# Getting Started Using Universal Mechanism

This manual leads you through the basic possibilities of Universal Mechanism software and shows you how to create and simulate models of several simple mechanical systems. It assumes that you go through the manual step by step sequentially.

Simulation of such mechanical systems as cars and railway vehicles has certainly its own features but basic concepts using UM still the same. These concepts are shown in this manual.

## Contact information

Universal Mechanism demo version you can download using the following link: http://www.umlab.ru/um40demo.exe.

The latest UM version as well as up to date UM user's manual available at http://www.umlab.ru/download.htm.

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# 1. Model of a pendulum

## 1.1. What we will learn

This lesson shows you how to create new model, add rigid bodies and joints, generate and compile equations of motion, simulate dynamics of a model and obtain plots of various performances of the model. This lesson is devoted to general overview of the UM possibilities and workflow.

At the end of the lesson we will have the model of the pendulum (you can find the final model in the **{um_root}\tutorial\eng\pendulum** directory)[1], which will include one rigid body – pendulum itself, one rotational joint and graphical object of the environment – support. After describing the model we will go through the all stages of the working with the model: synthesis and compiling of equations of motion, and then will come to the simulation of motion of the pendulum.

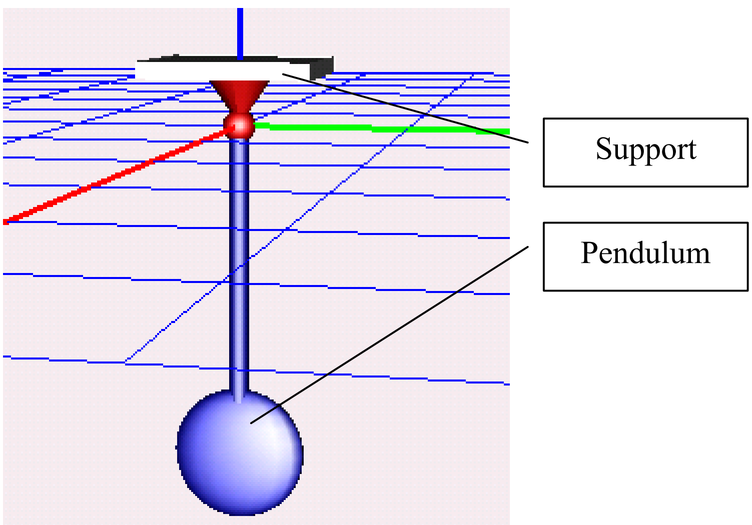
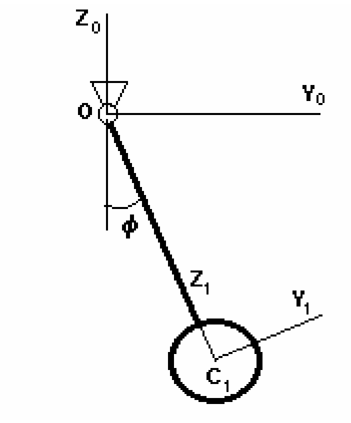



**Figure 1. Complete model**

[1] Pendulum model is also available at http://www.umlab.ru/download/40/eng/pendulum.zip

## 1.2. Model scheme




Before modeling the pendulum with the help of UM we recommend to draw its sketch like you can see at the left.

As you can see, we drew a simple pendulum and chose two systems of coordinates (SC) - the base frame $OX_0Y_0Z_0$ (SC0) and the body-fixed frame (SC1). The SC0 origin is placed in the center of the joint, the second one (SC1) - at the mass center of the pendulum. The axes of SC1 are directed along the pendulum principle axes of inertia. The base frame exists in every object and, as a rule, is connected with the Earth. There is only rotational joint connecting the pendulum and the base frame (the wall which the pendulum is attached to).

## 1.3. Creating the model

### 1.3.1. Running UM Input and creating new model

#### Running UM Input program

1. Click **Start/Programs/Universal Mechanism 4.0/UM Input**.

#### Creating a new model

1. From the **File** menu point to **New object MBS**[1].

The window of the constructor appears, see fig. 2.

### 1.3.2. Familiarizing yourself with Universal Mechanism

Take a few minutes to familiarizing yourself with the Universal Mechanism constructor window, see Figure 2.

**Tree of elements** of a model in the left top corner of the constructor window is used for getting access to elements of the model.

**Animation window** in the center shows the model or its elements. A frame is shown in the center of animation window. There is the following identification for axes: Red – X, Green – Y, Blue – Z (RGB). Point of view, zoom and other settings can be changed via toolbar buttons. Using the context menu you can set perspective parameters, supporting grid, etc.

**Inspector** at the right-hand side of the constructor is the main tool for the description of elements. It shows parameters of an active element. It contains full information about current element of the model.

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[1] MBS means "multibody system"

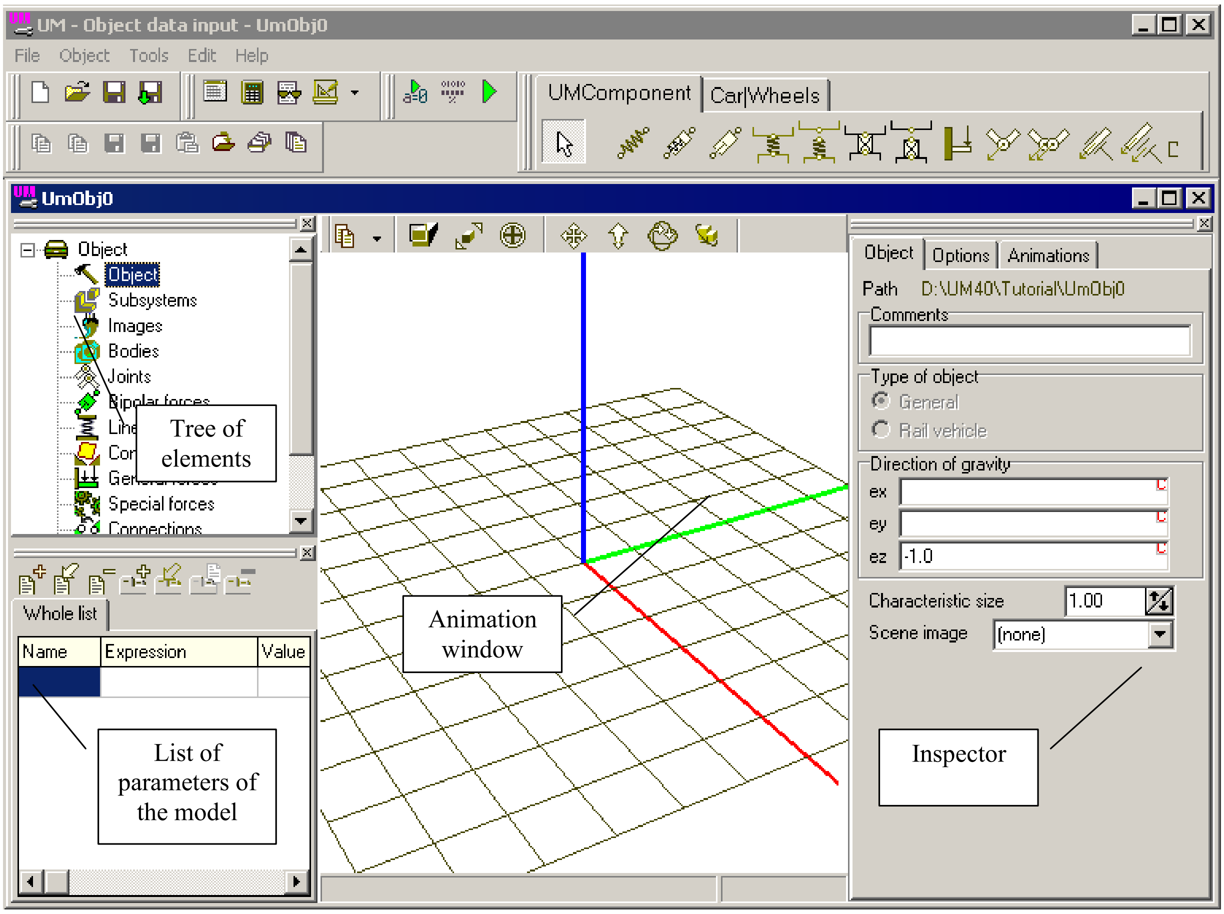



**Figure 2. Constructor window**

## 1.3.3. Creating graphical objects

We recommend to start describing any mechanical system with creating a set of graphical objects (GO) of the elements of the model.

### 1.3.3.1. Scene image

#### Creating new graphical object - scene

Scene is a graphical object corresponding to fixed elements of the object. Describing the scene is optional. To create a scene you should make a usual graphical object and assign it to the scene image. As for our example it is an image of the fixed joint where the pendulum is attached to – support. In order to create the corresponding image you should do the following steps.

1. Point to **Images** element of **Tree of elements**.
2. Click  button in the top of the **Inspector** to create new graphical object, see Figure 3.

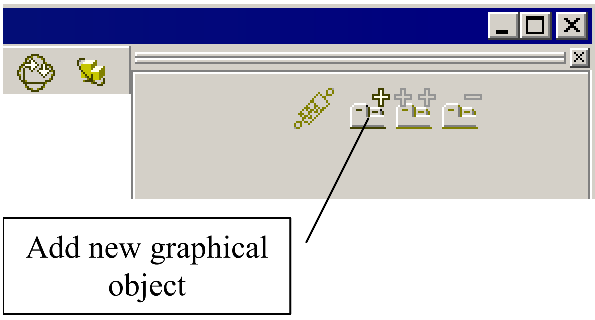



**Figure 3. Adding a new element**

**Note:** You can add new element of any type in the same way.

### Renaming the graphical object

As you create objects, UM automatically assigns names to them. Each name consists of a string containing the element type and a unique integer ID for that type. UM named the recently created graphical element **GO1**.

1. Point to the field with the name of the element and replace **GO1** with **Support**, see Figure 4.

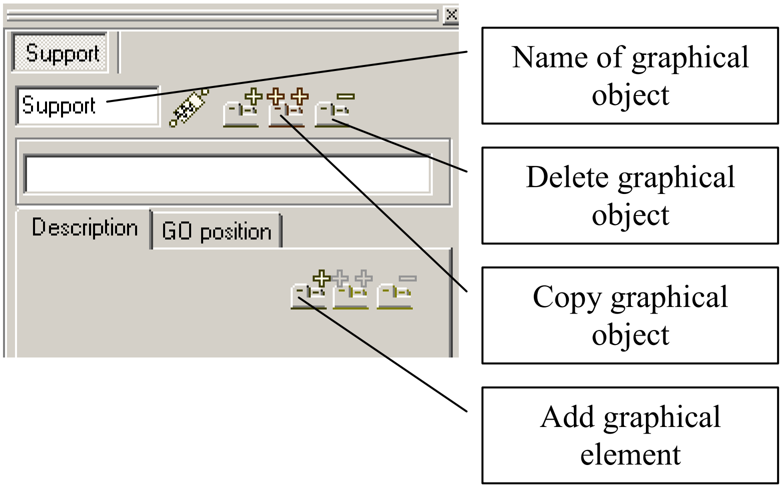



**Figure 4. Renaming the graphical object**

## Creating graphical elements

Every *graphical object (GO)* can include any number of various graphical elements *(GE)*. So you are able to create quite complicated images. Let's create three elements - sphere, cone and box, which form the image of the **support** altogether.

### Creating new graphical element: sphere

1. Click **Add new graphical element** button, see Figure 4.

New tab **GE1** appears, see Figure 5.

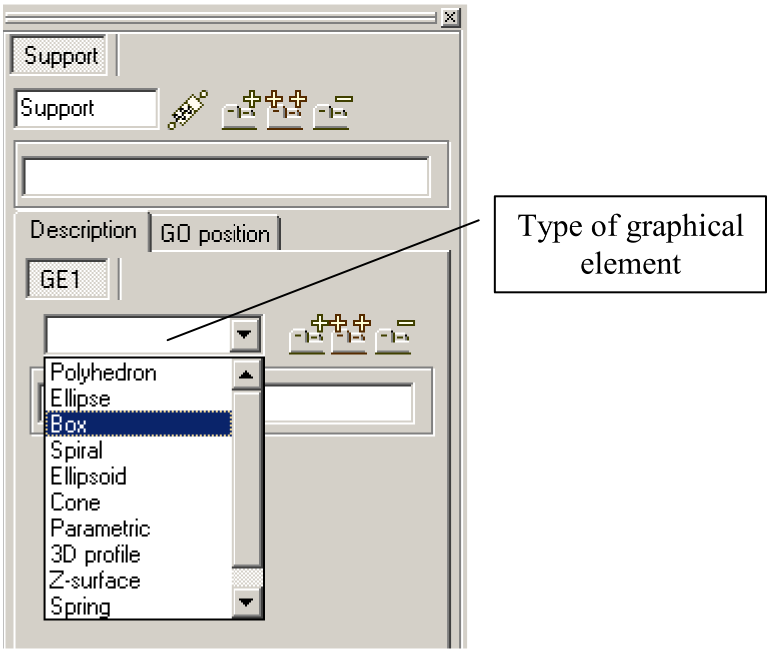



**Figure 5. Type of the graphical element**

2. Choose type for the new *graphical element* – **Ellipsoid**.
3. Point to the **Parameters** tab and set **a = b = c = 0.05**.
4. Point to the **Color** tab and set diffuse color to red.

### Creating new graphical element: cone

1. Create new *graphical element* and set its type to **Cone.**

**Note:** Do not add new *graphical object* instead new *graphical element* within graphical object. In this example we create the only *graph object* – **Support**, which contains three *graphical elements*: *sphere*, *cone* and *box*.

2. Point to **Parameters** tab and set **R2 = 0.1; R1 = 0; h = 0.15**.
3. Set diffuse color to red.

## Creating new graphical element: box

1. Create new graphical element and set its type to **Box**.
2. Point to **Parameters** tab and set **A = 0.5; B = 0.5; C = 0.05**.
3. Point to **GE Position** tab. Set **Translation/Z** to **0.15**, see Figure 6.

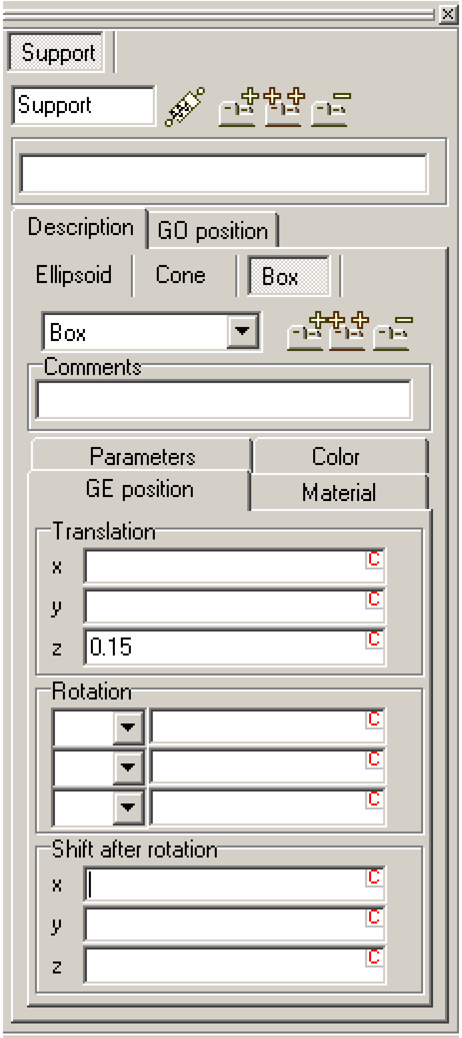
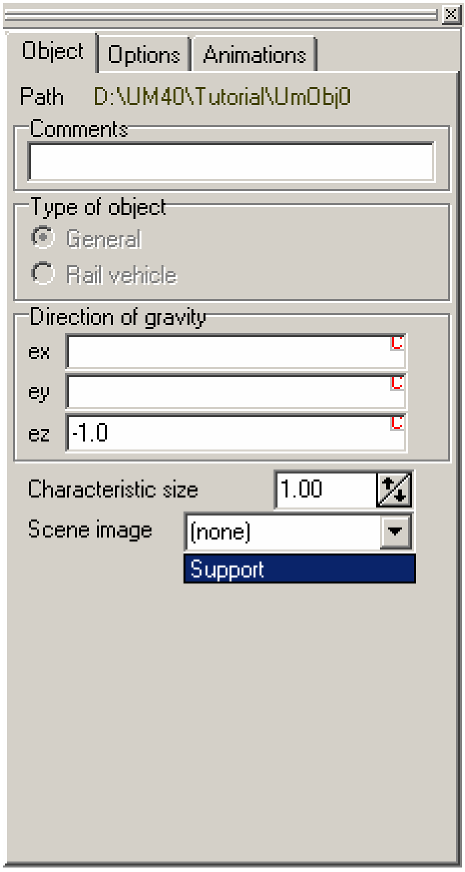



**Figure 6. Graphical element position**

### Assigning Support as scene image

1. Point to **Object** item of **Tree of elements**.
2. Select **Support** in the field **Scene image**.



#### 1.3.3.2. Image of pendulum

1. Return to the **Images** item in the **Inspector**.
2. Create new graphical object.
3. Rename new graphical object to **Pendulum**.

**Note:** Do not forget to press **Enter** after any modification of the text data in order to reflect this.

The pendulum image consists of two *graphical elements*: an ellipsoid and a cone.

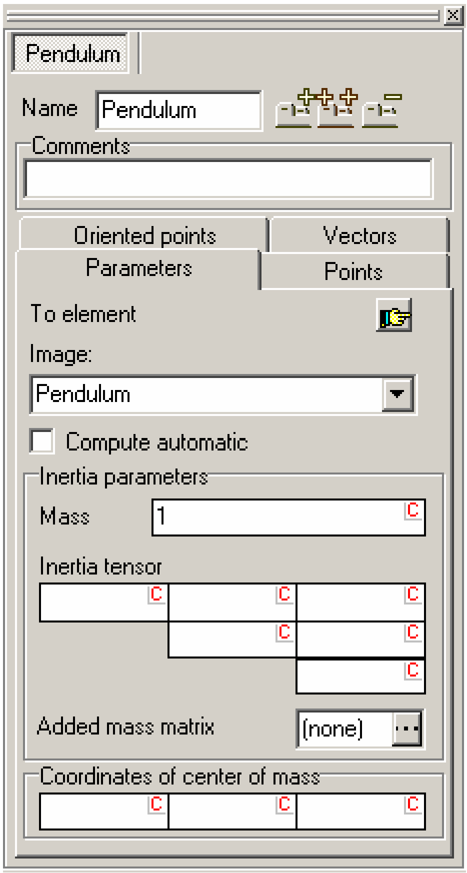
4. Add new graphical element **Ellipsoid** and set its parameters **a = 0.05; b = 0.2**; **c = 0.2.** Set diffuse color to blue**.**
5. Add new graphical element **Cone** and set its parameters **R2 = 0.03; R1 = 0.03; h = 1**. Set diffuse color to blue.

Now image of the pendulum is ready.

### 1.3.4. Creating rigid bodies

The pendulum as a mechanical system consists of the only body.

1. Point to the **Bodies** item in the **Inspector**.
2. Create new body.
3. Rename body to **Pendulum**.
4. Select **Pendulum** from the drop-down list **Image**.
5. Set **Mass** = **1** (kg).



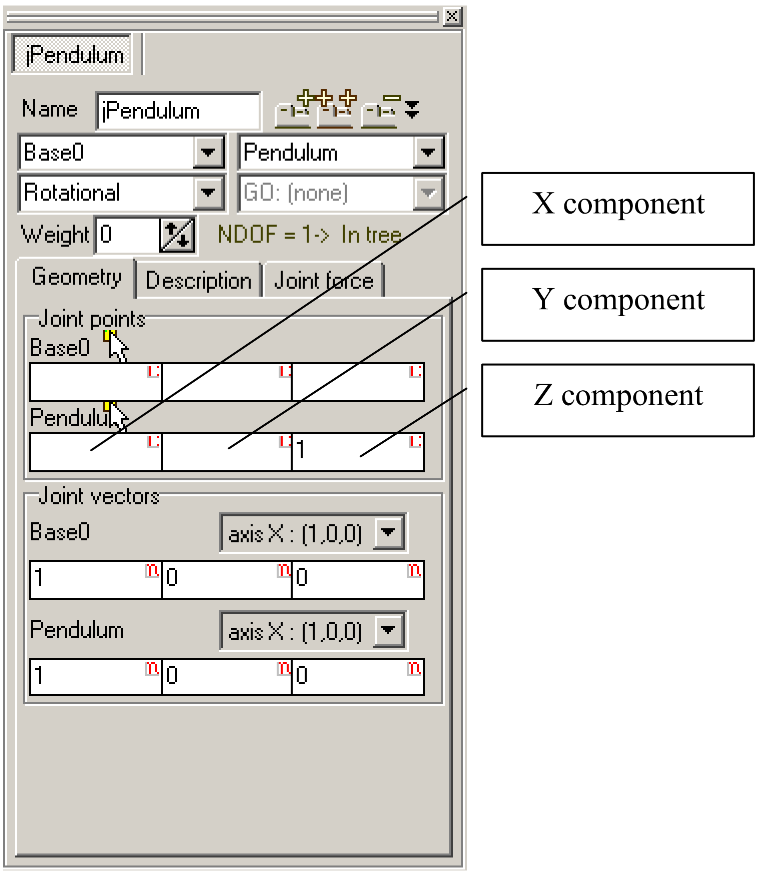
### 1.3.5. Creating joints

The rotational joint connects the Pendulum and the Base0. To create new joint do the following actions:

1. Point to **Bodies/Pendulum**.
2. Click the button **Adjust joint** and select **Rotational** joint in the context menu.

After that the rotational joint is created and named as jPendulum automatically. **Joint points** and **joint vectors** describe the position of the rotation axis relative to each of the bodies. Their coordinates must be given in the corresponding body-fixed systems of coordinates.

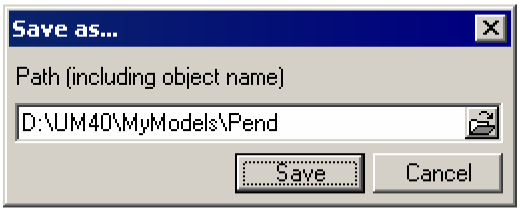
3. In the fields **Joint points/Pendulum** set **Z** position to **1**. So the pendulum will swing around its upper point.



### 1.3.6. Saving the model

Now your model is described completely. And it is high time to save it. Let the object name be **Pendulum**.

1. Select menu item **File/Save as…**
2. Set **Path** to ***{UM Path}*\Pend**, in the way how it is shown in the figure below.



### 1.3.7. Preparation for simulation

Program package Universal Mechanism (UM) consists of two programs: **UM Input** program - UMInput.exe and **UM Simulation** program - UMSimul.exe. The UM Input is used for creating objects, generating their equations and compiling them with the help of an external compiler. As a result you have got a dynamic-linked library UmTask.dll containing equations of motion of your object. The DLL is always located in the object directory. When DLL of the object exists a model is ready for simulation.

Now we should generate and compile equations of motion and start **UM Simulation** for dynamical analysis of the system.

#### Paths to external compilers

Universal Mechanism supports using Borland Delphi, Borland C++ Builder, Microsoft Visual C++ as external compilers.

1. Select **Tools/Options** menu item.

Your further actions depend on what external compiler you are going to use:

#### Delphi

2. Select **Paths/Delphi** tab.
3. Click **Search Delphi** button.

#### Borland C++ Builder, Microsoft Visual C++

2. Select **Paths/C++** tab.
3. Click one of the following buttons **Search Visual C** or **Search Borland C++ Builder** depending on which C compiler is installed on your PC.

If UM successfully detects external compiler all paths are set automatically.

### Generating and compiling equations of motion

1. Select **Object/Generate equations**.

If your description of the model is correct the corresponding dialog box appears. If your model description is not correct then tab **Summary**, which contains all detected errors, appears.

2. Select **Compile equations**.
3. Click **Generate** button.

If generating and compiling equations of motions end successfully you'll see the message box: «**Compiling successful. Object is ready for simulation.**». The model is ready to be loaded in the UM Simulation program.

### Run UM Simulation program

1. Select **Object/Simulation** menu item.

UM Simulation program starts and opens the current model.

## 1.4. Simulation of the motion

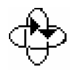
Now we are in the simulation program. We will open new animation window, deflect the pendulum from vertical position to 1 radian and run simulation of dynamics of pendulum.

### Creating new animation window

1. From the **Tools** menu, select **Animation window**. New animation window appears. Familiarize yourself a bit with animation window.

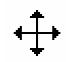
### Rotating

Point the mouse cursor to the animation window so that cursor looks like the picture in the figure to the right. Press left mouse button and rotate the model in the animation window.



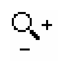
### Shifting

Point the mouse cursor to the animation window so that it has *Rotating* shape, press **Ctrl** key and mouse cursor changes to *Shifting* mode. Press left mouse button and shift model in the animation window.

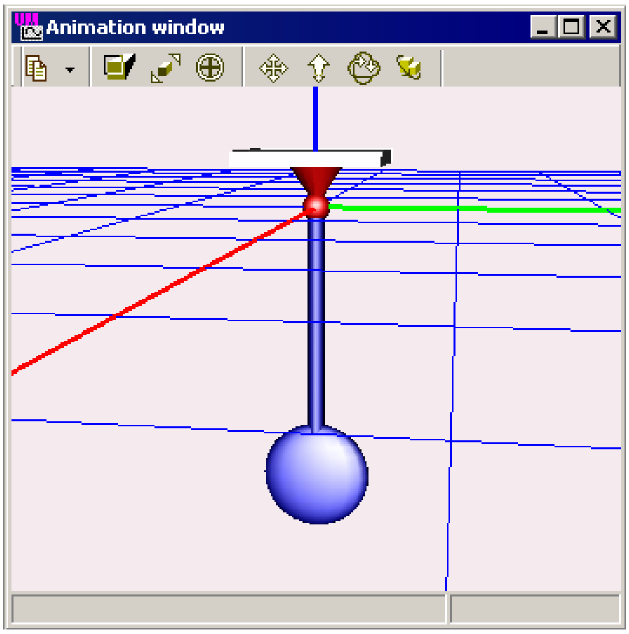


### Zoom in/zoom out

Point the mouse cursor to the animation window and press **Shift** key and with the help of left mouse button zoom in/out the model.



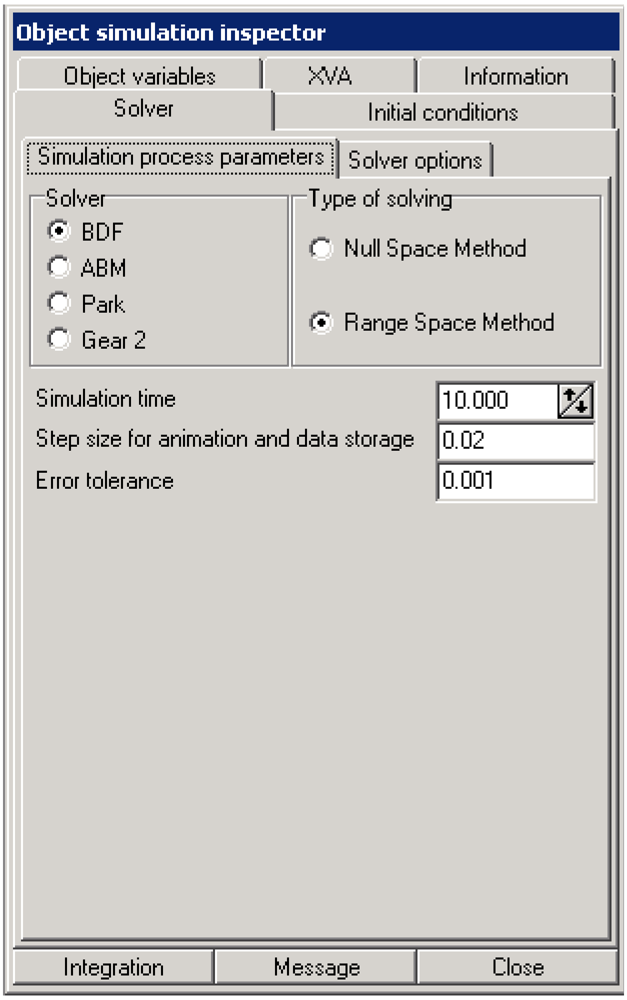
After some practice you can get something like shown in the figure below.



## Start simulation

1. From the **Analysis** menu, select **Simulation**.

Window of the **Object simulation inspector** appears.



### Initial conditions

You should deflect the pendulum a bit in order to obtain its motion. There exists a special tool for this purpose: a wizard of the initial conditions.

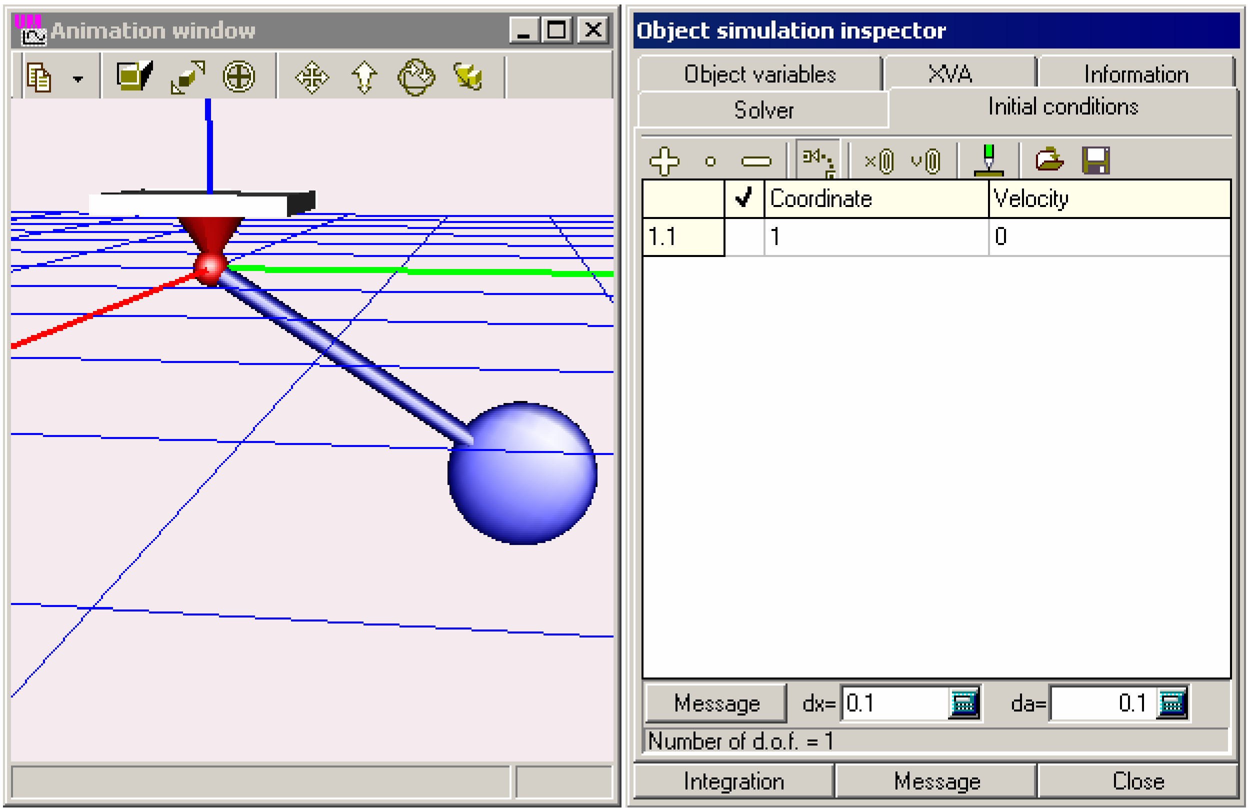
1. Select the **Initial conditions** tab.

You can see a complete list of the object coordinates. In our case there is only one coordinate in **jPendulum** joint.

2. Set **Coordinate** to **1**. Press **Enter** key.

Your pendulum has deflected.

**Note:** Universal Mechanism uses *System International (SI)*. Angular values have dimensions of *radian*.



## Simulation

Now your model is ready for simulation. Simply start simulation process for the 10 seconds.

1. Click **Integration** button in the **Object simulation inspector**.

At the end of the simulation the **Pause** window appears. You can increase the simulation time, change the numerical method etc.

2. Press the **Interrupt** button. **Object simulation inspector** appears.

## Drawing plots

During the simulation you can see plots of various variables. Such as velocities, accelerations, forces and so on. We will open new graphical window, create new variable to plot – Y coordinate of the center of mass of the pendulum and draw its plot.

Well, let us create new graphical window.

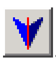
1. From the **Tools** menu, select **Graphical window**.

Open **Wizard of variables**.

2. From the **Tools** menu, select **Wizard of variables**.

The **Wizard of variables** is a special tool for creating variables, which can be drawn in graphical windows or animated in animation windows (in cases of vectors or trajectories).

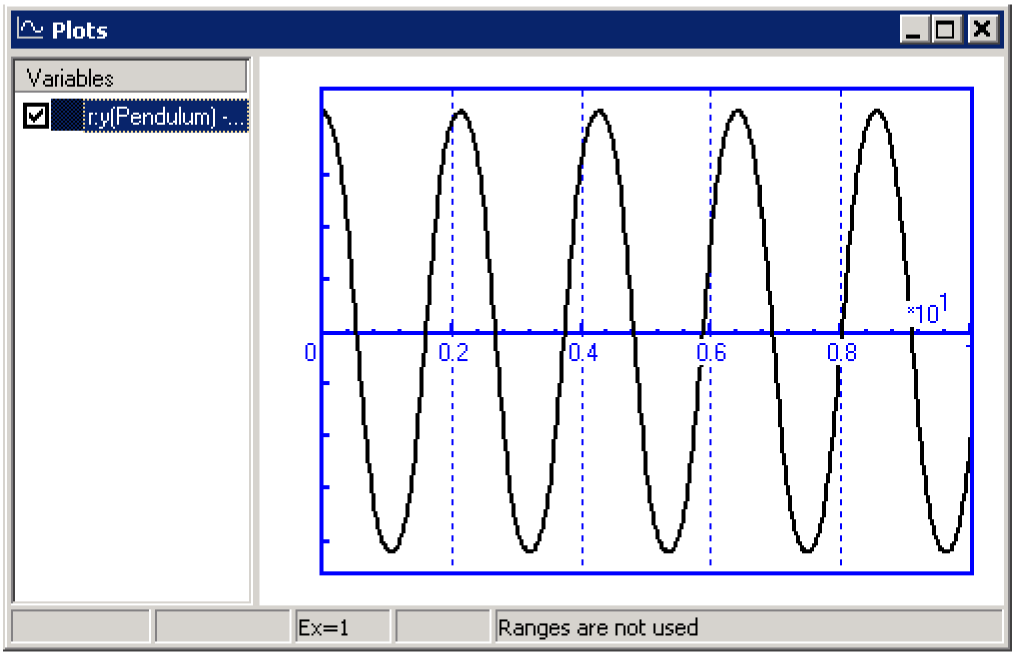
Let us draw a plot of Y coordinate of the mass center of the pendulum.

3. Select **Linear var.** tab (linear variables: coordinates, velocities, accelerations etc.).
4. Select **Y** in the **Component** group.
5. Then move the variable to the container with the help of the button .

New variable **r:y(Pendulum)** appears in the container of variables.

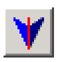
6. Select the variable in the **Wizard of variables** and drag it to the graphical window.
7. Select the **Object simulation inspector** and click the **Integration** button.

You can see the plot of your variable in the graphical window.




### Animation of vectors and trajectories

During the simulation you can animate various vector variables in an animation window. Let us animate the vector of the mass center velocity. Firstly, we need to create such variable in the **Wizard of variables**.

1. Select the **Wizard of variables** and there select the **Linear var.** tab.
2. Select **v** (velocity) in the **Type** group.
3. Select **V** (vector) in the **Component** group.
4. Add this variable to the container clicking the  button.
5. Drag new variable to the animation window.

A list of animated vectors is hidden by default. You can make it visible and change its position with the help of the **Position of list of vectors** command of the pop up menu of the animation window.

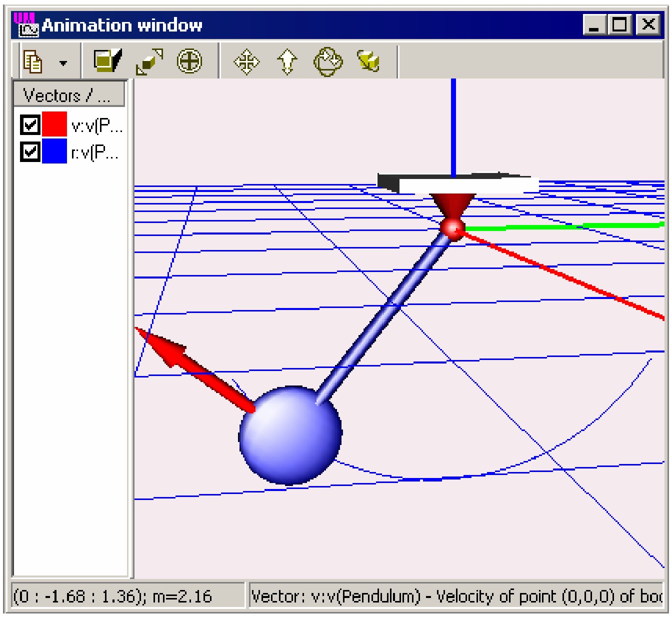
6. Select animation window, click right mouse button and select **Position of the list of vectors/Left**.

To draw a trajectory of the pendulum create a new variable with the help of the master.

7. Repeat all steps we made for the velocity, but the **Type** of the variable set to **r** (radius-vector). Drag this variable to the animation window.
8. Double click on the velocity item in the **List of vectors** and select red color for the vector of velocity and than double click trajectory item and select blue color for it.
9. Click the **Integration** button in the **Object simulation inspector**.

Now you can see the vector of the velocity and trajectory of the center of the mass of the pendulum. You should use the **Scale of vectors** command of a pop up menu to specify its scale.

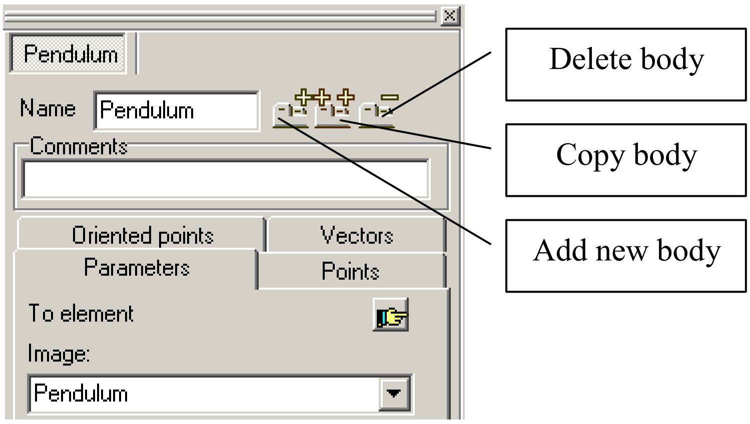
Double click on an element of the list of vectors or on a vector/trajectory image to change the color of the vector and trajectory (in addition for the trajectory - to change the number of points on the curve).



## 1.5. Multibody pendulum

It is very easy to convert the object to a multibody system, which contains several bodies – a chain of pendulums.

1. Close the UM Simulation program and come back to the UM Input program.
2. Select **Bodies** and copy the pendulum two times.




3. Rename new bodies to **Pendulum2** and **Pendulum3**.
4. Select **Joints** and copy the joint two times too.
5. Change the connecting bodies: **Pendulum** and **Pendulum2** for the second joint, **Pendulum2** and **Pendulum3** for the third one.

**Note:** Use the  button in the top of the animation window to switch the mode of window Full object / Single element.

6. Generate and compile equations of motion.
7. Run UM Simulation.
8. Create a new animation window.
9. Select the **Analysis/Simulation** menu item.
10. Set a proper initial position of the chain with the help of the **Initial conditions** tab.
11. Click **Integration** to run the simulation.

# 2. Free and forced oscillations

## 2.1. What we will learn

In this lesson we will learn how to add forces, preset movement of a body as a time function and use parameterization of a model. We will use **Linear analysis** for obtaining the equilibrium position of a system, natural frequencies and forms. As well as we will analyze the spectrum of output data using the **Statistics** tool.

## 2.2. Model scheme

The example of simulation of free and forced damped oscillations is considered. In this lesson we will create the model shown in the Fig. 2.1. Model consists of two rigid bodies **Top** and **Brick**, two translational joints, a linear spring and a damper. We will set vertical coordinate of the upper body as a sinusoid function.

You can find the final model in the **{um_root}\tutorial\oscillator** directory or download it using the following link:
http://www.umlab.ru/download/40/oscillator.zip

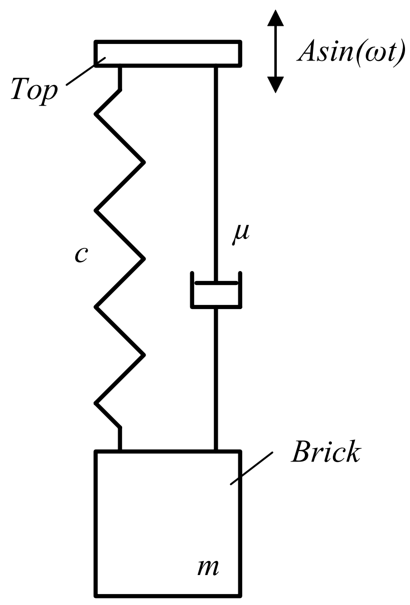



Figure 2.1. Model scheme

## 2.3. Creating the model

### 2.3.1. Running UM Input and creating new model

#### Running UM Input program

1. Click **Start/Programs/Universal Mechanism 4.0/UM Input**.

#### Creating a new model

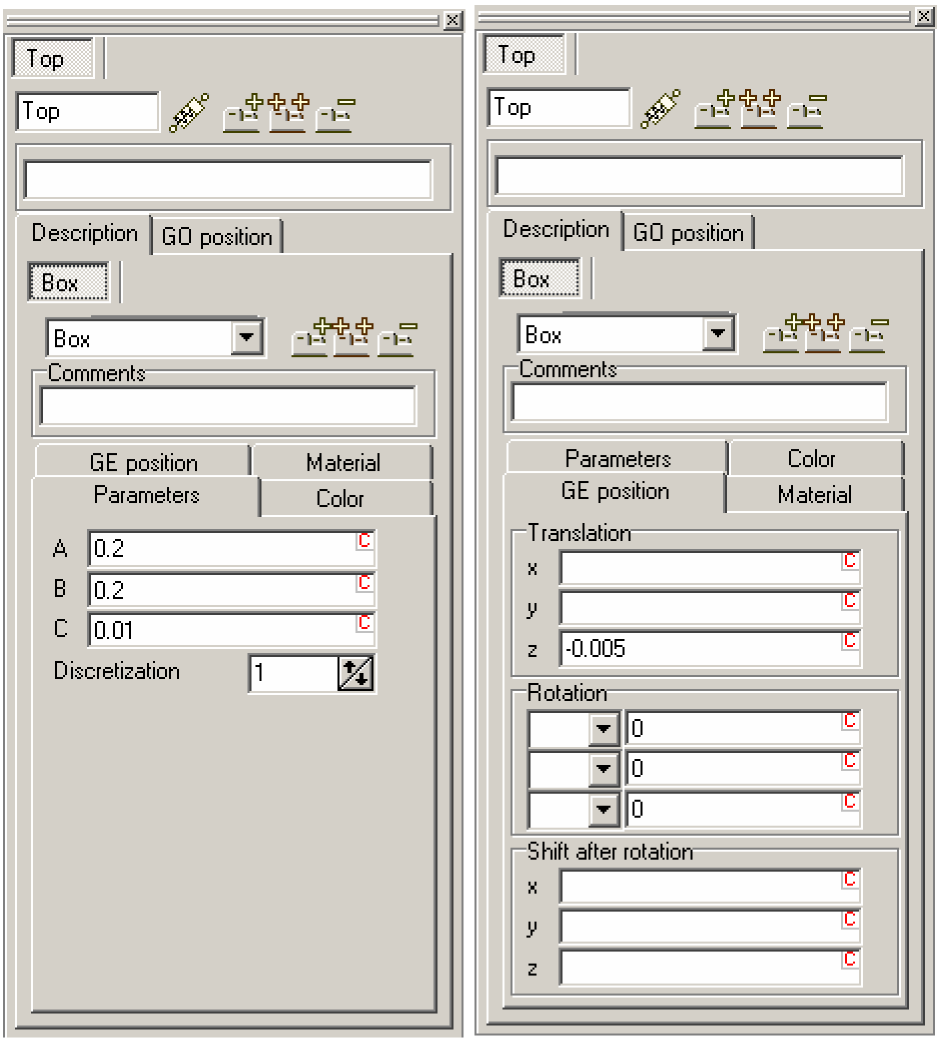
1. From the **File** menu point to **New object**. The window of the constructor appears.

### 2.3.2. Creating graphical objects

#### Top

We will create a thin rectangular plate as a graphical object for the **Top** body.

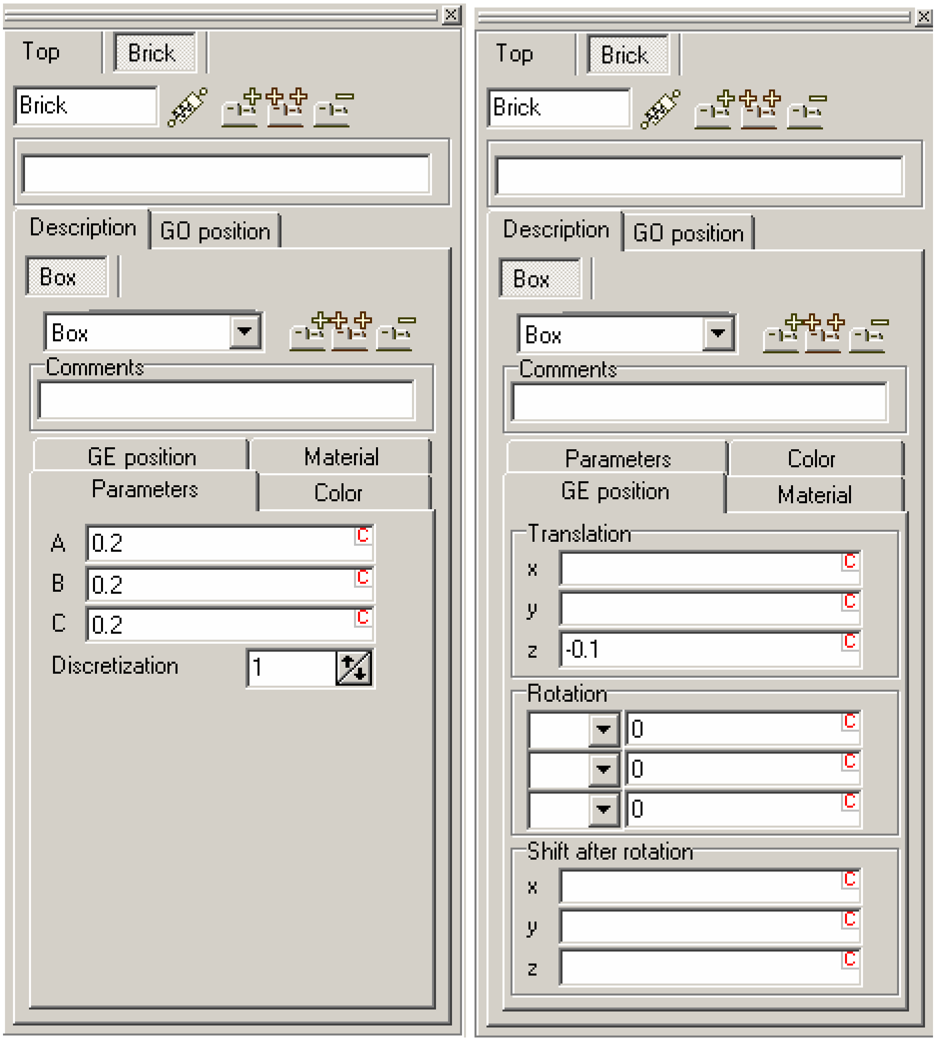
1. Create new graphical object.
2. Set its name to **Top**.
3. Add new graphical element – **Box**.
4. Set parameters and GE position for the **Box** as it is shown below.
5. Select the **Color** tab and choose **blue** for **diffuse** and **specular** colors.



### Brick

Let us describe the brick as a cube of **0.2 m** side length.

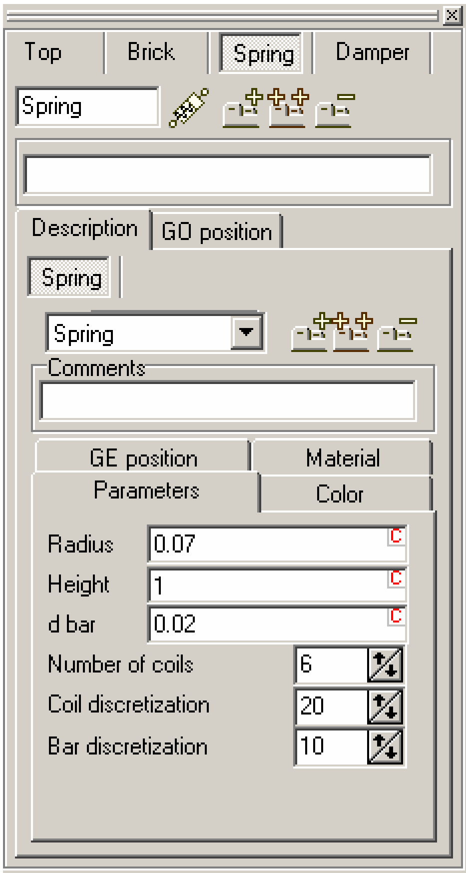
1. Create new graphical object.
2. Set its name to **Brick**.
3. Add new graphical element **Box** into this graphical object.
4. Set its parameters and GE position.
5. Select the **Color** tab and set **red** for **diffuse** and **specular** colors.



## Spring

Now we will create the graphical object for the spring.

1. Create new graphical object.
2. Set its name to **Spring**.
3. Add new graphical element – **Spring**.
4. Set **Spring** parameters as it is shown below.



### Damper

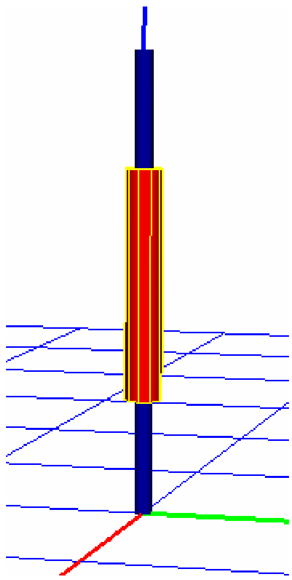
Now we come to the last graphical object in this model – damper.

1. Create new graphical object.
2. Set its name to **Damper**.
3. Add new graphical element for the **Damper** – **Cone**.
4. Set parameters as follows:

   **R2 = 0.02**;

   **R1 = 0.02**;

   **h = 1**.
5. Select the **Color** tab and choose **blue** for **diffuse** and **specular** colors.
6. Add one more **Cone** with the following parameters: **R2 = 0.04**; **R1 = 0.04**; **h = 0.5**. In the **GE Position** tab set **Translation/Z** to **0.25**. Select **red** **diffuse** and **specular** colors.

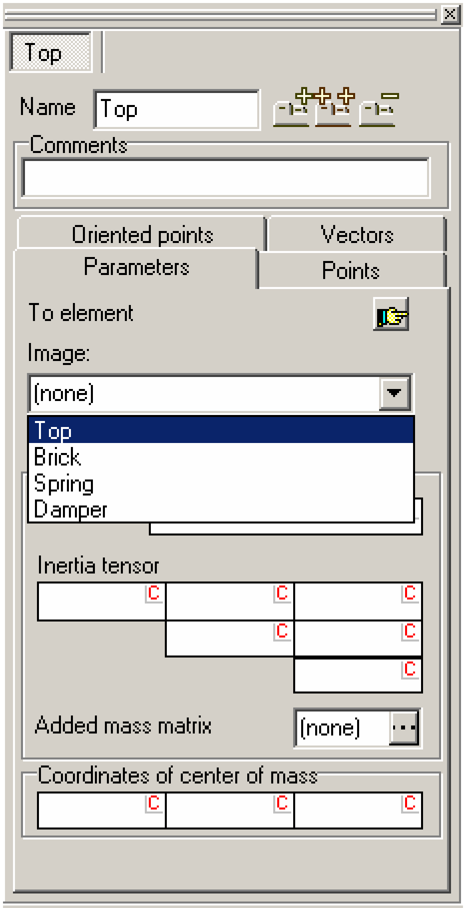


### 2.3.3. Creating rigid bodies

**Top**

Create new rigid body – **Top**.

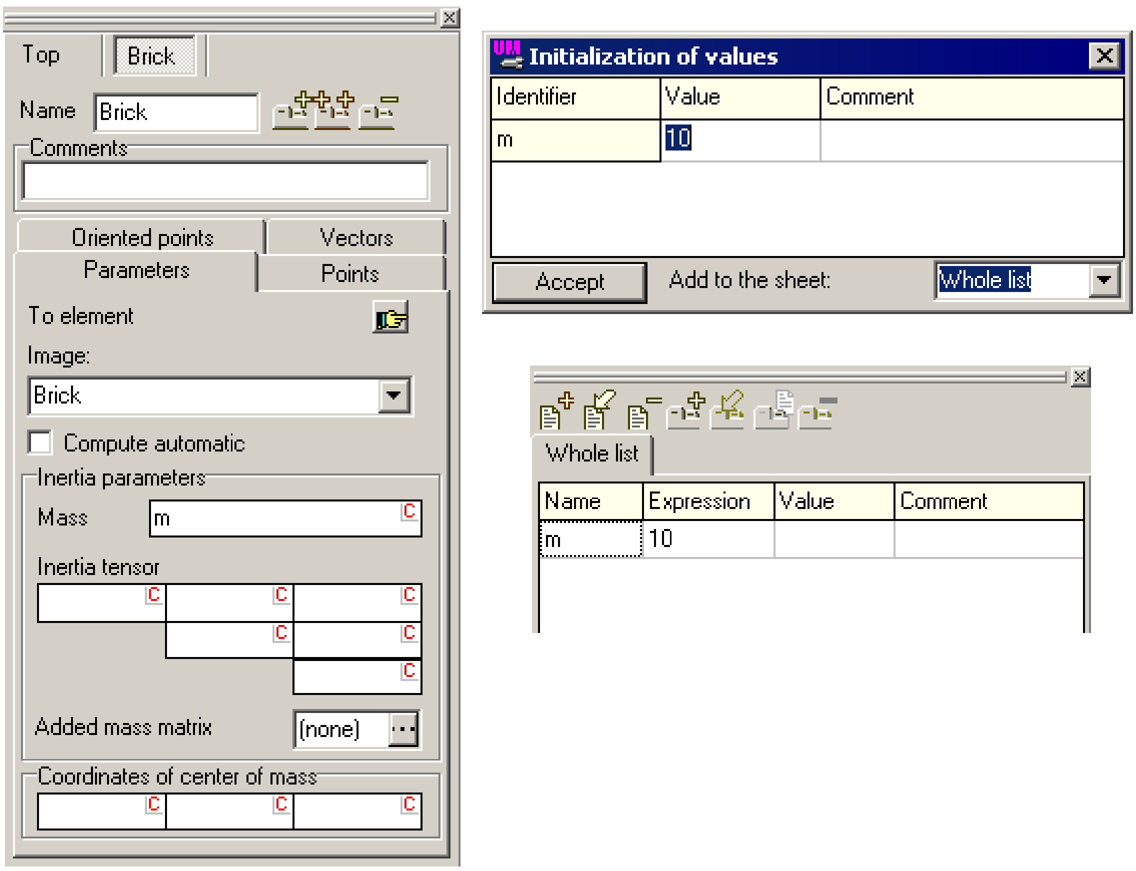
1. Add new rigid body.
2. Set its name to **Top**.
3. In the **Image** list select **Top**.
4. Leave **Mass** and **Inertia tensor** empty.



### Brick

Now we will create one more rigid body – **Brick**. Its mass we will express via parameter (identifier) **m**. Such a parameterization gives us a possibility to change its mass easily and quickly obtain results for various values of the mass of the brick without regeneration equations of motion. Otherwise we would have to generate equations every time we want to change its mass.

1. Add new rigid body.
2. Rename it to **Brick**.
3. In the **Image** list select **Brick**.
4. Set **Mass** to **m** and press **Enter**. New **Initialization of values** window appears.
5. Set **Value** to **10**. Press **Enter**.
6. This new parameter appears in the parameter list in the bottom left corner of the constructor window, see the figure below.



### 2.3.4. Creating joints

#### Joint for the top

The **Top** body moves along the vertical direction according *A·sin(ω·t)* function. Now we will describe the translational joint between the base and the **top** and set the coordinate in this joint as a time function.

1. Select the **Top** body in the tree of elements.
2. Click the button. Select **Create joint** and in the drop-down list select **Translational**, see the Fig. 2.2, left. The new joint of this type is created. Now you can see parameters of the joint.
3. Select the **Geometry** tab and set joint parameters as it is shown in the Fig. 2.2, right.

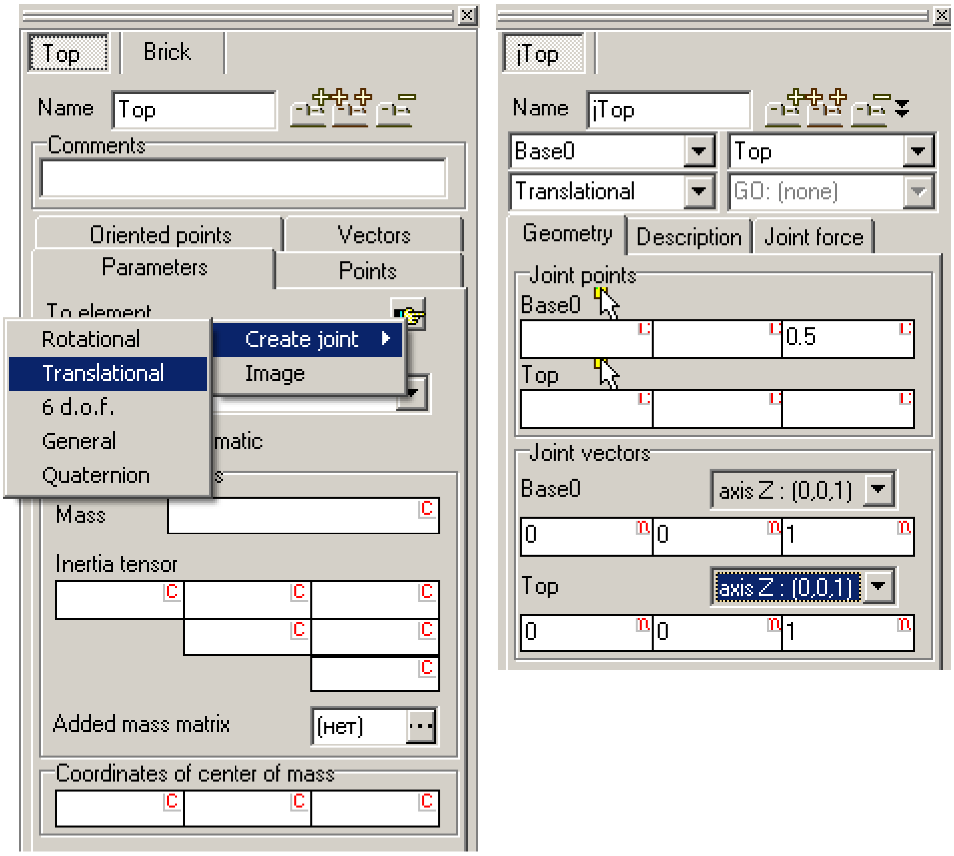



Figure 2.2. Creating translational joint

4. Point to **Description** tab.
5. Turn on the **Prescribed function of time** check box.
6. Set the **Type of description** to **Expression**, and then input **a*sin(omega*t)**, see the Fig. 2.3, and press **Enter**.

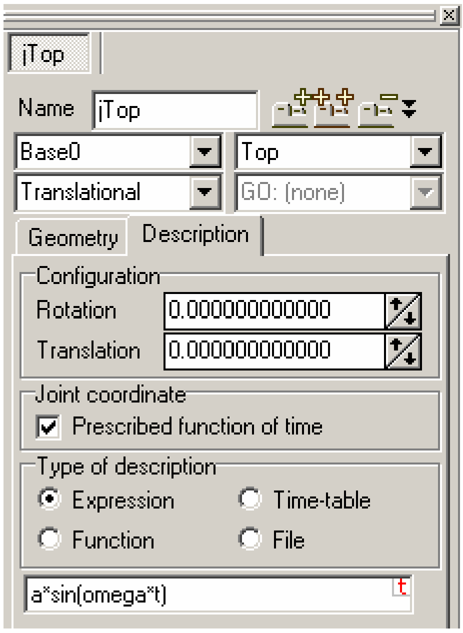
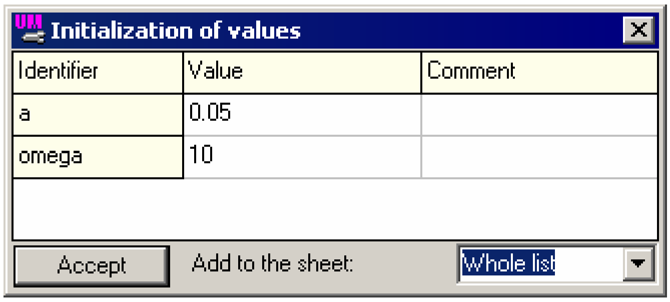


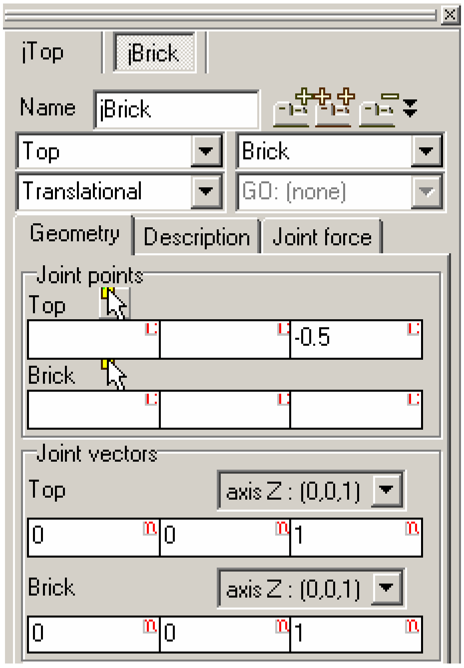

Figure 2.3. Prescribed function of time

7. In the **Initialization of values** window set **a = 0.05** (m) and **omega = 10** (rad/s).



### Joint for the brick

1. Select the **Brick** body in the tree of elements.
2. Click the  button.
3. In the drop-down list select **Prismatic** again.
4. Select the **Top** as the first body instead **Base0**, see the figure below.
5. Set the rest parameters of the joint as it is shown below.



### 2.3.5. Creating force elements

Now we will describe elastic and damping force elements between the top and the brick. Let us use **c** parameter for the stiffness coefficient of the spring and **mu** parameters for the damping coefficient of the damper. Length of the unloaded spring let us denote as **l0**.

1. Select the **jBrick** joint.
2. Select the **Joint force** tab.
3. In the **Joint force** list select the **Linear**.
4. In the **c** field input **c** (stiffness coefficient), in the **x0** field input **l0** and set **d** to **mu**, see Fig. 2.4. Press **Enter**. Set values of parameters as follows: **c = 250**, **l0 = 0.4**, **mu=5**.

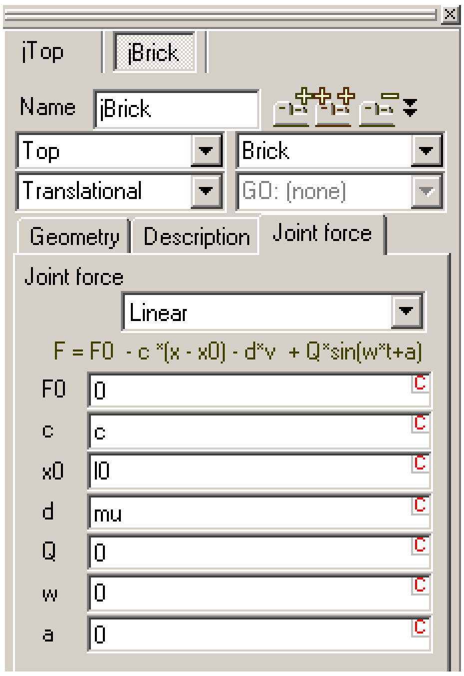



Figure 2.4. Elastic and damping joint forces

### 2.3.6. Visualization of spring and damper

After all we have completely described object from the mechanical point of view. We described all elements we need: rigid bodies, joints and force elements. However our model now looks not so good – spring and damper introduced as joint forces that cannot be visualized, see the Fig. 2.5, left. In order to visualize spring and damper we will create two **bipolar** forces in the model. Their values we set to zero. That is why these bipolar forces will not influence on the dynamics of the model, but give us a possibility to show the spring and the damper, see the Fig. 2.5, right.

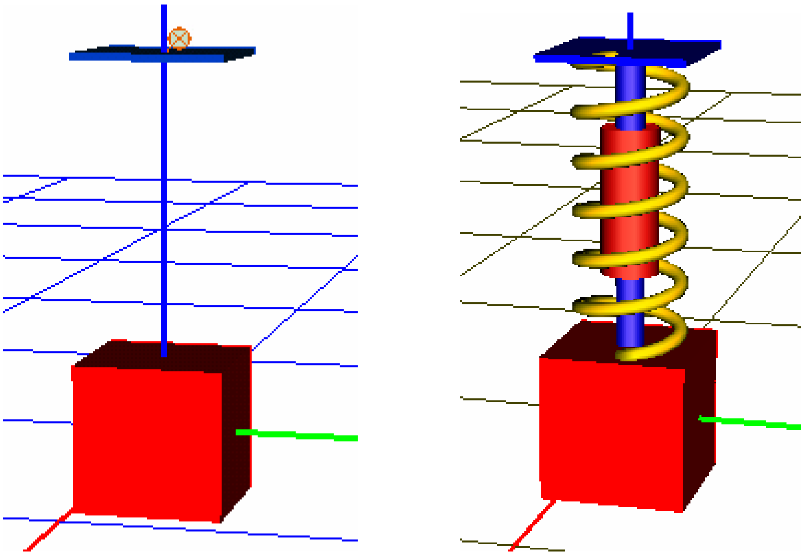


Figure 2.5. Visualization of forces

**Note.** There are several possible ways to describe elastic and damping forces in our model. We used the way to describe them as joint forces, but it is not the only right way. We could introduce them as bipolar as well. And in this latter case we would visualize them and introduce forces at once without intricate describing additional fake bipolar forces.

But such a way leads to a following problem. Our ideal case that we consider here allows to model the situation when the length of the spring and damper equal to zero. Imagine that the brick has so large amplitude that the attachment points of the spring and damper will be on the same level. In such a case we have degeneration of bipolar forces that act along the line between the attachment points. When we have zero length we could not find the direction of the bipolar forces. Joint forces have no such a degeneration, because they direction always coincide with the axis of the joint. That is why we used very joint forces here.

1. So, select the **Bipolar force** in the tree of elements.
2. Add two bipolar force elements. Set their parameters as it is shown in the Fig. 2.6.

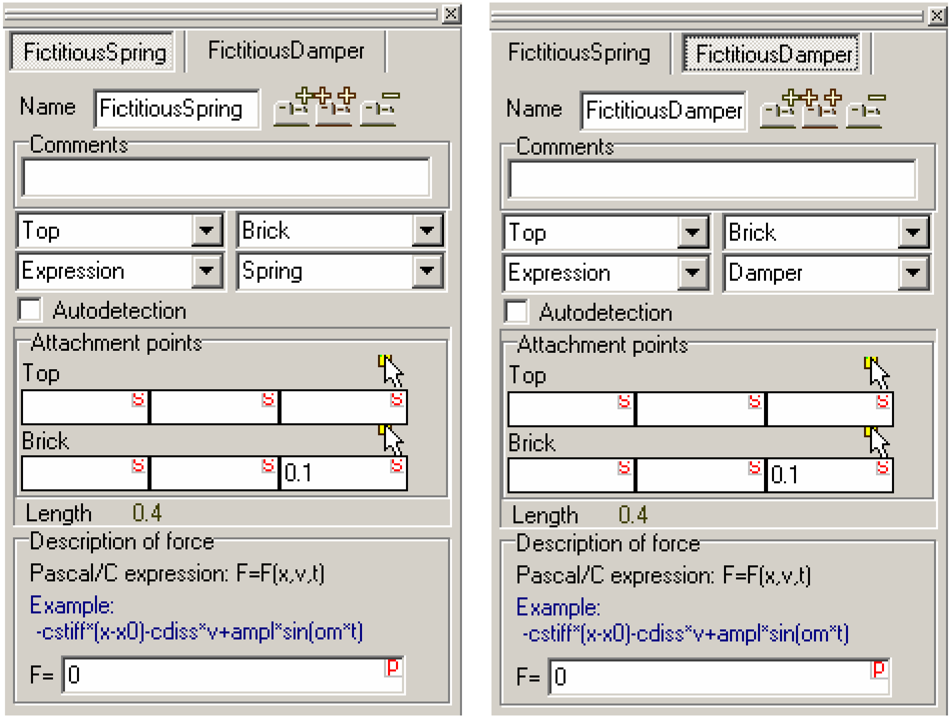



Figure 2.6. Fictitious bipolar forces

### 2.3.7. Additional parameters

Using UM you can express one parameter via others. Here we will add two new parameters in the model – accurate analytical values of the natural frequency and the critical damping coefficient. Our model is very simple that is why we can obtain analytical solutions easily.

Natural frequency can be obtained according to the following formula:

$$k = \sqrt{\frac{c}{m}}, \text{ where}$$

$k$ – natural frequency, rad/s;

$c$ – stiffness coefficient, N/m;

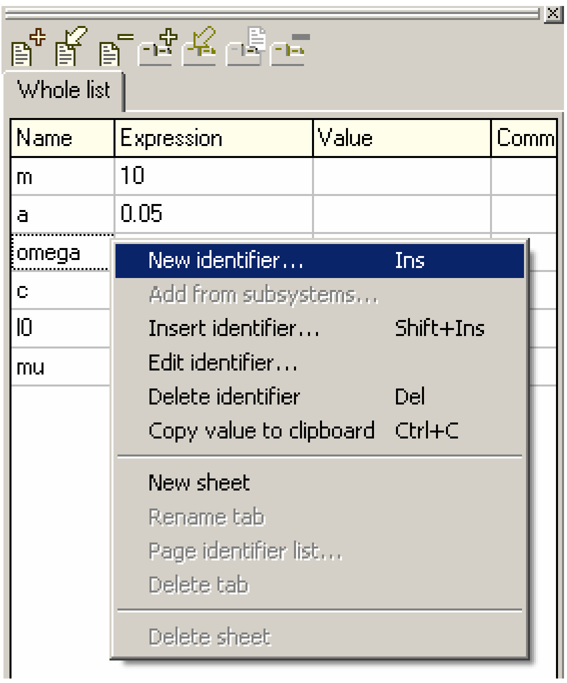
$m$ – mass of the body, kg.

Critical damping coefficient can be found as:

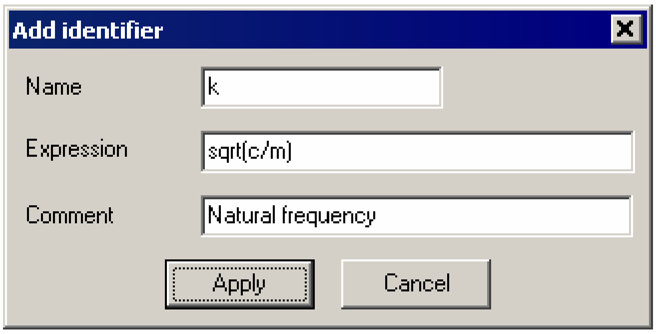
$$\mu^* = 2\sqrt{cm}, \text{ where}$$

$\mu^*$ – critical damping coefficient, Ns/m.

1. Well, add new identifiers (parameters) to our model. Click the  button in the list parameters or select the **New identifier** menu command from the context menu.



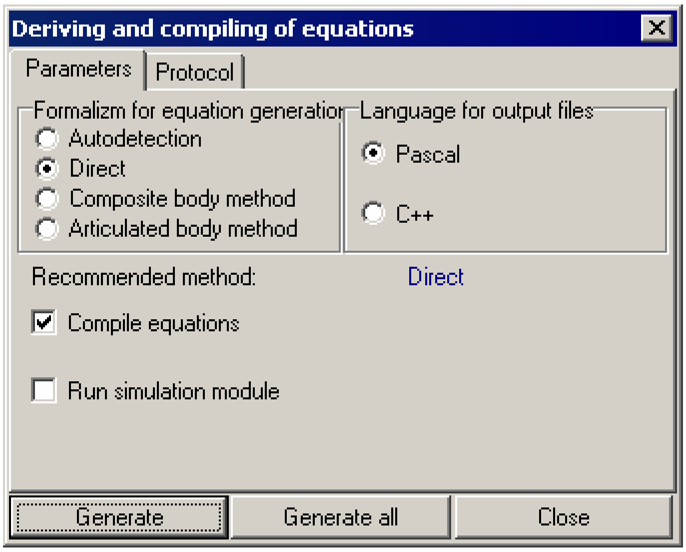
2. Fill out the **Add identifier** form as it is shown in the figure below.




3. Add one more identifier: **mu_star = 2*sqrt(c*m)**. It is a critical damping coefficient.

### 2.3.8. Preparation for simulation

1. Save the model as **Oscillator** (use menu command **File/Save as**).
2. From the **Object** menu select the **Generate equations** item. New dialog box appears. Turn on the **Compile equations** check box.
3. Click the **Generate** button.




In the case of successful generation and compiling equations of motion you will see the following message: «**Compiling successful. Object is ready for simulation**». It is true. The model is really ready. Let us start its simulation.

4. Click the **Close** button.

Now we will come to the simulation program.

5. From the **Object** menu select **Simulation**, or simply press **F9** key.

The simulation programs starts and opens the current model.

## 2.4. Simulation of the motion

Let us consider some particular cases of oscillations: free damped oscillations and forced oscillations without damping.

### 2.4.1. Free oscillations

#### Free damped oscillations

1. Open new animation window (**Tools/Animation window**).

Open new graphical window, where we will plot time history of the vertical position of the brick.

2. Open new graphical window (**Tools/Graphical window**).
3. Open **Wizard of variables** (**Tools/Wizard of variables**).
4. Select the **Linear var.** (linear variables) tab, select **Brick** in the list of bodies, set **Type** to **r** (coordinate), set **Component** to **Z**. Click the  button to create new variable. The variable appears in the container of variables. Drag the variable to the graphical window. Close the **Wizard of variables**.
5. From menu **Analysis** select **Simulation**. The **Object simulation inspector** appears.
6. Arrange windows on the desktop as you prefer, for example, as it is shown in the Fig. 2.7.

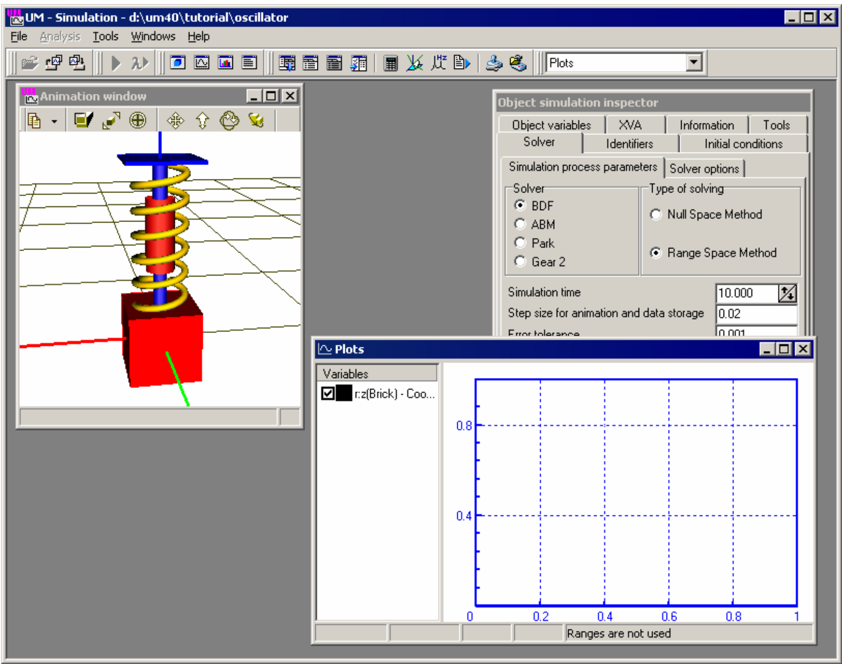



Figure 2.7. Desktop of the simulation program

7. Select the **Object simulation inspector** and click the **Identifiers** tab.
8. Set **a** to **0** and press **Enter**. So we set zero amplitude of the oscillations of the **Top** body, in other words we fix the **Top** in order to analyze free oscillations.

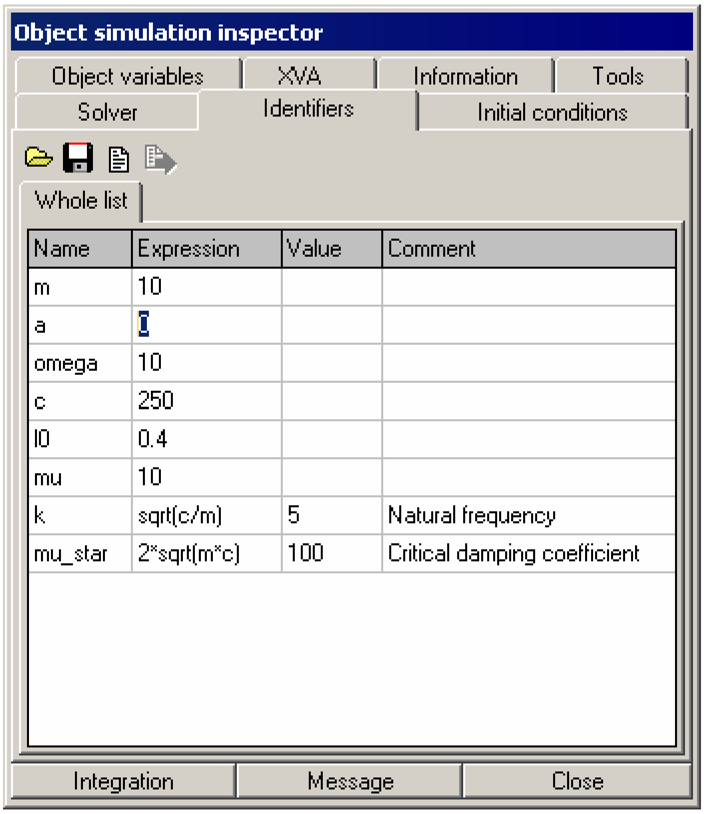
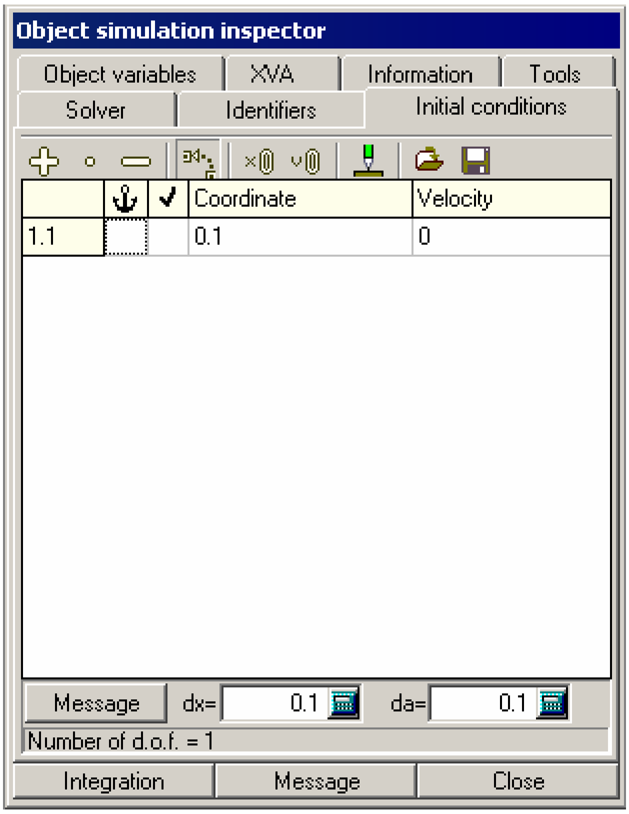



Figure 2.8. Parameters of the model

9. Select the **Initial conditions** tab. In the **Coordinate/1.1** input **0.1**. We need to shift the brick a bit because its position at zero coordinate is quite near to its equilibrium position that gives us small amplitude of oscillations if we do not shift the body.




10. Select the **Solver** tab. Set **Simulation time** to **25** (seconds).
11. Run simulation clicking the **Integration** button.

Process of the numerical simulation starts for 25 seconds period. You can see oscillations of the **Brick** in the animation window and time history of the vertical position of the brick.

12. Click the **100%** button in the drop-down tool panel in the top or click the **Show all** menu command in the context menu, see the Fig. 2.9. Plot now fits the window.

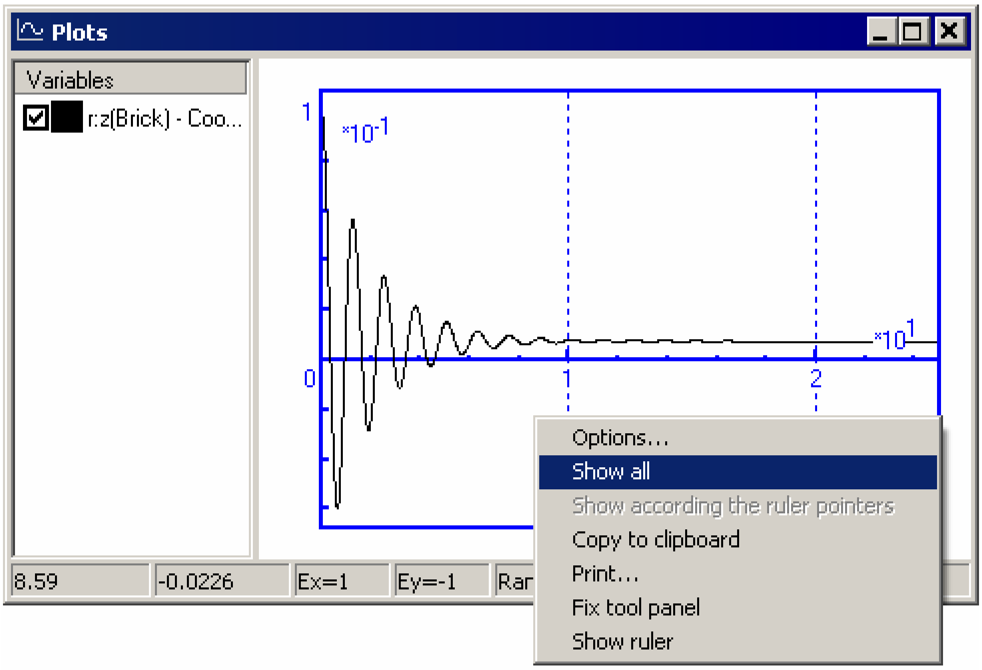



Figure 2.9. Graphical windows after the first experiment

## Free oscillations without damping

Now we will turn off damping and compare plots for damped and free oscillations. Using zero damping coefficient gives us free oscillations.

1. Select the graphical window. Point to the **r:z(Brick)** variable in the list of variables. Open context menu. Select the **Copy as static variable** menu command. The second variable appears.
2. Select the **Pause** inspector and click the **Interrupt** button. **Object simulation inspector** appears.

**Note.** The **r:z(Brick)** variable, which we dragged from the **Wizard of variables**, will be recalculated for every numerical experiment. It is so-called *dynamic* variable. In order to compare plots for different experiments we need to copy *dynamic* variables as *static* ones. *Static* variables are not changed from one experiment to another.

3. Select the **Object simulation inspector** and point to the **Identifiers** tab.
4. Set **mu = 0** and press **Enter**. So we have just turned off damping.

5. Click the **Integration** button.

It will take you some seconds to finish the simulation. In the Fig. 2.10 you can see the graphical window after two numerical experiments.

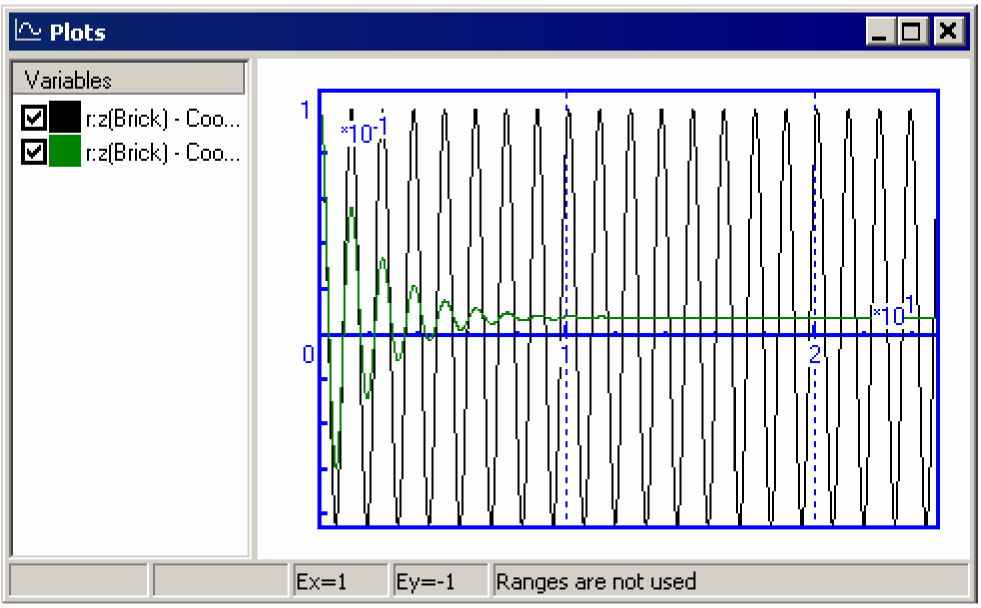



Figure 2.10. Graphical windows after the first experiment

### Free oscillation: critical damping

As we showed above critical damping coefficient is **mu = 100** Ns/m. Let us analyze the motion of the **Brick** in such a case.

1. Point to the graphical windows. Select the first variable **r:z(Brick)** and copy it as a static one again (use the **Copy as static variable** item from the context menu).
2. Select the **Pause** inspector and click the **Interrupt** button. **Object simulation inspector** appears.
3. Select the **Identifiers** tab and set **mu = 100**.
4. Click **Integration**.

Now you can see that the motion of the brick is non-periodic, see the Fig. 2.11.

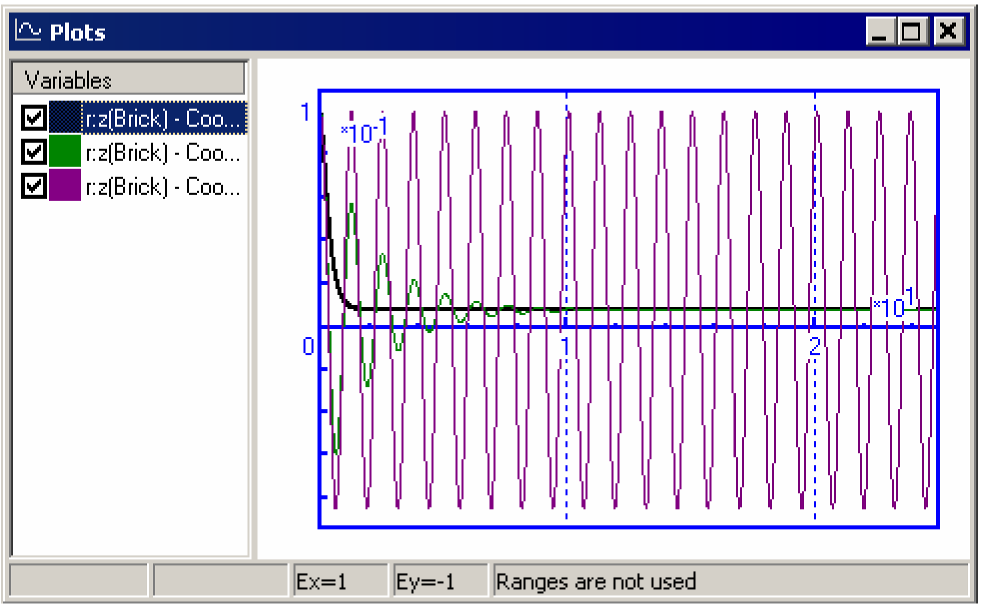



Figure 2.11. Graphical window after three numerical experiments

5. Make numerical experiments for other values of the damping coefficient. Do not forget to copy variables as static ones.
6. If you changed the value of the damping coefficient, set it again to mu = 100 Ns/m.

### 2.4.2. Statistical analysis

Now we will come through some additional tools for analysis of results of the simulation.

1. From the **Tools** menu select **Statistics.** New **Statistics** window appears.
2. Drag the variable, which corresponds to free oscillations, from the graphical window to the **Statistics** window.
3. Select the **Statistics** window and point to **Power spectral density**.

The characteristic shape of the power spectral density shows the process has the only frequency, which corresponds to natural frequency. We have the accurate analytical solution – 5 rad/s. Not let us obtain this frequency numerically from the plot of the power spectral density, see the Fig. 2.12. It is approximately **0.78** Hz, see abscissa in the left bottom corner, 0.78 Hz gives us $0.78 \cdot 2\pi = 4.9$ rad/s. You can see that numerically obtained values are quite close to analytical one.

**Note.** To pick the frequency more precisely use changing scale of the window as it is shown in the Fig. 2.12.

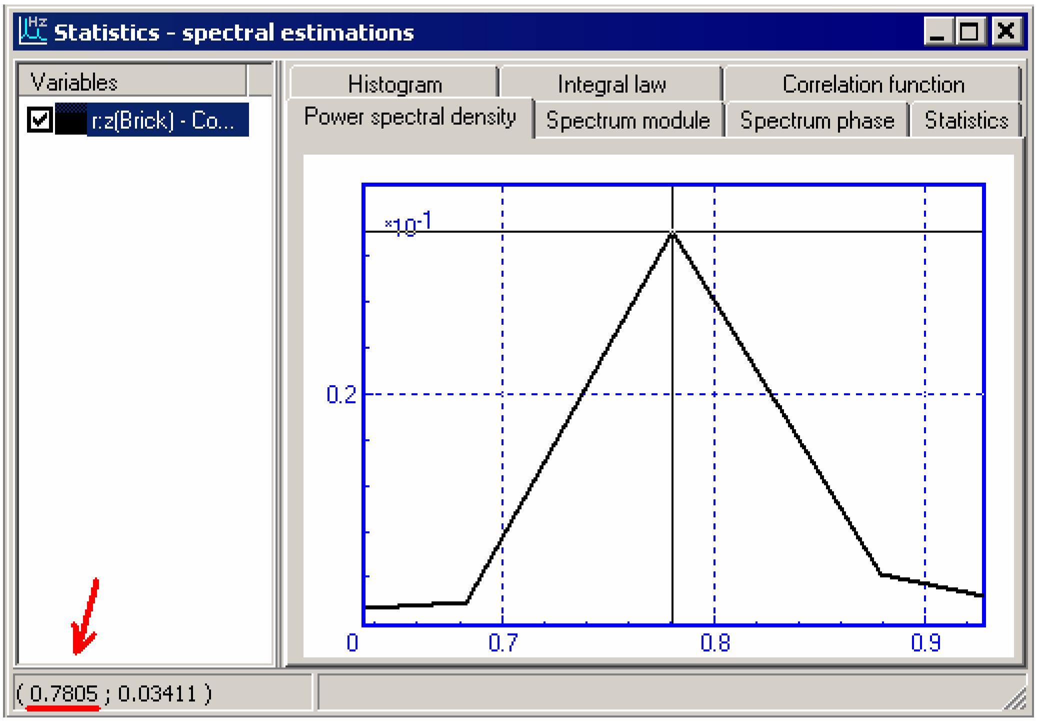



Figure 2.12. Power spectral density of the free oscillations

### 2.4.3. Linear analysis

Let us consider an example of using the **Linear analysis**. With the help of this tool we will find the equilibrium position of the system, its natural frequencies and forms, define how much the actual damping ration relative to the critical one.

Well, at first you need to close **Pause** and **Object simulation inspector** windows.

1. Select the **Pause** windows and click **Interrupt**.
2. Select the **Object simulation inspector** and click **Close**.

#### Open Linear analysis window

3. From the **Analysis** menu select **Linear analysis**. The **Linear analysis** window appears.

#### Equilibrium position

4. In the **Linear analysis** window select the **Equilibrium** tab. Click the **Compute** button. You can see the message "**Equilibrium position is successfully computed!**". The brick in the animation window is now in its equilibrium position.

**Note.** Obtained coordinates, which correspond to equilibrium position, you can save to a file. To do it use the button in the **Initial conditions** tab. This file with initial conditions you can loaded using **Object simulation inspector** in order to start simulation form the equilibrium position if necessary.

#### Natural frequencies and forms

5. Select the **Frequencies** tab. In the left list you can see the natural frequencies of the system. As you can see our system has only one frequency and this frequency is 0.795775 Hz, what corresponds to 5.0000 rad/s.
6. Click the **Show** button to start animation of the natural forms. Adjust appropriate **Amplitude** and **Rate**. Click the **Stop** button to finish animation.

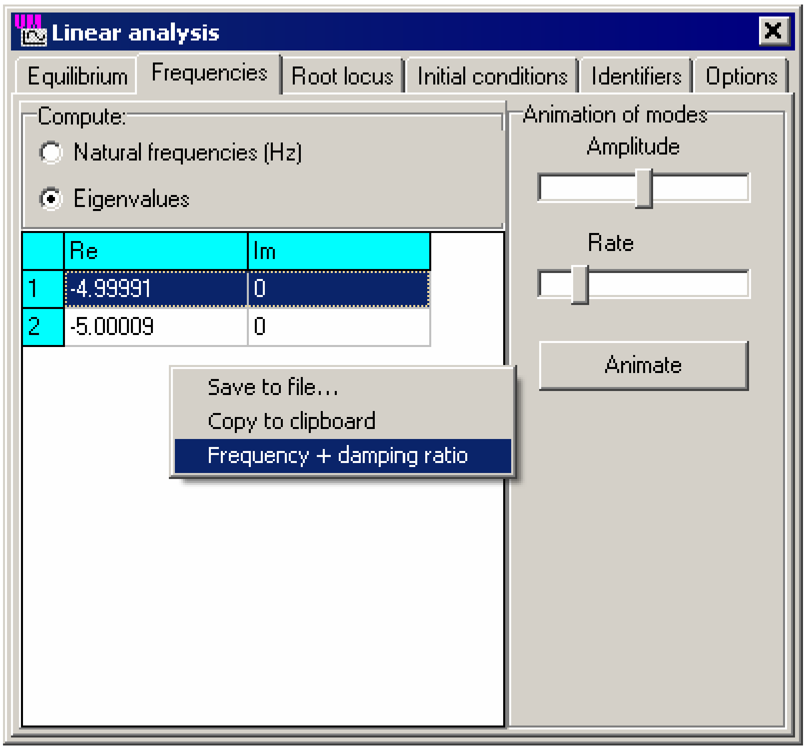
## Stability

Let us find the roots of the linearized system. It gives us the information about stability of the model.

7. Set the **Compute** to **Eigenvalues**. You can see that the real parts of roots are negative, therefore system is stable.

## Damping ratio

8. Let us describe the damping ratio of the system. Click the right mouse button on the list of eigenvalues and from the context menu select the **Frequency + damping ratio** menu command. We have **Beta = 100 %**, that corresponds to critical damping.




**Note.** Damping ration shows us if all forms are damped properly and thus change damping coefficients or geometry of attachment point of dampers if necessary.

9. You can change the value of the **mu** identifier in the **Identifiers** tab and see what will happen with damping ratio.
10. Close the **Linear analysis** window.

### 2.4.4. Forces oscillations

Let us consider simulation of forced oscillations without damping.

1. Delete all variables from the graphical window except the first (dynamic) one.
2. From the **Analysis** menu select **Simulation**.
3. Select the **Identifiers** tab. Set the following values: **a = 0.05**, **omega = 8**, **mu = 0**.
4. Run integration. Now you can see that the body **Top** also moves. The time history of the vertical position of the **Brick** is given in the Fig. 2.13.

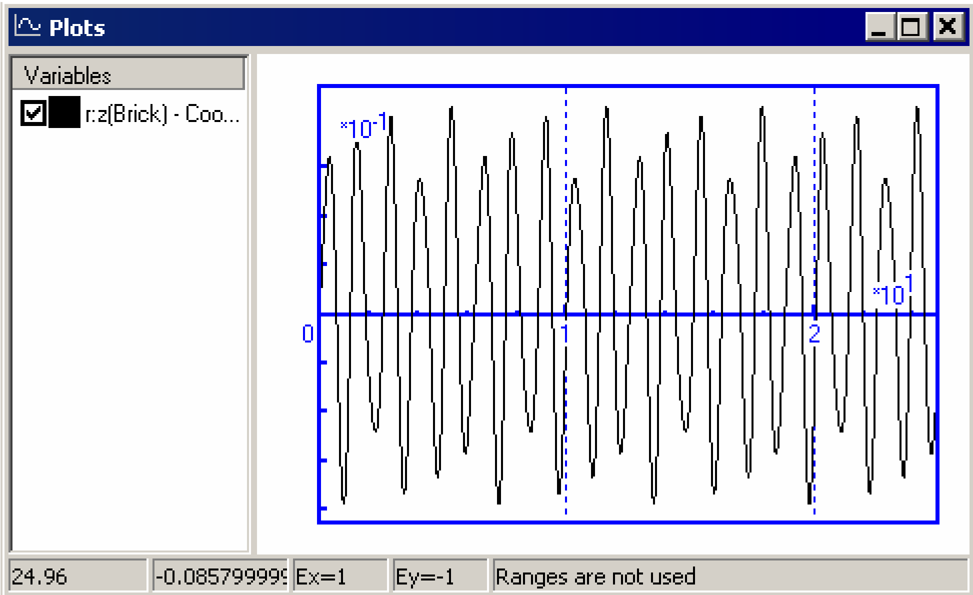



Figure 2.13. Forced oscillation (omega = 8 rad/s)

## Resonance

In conclusion we consider the resonance case, when the excitation frequency is equal to the natural frequency of the system.

1. In the **Pause** window click the **Interrupt** button.
2. In the **Object simulation inspector** set **omega = 5**.
3. Run integration. As we expected in the resonance case the amplitude of the oscillations increases in the long run, see the Fig. 2.14.

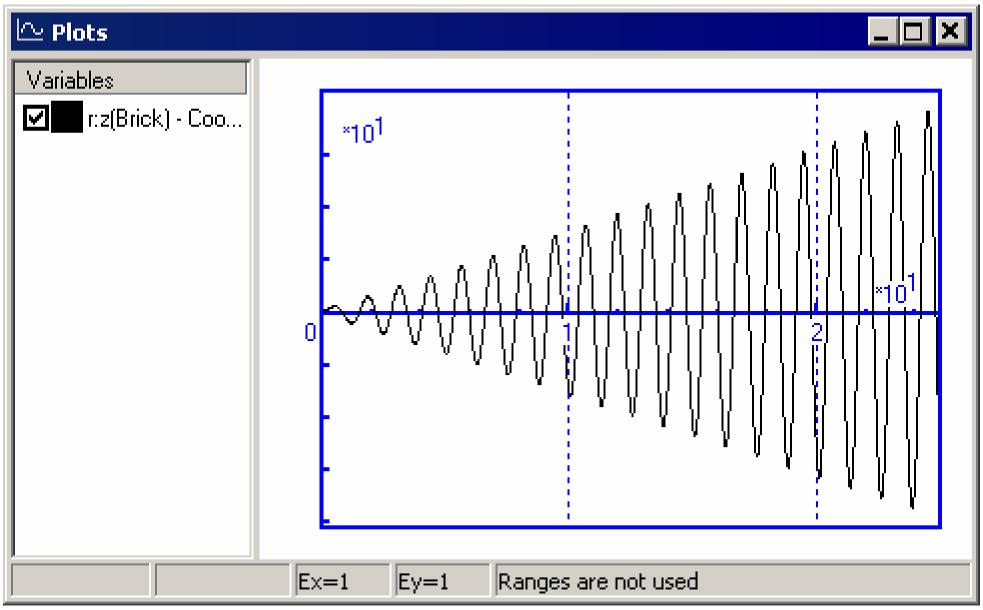



Figure 2.14. Forced oscillations: resonance case

# 3. Subsequent studying Universal Mechanism

You have come through two examples of dynamical systems (pendulum and sprung body) and have seen the basic tools and features of the UM Base version.

The *Getting Started* series includes other manuals that devoted to the rest modules of the Universal Mechanism. Here they are:

- Getting Started: simulation of road vehicles;
- Getting Started: railway vehicle dynamics;
- Getting Started: Matlab/Simulink interface;
- Getting Started: optimization module;
- Getting Started: elastic bodies with UM FEM.

### Library of simple models: how to…

The Part 7 of the UM User's Manual is devoted to consideration of simple models that show you how to create/model various graphical elements, joints and force elements. Studying these examples helps you familiarize yourself with basics of Universal Mechanism and approaches for simulation of objects of different kind. The library of models is in the **{um_root}\library** directory.

The **part7.pdf** you can find in the **{um_root}\manual** directory or download using the following link: http://www.umlab.ru/download/docs/eng/part7.pdf.