describe how to create these constraints with Working Model.

Creating the Keyed Slot

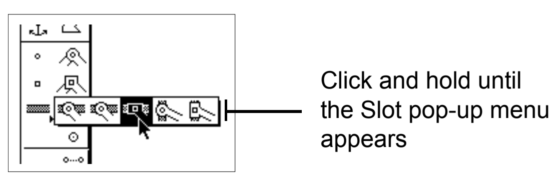
The connecting rod slides in a sleeve. The sleeve prevents the connecting rod from moving vertically or rotating. To model the sleeve, a keyed slot joint will be used. The Keyed Slot tool attaches a square point to the top mass object, and a slot to object beneath the point (in this case it is the background), and then automatically joins them. The position of the keyed slot is not critical. It can be placed anywhere on the connecting rod. To create and position the keyed slot:



1. Choose the Horizontal Keyed Slot tool from the Slot pop-up menu on the toolbar (see figure 2-6 below).

Place the mouse pointer over the slot tool. Click and hold the mouse button down until the pop-up menu appears. Choose the horizontal slot.

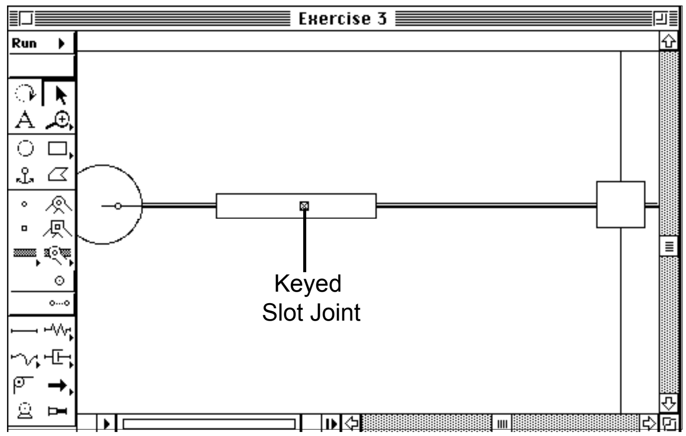
Figure 2-6
The Slot pop-up menu



2. **Click on the connecting rod.**

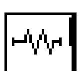
A slot will appear on the background. It will be joined to a point on the connecting rod (see figure 2-7 below).

Figure 2-7
A keyed slot joint attaches the connecting rod to the background



Creating a Spring

To draw the spring, the Spring tool will be used. The spring constant is preset at 50 N/m. To draw the spring:



1. **Click the Spring tool on the toolbar.**

2. **Click on the connecting rod rectangle and drag to the block.**

To accurately position the spring's endpoints:

1. **Select the endpoint of the spring that lies in the rectangle.**

The point will turn black when it is selected.

2. **Choose Properties from the Window menu.**

3. **Enter 1 and 0 into the X and Y fields, respectively.**

   This positions the endpoint of the spring at the right end of the connecting rod rectangle.

4. **Select the spring's other endpoint.**

   This may require the use of box select. To box select: click and hold the mouse button down on the background and then drag over the point. Be sure that the only the point is inside the box.

   The point will turn black indicating it is selected.

5. **Choose Properties from the Window menu.**

6. **Enter 0 and 0 into the X and Y fields.**

   The spring's endpoint will move to the center of the block.

   Your workspace should resemble figure 2-8 below.

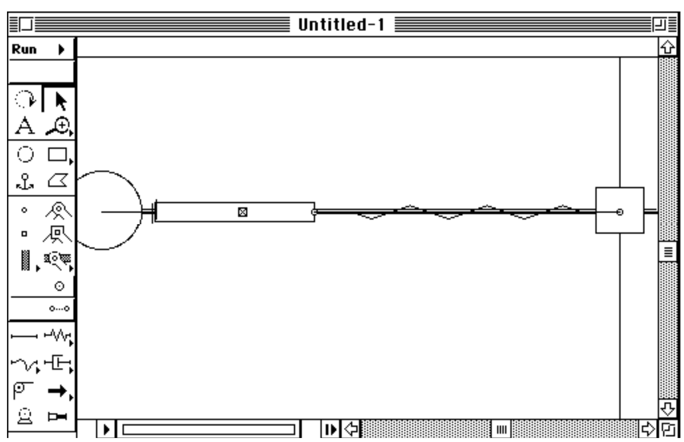
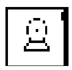


Figure 2-8
The spring attached is to the block and connecting rod

Creating the Drive Motor

The crankshaft is driven by a motor. Its position will be set using the Properties utility window.

To draw the Motor:



1. **Click the Motor tool on the toolbar.**

2. **Click at the center of the circle.**

   When a motor is created, two points are also created. One point is attached to the circle (the Point) and one is attached to the background (the Base Point).

Center the Motor on the Crankshaft

In this exercise it is important that the motor be positioned in the center of the circle. To position the motor in the center of the crankshaft:

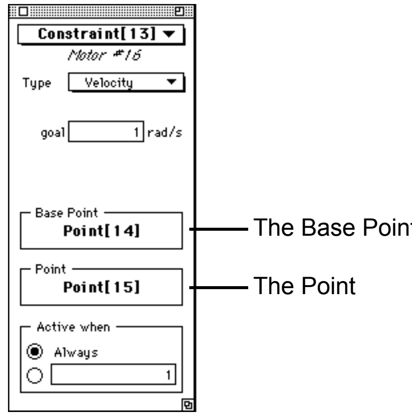
1. **Select the motor if it is not already selected. This may require the use of box select.**

   Be sure that the only the motor is inside the box.

   The center of the motor will turn black, indicating that it is currently selected.

2. **Choose Properties from the Window menu. Take note of the "Base Point's" object id number (i.e. Point[14]) and The "Point's" object id number (i.e. Point[15]). Refer to figure 2-9.**

Figure 2-9
The motor's properties window

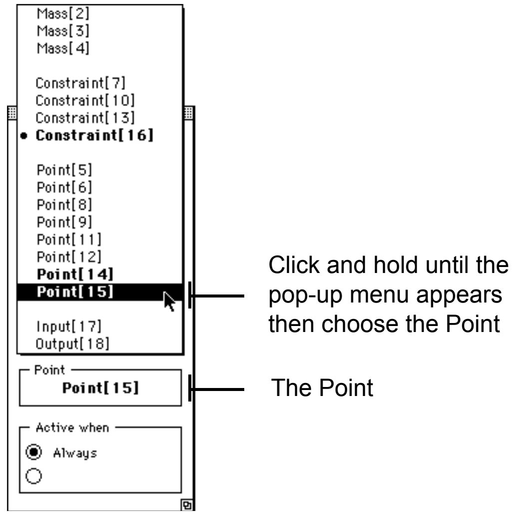


The "Base Point" is the point connecting the motor to the background. The "Point" is the connection between the motor and the crankshaft.

3. Choose the "Point" from the Properties pop-up menu (see figure 2-10 below).

In the pop-up menu, three objects will be in bold face text: the Constraint[] (motor), and two Point[]s (The Base Point and the Point). The bold face indicates that these object are related to one another. In this case they are components of the background-motor-crankshaft connection.

Figure 2-10
Choosing The Point from force's Properties pop-up menu



4. **Enter 0 into both the X and Y fields.**

   The circle, not the motor (the motor is connected to the background by the Base Point), will move so the point is located at the center of the circle.

   The Base Point is the other Point[] that was in bold faced when the pop-up menu was first activated (it will now be in normal text).

5. **Choose the Base Point from the Properties pop-up window.**

6. **Click in the X field and enter the value -6.5.**

7. **Click in the Y field and enter the value 0.0.**

   The motor and the circle will move to the location (-6.5, 0), which is the proper location for the center of the crankshaft.

Creating a Slider Input Device

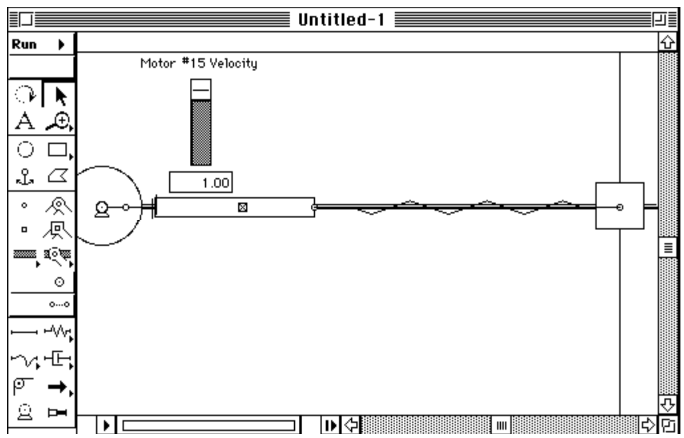
The goal of this experiment is to find the rotational speed of the motor when resonance occurs. Different speed values could be entered via the Properties utility window, but a much more efficient way is to create a Control input device called a slider. To create a slider:

1. **Select the crankshaft motor. Use the box select to select the motor.**

2. **Choose New Control from the Define menu, and Rotational Velocity from the New Control submenu.**

   A slider similar to the one in figure 2-11 below will appear on the screen.

Figure 2-11
A slider is created



Setting the Range of Slider

The default range of a slider (0 to 1.0) is seldom the proper one for a problem. To modify the slider range:

1. **Select the slider.**

2. **Choose Properties from the Window menu.**

3. **Enter 10 in the Max fields of the slider's Properties window.**

Joining the Connecting Rod to the Crankshaft

There are only two points in this exercise which need to be joined, the point on the crankshaft and the slot on the connecting rod. To create the joint between the connecting rod and the crankshaft:

1. **Select both, the point on the crankshaft, and the slot on the connecting rod. Use box select.**

2. **Click the Join button on the toolbar.**

Setting the Spring's Rest Length

When the connecting rod and crankshaft were joined, the connecting rod moved a substantial distance to the left. This movement stretched the spring, pre-loading it. To remove the pre-load, the spring's rest length will be reset to the larger current length. To reset the springs rest length:

1. **Select the spring.**

2. **Choose Properties from the Window menu.**

3. **Click on the "(current)" value. Press Return.**

   The value in the "length" field will automatically change to the current length. The spring's rest length will now be set to the current length.

Preventing a Collision

The connecting rod and block will collide when resonance is achieved. The collision will dampen the motion of the block. To make the results of the simulation more interesting we will prevent the connecting rod-block collision. To prevent a collision:

1. **Select the connecting rod and while holding the Shift key down select the block.**
2. **Choose Do Not Collide from the Object menu.**

   The model is now complete and can be run.

3. **Click the Run button on the toolbar.**

   You must always reset the simulation before attempting editing. If you do, not the initial conditions of the experiment will be effected.

4. **Click the Reset button.**

Measuring Properties from the Experiment

It is interesting to watch the graphical motion of the driver and the driven objects as they interact in this simulation. To do so, a graph displaying two properties must be created.

Creating the Graph

The following steps describe how to create a graph of the block's position vs. time. The graph will be moved to the bottom of the screen. It will be enlarged so it reaches across the screen. To display the graph:

1. **Select the block.**

2. **Choose Position from the Measure menu, and X Graph from the Position submenu.**

   This meter will graph the x position of the block (driven mass) with respect to time.

To position the graph:

1. **Select the graph.**

2. **Click on the graph and drag it to the lower left corner of the screen.**

To size the graph:

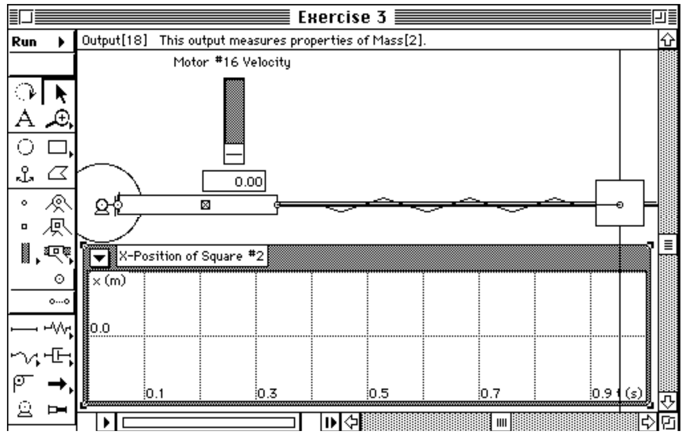
1. **Select the graph.**

   Four squares (called handles) will appear at the corners of the graph indicating the meter is selected.

2. **Click on the lower right handle and drag to the right side of the screen.**

   The graph will stretch to a larger size (see figure 2-12).

Figure 2-12
An x-y graph is added



Add a Parameter to the Graph

The second object of interest to graph is the connecting rod (driver). To add the parameter to the graph:

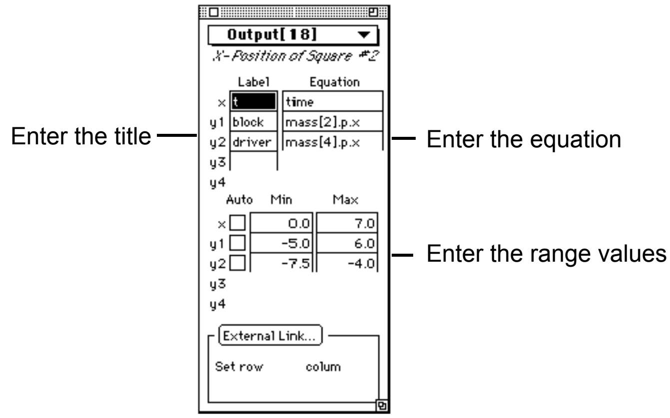
1. **Select the graph.**

2. **Choose Properties from the Window menu.**

3. **Click in y2's Label field and type "driver" (see figure 2-13 below).**

   This titles the new parameter. The text "driver" will appear in the y-axis of the graph.

Figure 2-13
Meter's Properties utility window



4. **Press the Tab key.**

   This enables the meter's y2 Equation field, allowing for editing of that field.

   Note: some text must be entered into the Label field or the Equation field will remain disabled.

5. **Click in the y2's Equation field and enter the following formula:**

   `mass[`***object id***`].p.x`

   *The **object id** number for the connecting rod can be determined by placing the cursor over the connecting rod and reading the ribbon help at the top of the workspace.*

   This will produce a graph of the values of the connecting rod's x-position.

Set the Range of a Graph

Changing the x and y range of a graph can improve the quality of the graphical output. To set the range:

1. **Select the graph.**

2. **Choose Properties from the Window menu.**

3. **Click on y1's Auto checkbox to turn off the graph's auto ranging.**

4. **Enter various values into the Max and Min fields of y1 and y2 variables (see figure 2-13 above). The following values work well:**

	Min	Max
y1	-5.0	6.0
y2	-7.5	-4.0.

Experiment with different values and notice the Changes in the graph. Be sure to turn off automatic range after you enter your variables or Working Model will modify the values upon running.

Finding the Resonance

Run the simulation and vary the speed of the motor until resonance is achieved.

The equation for the amplitude of driven harmonic motion is:

$$A = \frac{\Phi}{\sqrt{\mu^2(\omega^2 - \omega_o^2)}}$$

where: A is the block's displacement amplitude
F is the driving force
m is the blocks mass
ω is the frequency of the driving force
ω_o is the natural frequency of a spring-

mass combination $\sqrt{\frac{k}{m}}$ (7.1 for this experiment).

As the frequency of the driver (ω) approaches the natural frequency of the spring/mass combination (ω_0), the amplitude approaches infinity. This condition ($\omega = \omega_0$) is known as resonance. For this exercise resonance will be achieved when the crankshaft's rotational velocity reaches t$\omega_0 = \sqrt{\frac{k}{m}}$, 7.1 rad/s. Click in the slider's field and enter the value 7.1. Now run the experiment.

The Next Step

Congratulations, you have completed the Complex Tutorial! If you have enjoyed using Working Model and are now ready to build some 'real' systems, please call us to order the full version. See the file called Order Form for all the details. Thank you for your attention.