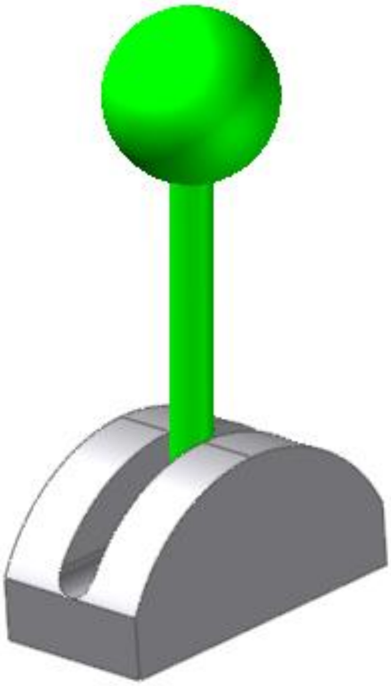
Pendulum Tutorial (CoLink)



FunctionBay

Edition Note

This document describes the release information of **RecurDyn V9R4**.

Table of Contents

Chapter 1

Getting Started

Objective

In this tutorial, you will simulate and control a dynamic system using CoLink, an interactive environment for designing, simulating, and testing time-varying systems. You will define a control system in CoLink to control a mechanical system that you create in standard RecurDyn.

The system to be simulated is a simple inverted pendulum which is mounted on a base which can move side to side. The pendulum can be balanced in its upright position by applying a sideways force to the base. In this tutorial, you will implement various control systems to control this sideways force.

Audience

This tutorial is intended for intermediate users of RecurDyn who previously learned how to create geometry, joints, and force entities. All new tasks are explained carefully.

Prerequisites

You should first work through the 3D Crank-Slider and Engine with Propeller tutorials, or the equivalent. We assume that you have a basic knowledge of physics.

Procedures

The tutorial is comprised of the following procedures. The estimated time to complete each procedure is shown in the table.

Procedures	Time (minutes)
Creating the initial model	10
Integrating CoLink	15
Adding Derivative Control	10
Adding Integral Control	5
Total:	40

Estimated Time to Complete

This tutorial takes approximately 40 minutes to complete.

Chapter

2

Creating the Initial Model

Task Objective

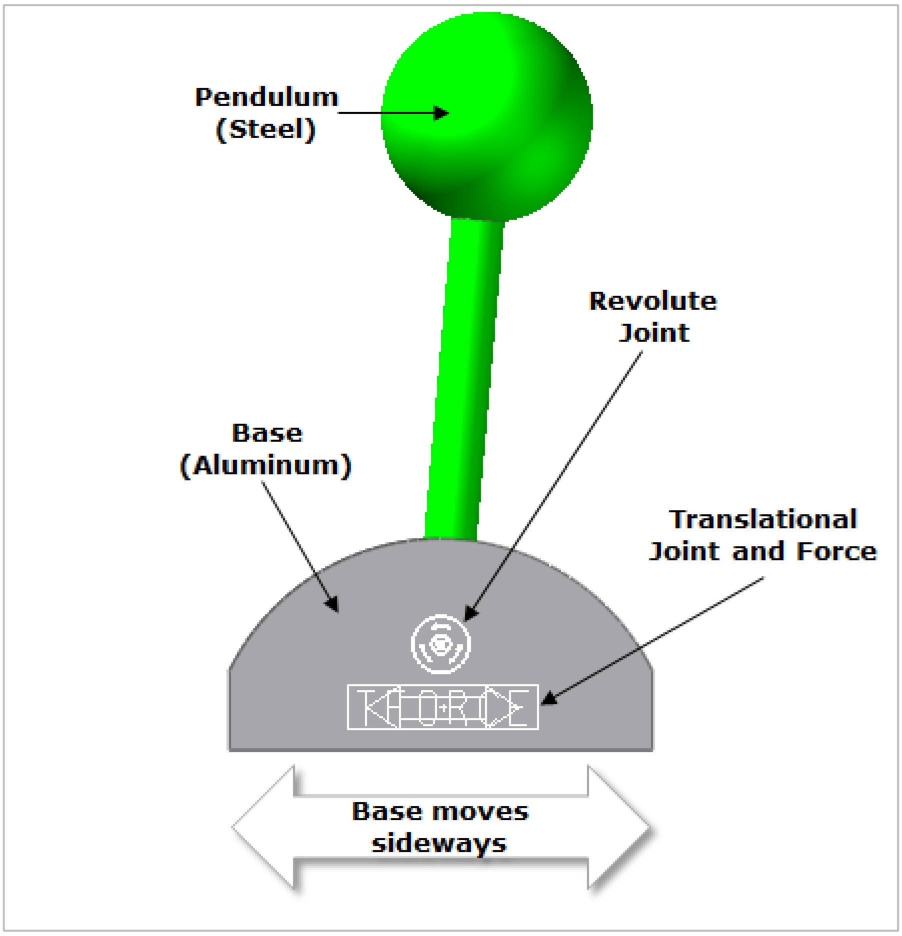
Learn how to create a mechanical model in preparation for refining the model for use with a control system.

Estimated Time to Complete

10 minutes

Understanding the Model

Before starting, the diagram below shows what the completed model should look like.

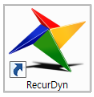


Things to note about the model are:

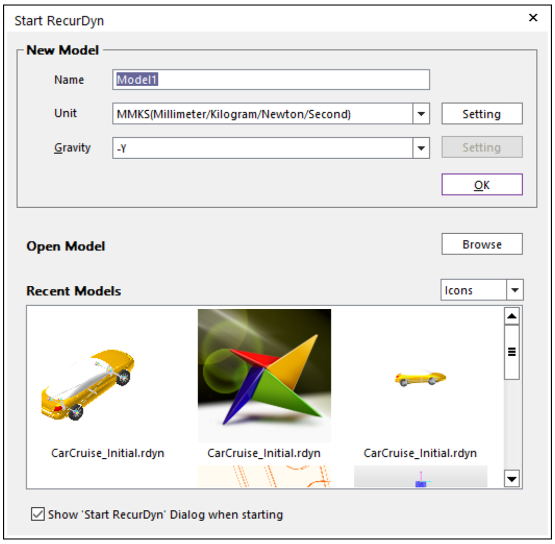
- The pendulum starts offset at a 5-degree angle (from vertical) to perturb the system.
- The base is made of aluminum while the pendulum is steel. The appropriate mass densities are already defined in the Parasolid file. You will be able to see the different densities under the Body tab of the Body Properties window after you import the geometry.
- The model will be simulated for 5 seconds.

Starting RecurDyn and Importing the Geometry

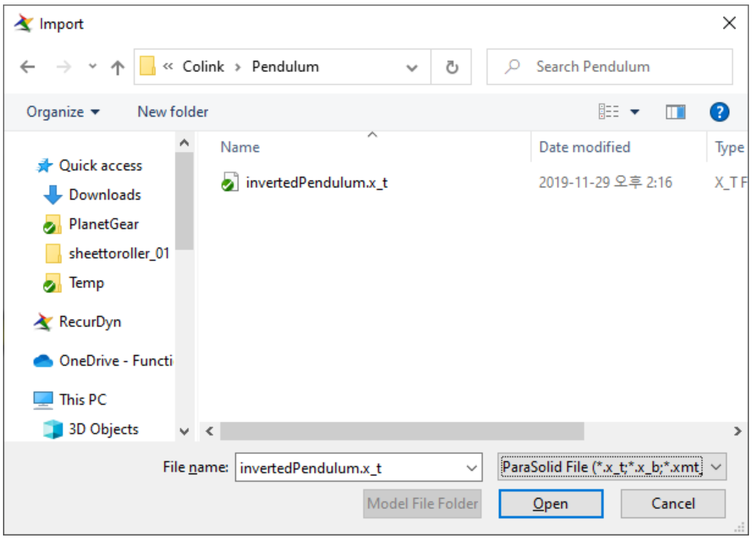
To start RecurDyn:



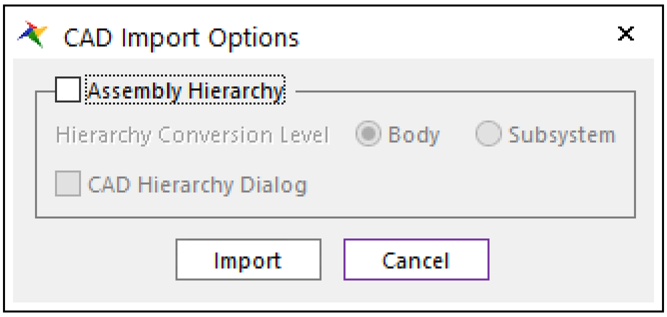
1. On your Desktop, double-click the **RecurDyn** icon.
2. In the Start RecurDyn window, enter **Pendulum** as the **Model Name**.
3. Click **OK**.

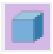


To import the geometry:



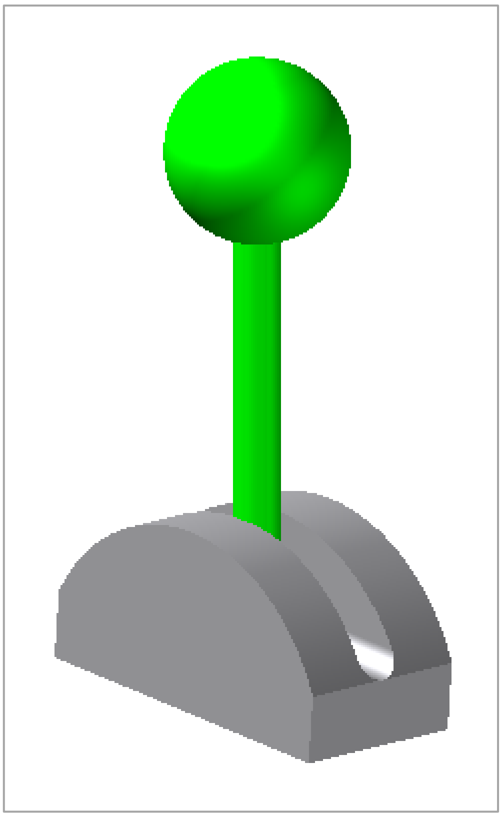
1. From the **File** menu, select **Import**.
2. Use the dropdown menu to select **ParaSolid File** as the file type to import.
3. Navigate to the CoLink tutorial directory.
4. Select the file named **invertedPendulum.x_t**. (**The file location:** <Install Dir> \Help \Tutorial \Colink \Pendulum)
5. Click **Open**. The **CAD Import Options** window appears. Clear the **Assembly Hierarchy** checkbox and click the **Import** button.





6. Change the **Render Mode** to **Shade**.

   You should now see the two parts of the mechanical model, the inverted pendulum and the base, as shown below.



7. Select the **base** and right-click and select **Properties**.
8. Under the **General** tab, change the Name to **Base**.
9. Click **OK**.
10. Repeat steps 7-9 for the pendulum, naming it **Pendulum**.

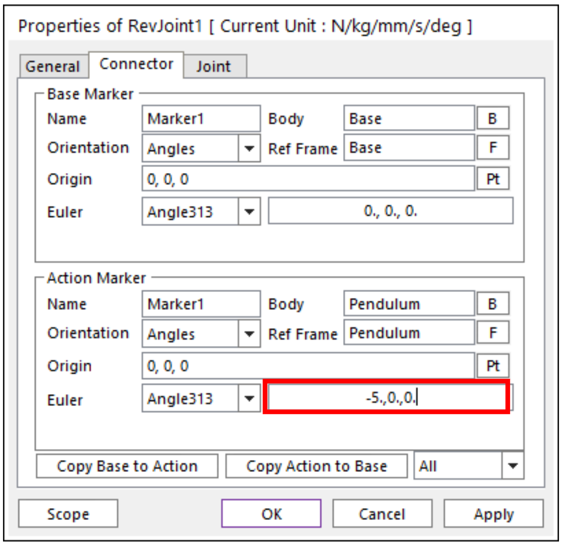
Adding Joints and Forces

You will now add two mechanical joints and a translational force.

To add the revolute joint:

1. From the **Joint** group in the **Professional** tab, click **Revolute**.
2. Set the **Creation Method** to **Body, Body, Point**.
3. Select **Base** as the base body.
4. Select **Pendulum** as the action body.

5. Enter the point **0, 0, 0** as the joint origin.
6. From the **Database window**, right-click on **RevJoint1** and select **Properties**.
7. Under the **Connector** tab, change the Action Marker's Euler angle to **-5, 0, 0**.

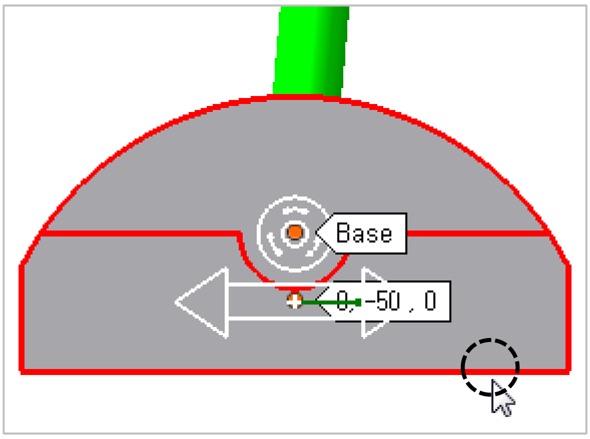


Note: This sets the initial rotational offset of the joint to -5 degrees, which is necessary for the control system to recognize as the starting position.

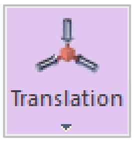
8. Click **OK**.

To add the translational joint:

1. From the **Joint** group in the **Professional** tab, click **Translate**.
2. Set the **Creation Method** to **Body, Body, Point, Direction**.
3. Select **Ground** as the base body.
4. Select **Base** as the action body.
5. Enter the point **0, -50, 0** as the joint origin.
6. Mouse over the bottom edge of the **Base**, to the right of the base's center. The direction of the joint should be indicated as shown at right.
7. Click on the edge of the **Base** body.



To add the translational force:



1. From the **Force** group in the **Professional** tab, click **Translational**.
2. Set the **Creation Method** to **Body, Body, Point, Point**.
3. Select **Ground** as the base body.
4. Select **Base** as the action body.
5. Enter the point **0, -50, 0** twice, as both the base and action point.

Save the RecurDyn Model:

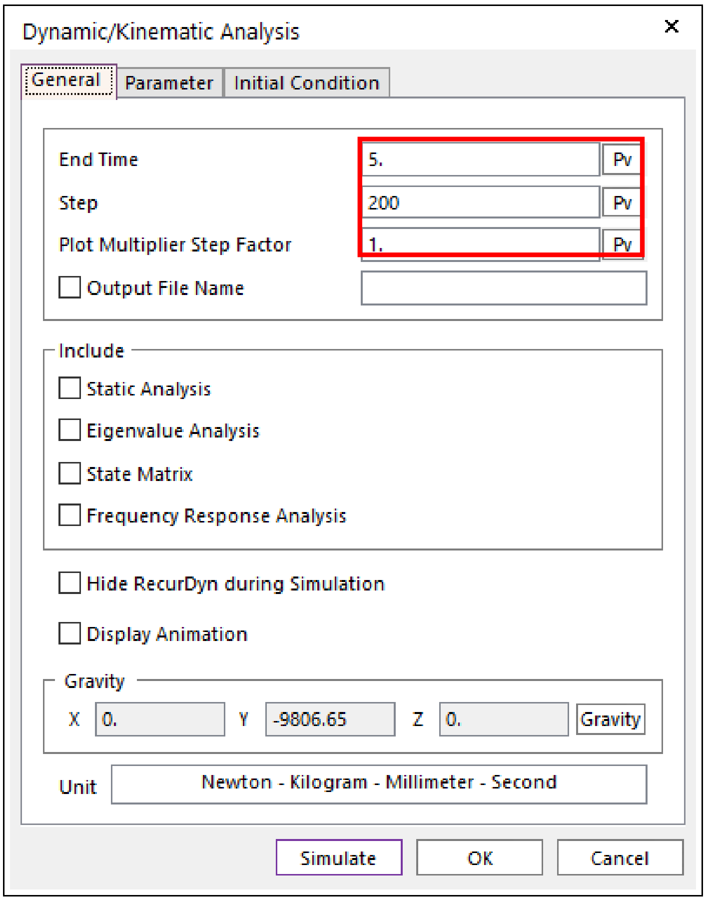
Save the Model as **Pendulum_P.rdyn**.

Running a Simulation

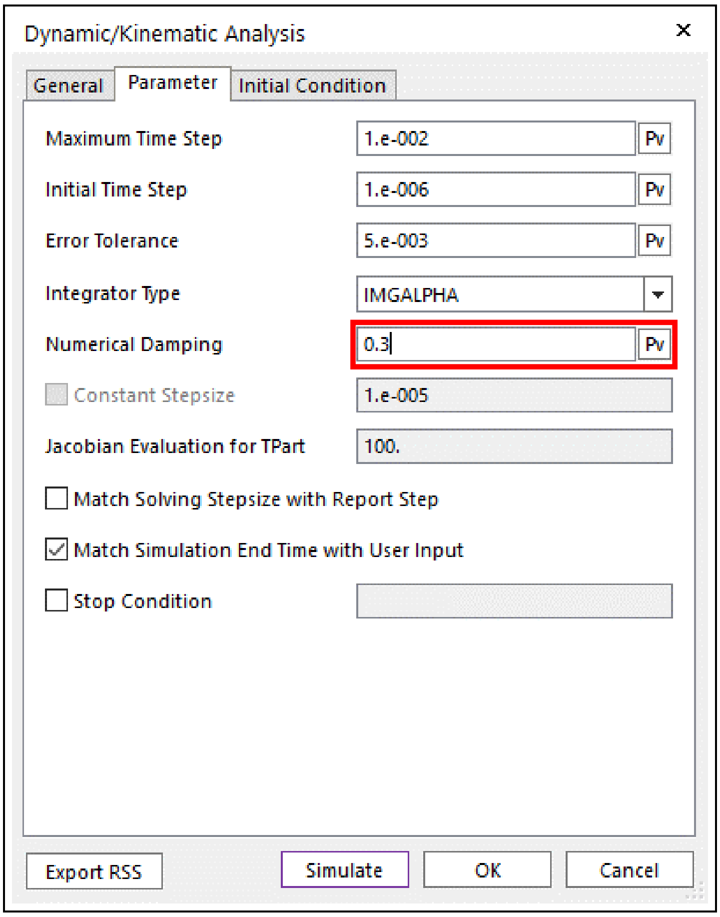
You can now run a simulation to see how the uncontrolled pendulum system behaves.

To run a simulation:

1. Click the **Dyn/Kin** of the **Simulation Type** group in the **Analysis** tab.
2. Set the simulation to run for **5** seconds with **200** steps as shown in the figure on the right. This will give adequate time to view the motion of the pendulum.



3. Under the **Parameter** tab, set **Numerical Damping** to **0.3**.
4. Click **Simulate**.

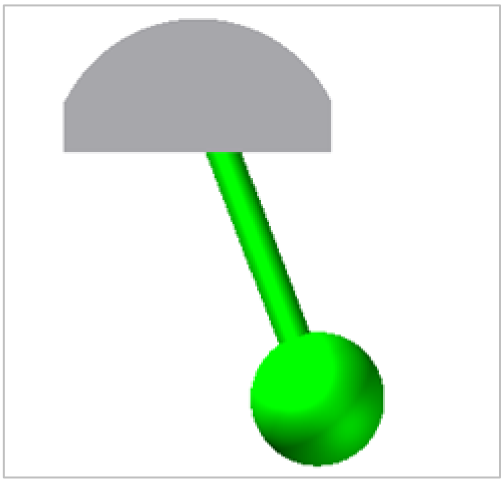


Viewing the Results

To view the results:

1. Click the **Play** button on the Animation Control group in the Analysis tab at the top of the window to play the results.

   You should see that the pendulum freely swings downwards, and the base freely moves side to side.



Save the RecurDyn Model.

Chapter

3

Integrating CoLink

Task Objective

In this chapter, you will set up the model for integration with **CoLink** and create the **CoLink** model. The **CoLink** model will be a simple Proportional (P) control system.   You will then simulate the controlled system and plot the results.

Estimated Time to Complete

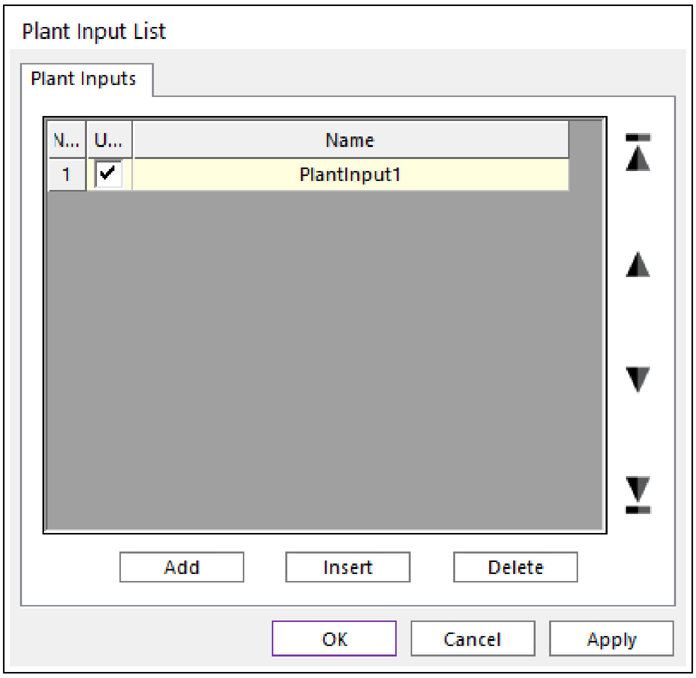
15 minutes

Creating the Plant Input

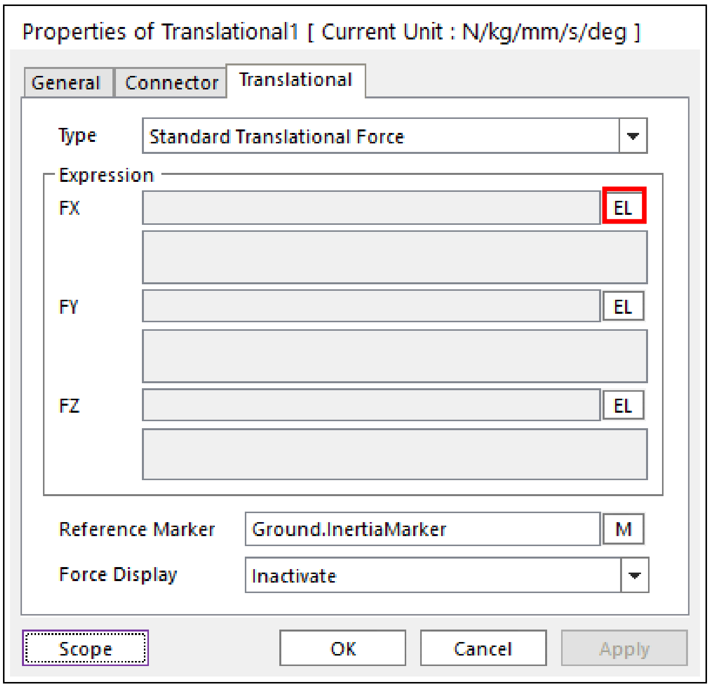
You will first create an input to the model from the control system. This entity will be created as a placeholder that you will then go back and define later.

To create the Plant Input:

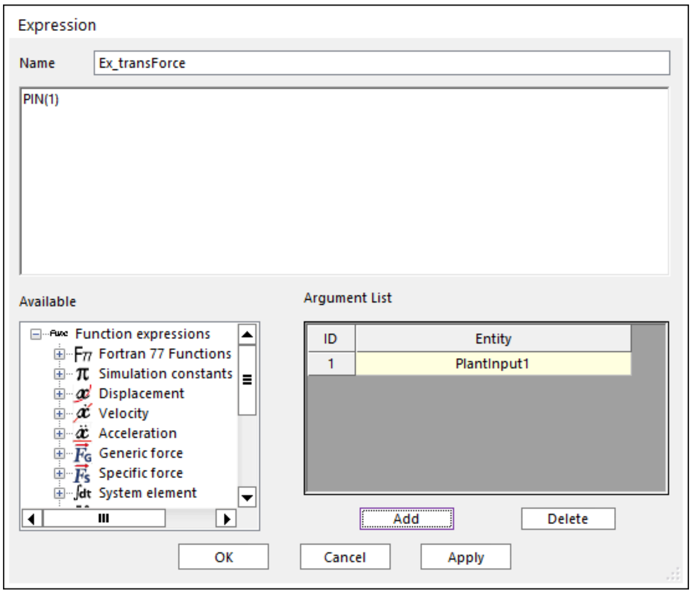
1. From the **Colink** group in the **Colink** tab, click the **Plant Input**.
2. Click **Add**.
3. Click **OK**.



4. In the **Database window**, right-click on the **Translational1** force and select **Properties**.
5. Click on the **EL** button to the right of **FX**, to define a driving force in the **X** direction.



6. In the Expression List dialog, click on the **Create** button.
7. Enter **Ex_transForce** as the expression **Name**.
8. Enter **PIN(1)** as the expression.
9. In the **Argument List**, click **Add**.
10. From the **Database window**, drag **PlantInput1** to the first entity of the **Argument List** as shown in the figure on the right.
11. Click **OK** three times to accept all changes.

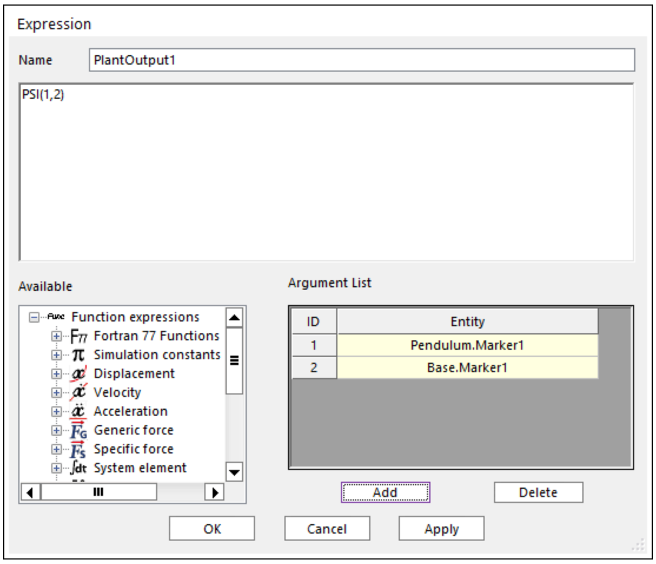


Creating the Plant Outputs

You will now create an output from the model to the control system. This output will be the pendulum angle, as measured from vertical.

To create the plant outputs:

1. Click **Plant Output** of the **Colink** group in the **Colink** tab.
2. In the Plant Output List dialog box, click **Add**.
3. Enter **PSI(1, 2)** as the expression. This expression refers to the PSI angle of the Euler angles to define the rotation between the **Pendulum** and the **Base**.
4. Add two entities to the **Argument List** and enter the markers that define the Revolute1 joint. Enter the Pendulum marker first, as shown at right.
5. Click **OK** twice to accept the changes.



Creating the CoLink Model

You will now open CoLink and create the control system. This will involve creating the block diagram from scratch. Blocks will be created to represent the RecurDyn model, gains for a standard P controller, and a scope output.

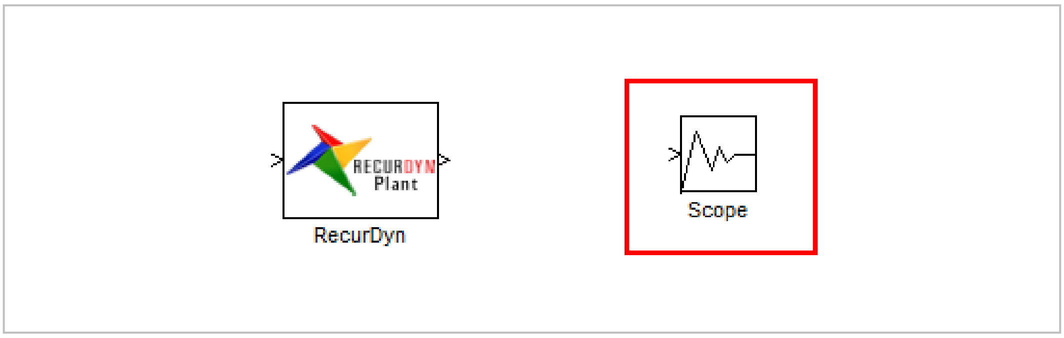
To create the CoLink model:

1. From the **Colink** group in the **Colink** tab, click the **Run CoLink**.

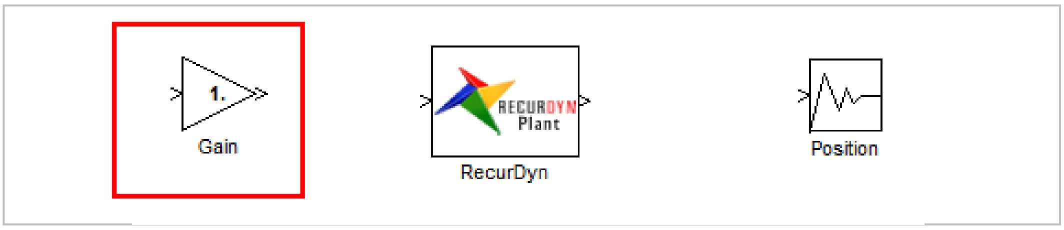
   CoLink opens with an empty model.

2. From the **Link** group in the **Connector** tab, click the **RecurDyn** block and then, click into the working window and place it about two thirds of the way to the right as shown below.

3. From the **Output** group in the **General** tab, click the **Scope** block and then, click into the working window and place it to the right of the **RecurDyn** block, as shown highlighted in the figure below.

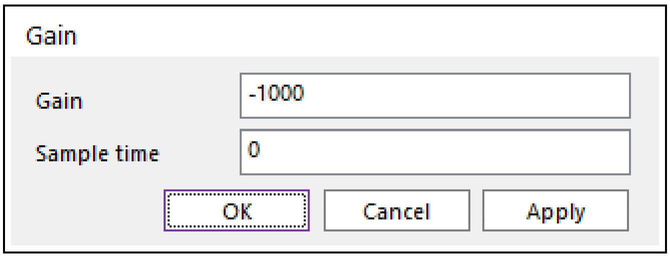


4. Double-click on the text below the **scope** block and change the name to **Position**.
5. From the **Math** group in the **Math** tab, click the **Gain** block and then, click into the working window and place it to the left of the **RecurDyn** block, as shown highlighted in the figure below.

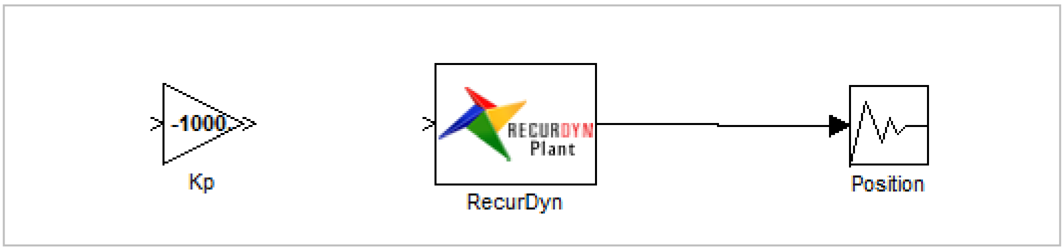


6. Change the name of the **Gain** block to **Kp** by clicking on the name. The vertical text bar will appear.

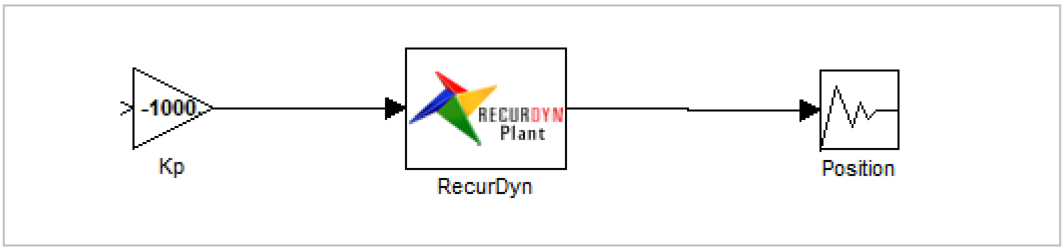
7. Double-click on the **Gain** block to edit the gain value.
8. Change the Gain to **-1000**.
9. Click **OK**.



10. To connect the RecurDyn block to the Position block, as shown below, click the **RecurDyn** block and hold down **Ctrl** key and click the **Position** block. Otherly, click the arrow on the right of the **RecurDyn** block and drag the cursor to the arrow on the left of the **Position** block, and then release the mouse button.



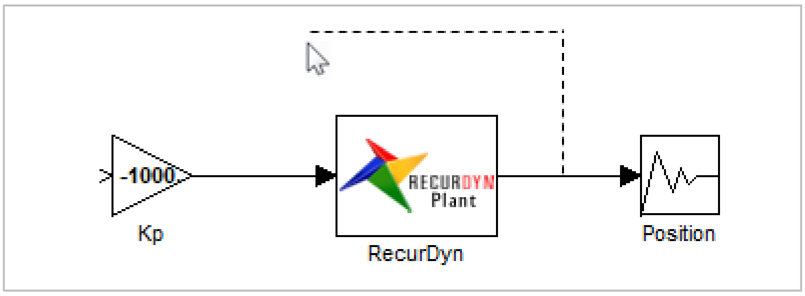
11. Connect the **Kp** block to the **RecurDyn** block.



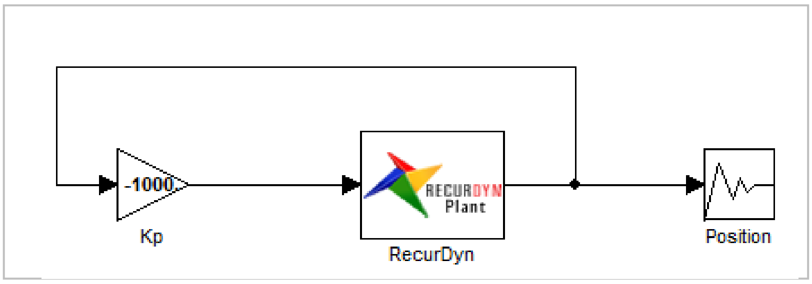
You are now ready to add a proportional control feedback loop that will connect the Position output to the **Kp** gain block.

To add a proportional control feedback loop:

1. **Right-click** on the line connecting the **RecurDyn** block to the **Position Scope** and Drag-Drop to the input of the **Kp** block.



2. This creates a junction at the point where you first right-clicked. You may need to click on the long horizontal line and drag it up so that it is clear of the other graphics.



Save the control system:

1. From the CoLink **Quick Access Toolbar**, select **Save**.
2. Save the CoLink file in the same directory as the RecurDyn model, with the name **Pendulum_P.clk**.

Simulating the CoLink Model

You will now simulate the **RecurDyn** model with the proportional control system you just created in **CoLink**.

To simulate the model with the control system:

1. The **CoLink** window does not have a status window. Therefore, before running the simulation you should adjust the location of the **CoLink** and **RecurDyn** windows such that you can see the RecurDyn Output window.
2. From the **CoLink Quick Access Toolbar**, select **Show Simulation Toolbar** button.

3. From the Simulation toolbar, change the simulation end time to **5** seconds, and then change the **Type** to **RecurDyn** and change the **Solver** to **RecurDynSolver**.

4. Press the **Start** button. You should be able to see run status in the RecurDyn Output window.

Tip: What if the co-simulation does not run?
If the co-simulation does not run, a Server **Busy** dialog box may appear. If the dialog box appears:

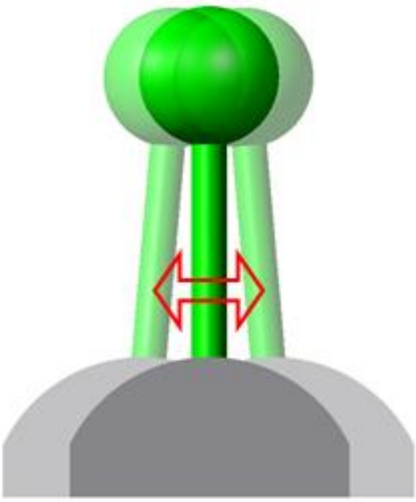
- Click Switch to and review the message in the RecurDyn Output window.

If the error message is that the **CoLink** model could not be found, review the locations of your RecurDyn and **CoLink** models. Make sure that both models are located in the same directory. If not, place both models in the same directory and restart both RecurDyn and **CoLink**. The simulation should now proceed properly.

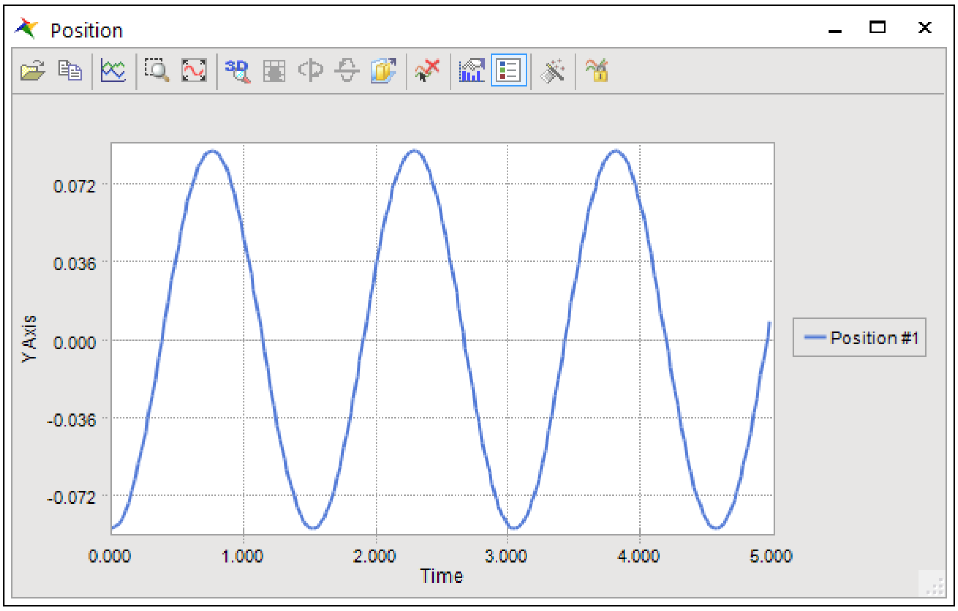
To view the results:

1. Return to the RecurDyn window and press the **Play** button.

   You should see that the pendulum is now kept upright by the control system, oscillating from side to side.



2. Return to the **CoLink** window and double-click on the **Position** scope. You should see a plot of the pendulum's angular position, as shown at right.



Although the pendulum is kept upright, the plot shows that it oscillates with amplitude that shows little attenuation with time. To remedy this, we will add derivative control in the next chapter.

Chapter
4

Adding Derivative Control

Task Objective

In this chapter, you will modify the **CoLink** model to include derivative control, thereby creating a Proportional-Derivative (**PD**) control system. You will then simulate the system and observe the results.

Estimated Time to Complete

10 minutes

Modifying the RecurDyn Model

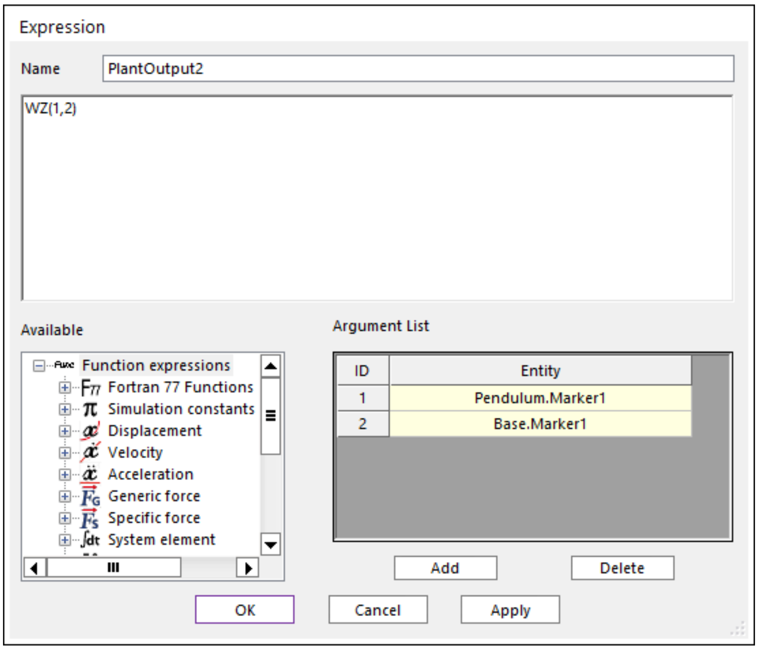
In order to add derivative control, you will first save the RecurDyn model to a different filename, and then modify it to output both pendulum position and velocity (the derivative of position) to the control system.

To save the model under a different name:

1. Return to the RecurDyn window.
2. From the **File** menu, select **Save As**.
3. Save the file as **Pendulum_PD.rdyn**.

To add a plant output for the rotational velocity of the pendulum:

1. From the **Database window**, Right-click on **PlantOutput1** and Select **Properties** to bring up the Plant Output List dialog.
2. Click the **Add** button.
3. Enter **WZ(1, 2)** for the expression.
4. Add the same two markers as before to the **Argument List**, as shown at right.
5. Click **OK** twice to accept the changes.



Adding Derivative Control

You will first save the CoLink model to a different filename, and then modify it to include another feedback loop which will handle derivative control.

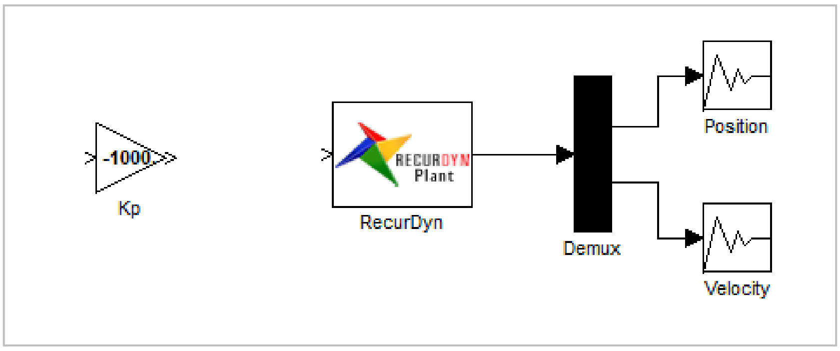
To save the control system under a different name:

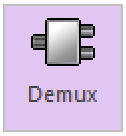
1. Return to the CoLink window.
2. From the **File** menu, select **Save As**.
3. Save the file as **Pendulum_PD.clk**.

To add derivative control:

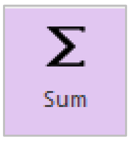
1. Delete all of the connections between the blocks by selecting them and then pressing the **Delete** key.

   Use the figure to guide you through the next steps:



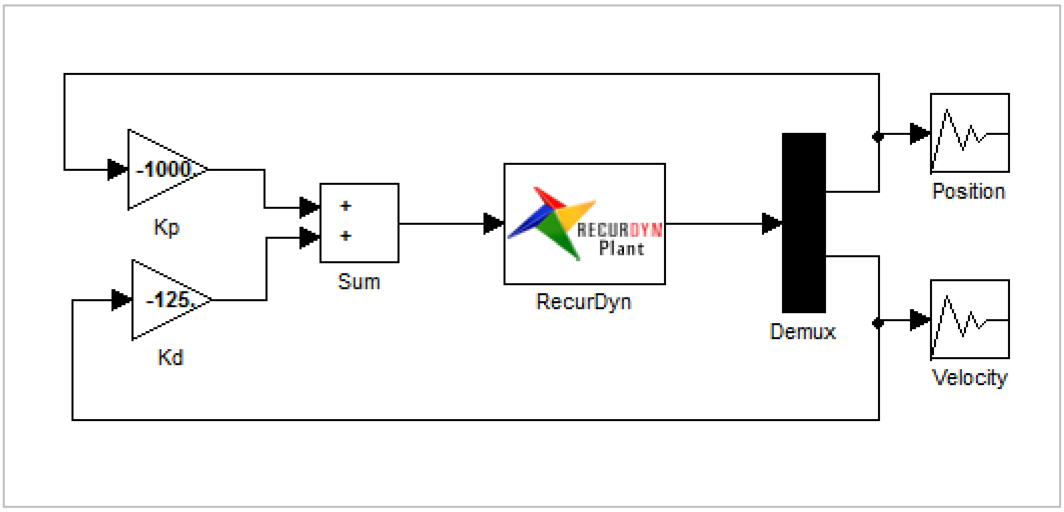


2. From the **Connector** group in the **Connector** tab, click the **Demux** block and then, click into the working window. Place it between the **RecurDyn** block and the **Position** scope.
3. Add another Scope (Output) below the **Position** scope.
   - Rename the scope to Velocity.
4. Make connections between the **RecurDyn** plant, the **Demux** block, and the **Position** and **Velocity** scopes according to the diagram.
5. Add another gain block below the **Kp** gain block, as shown below.
   - Rename the new gain block Kd.
   - Change the gain value to -125.



6. From the **Math** group in the **Math** tab, click the **Sum** block and then, click into the working window. Place it between the **Kp** gain block and the **RecurDyn** plant.

7. Make connections between the gain blocks, the sum block, and the **RecurDyn** plant according to the diagram below.



8. Press the Start button. You should be able to see run status in the RecurDyn Output window.
9. Save the control system.

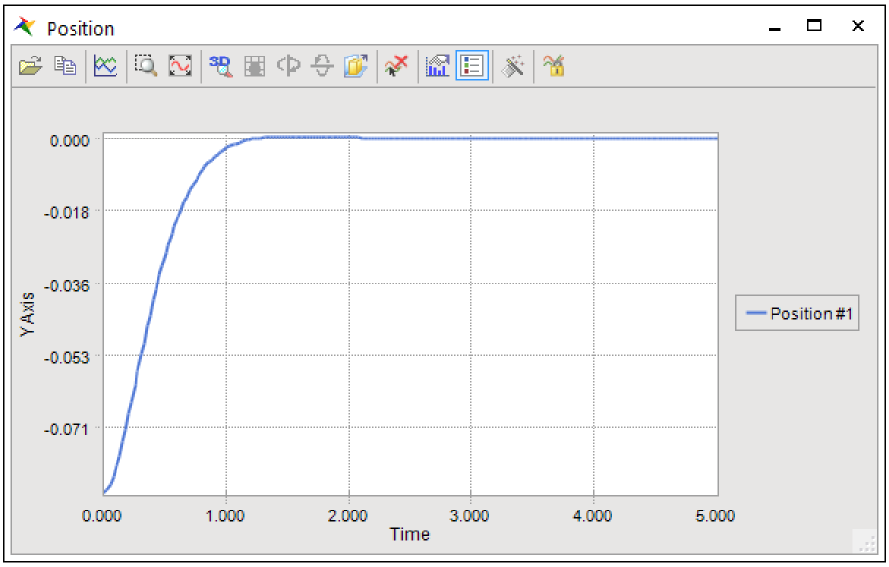
Simulating the Model with Derivative Control

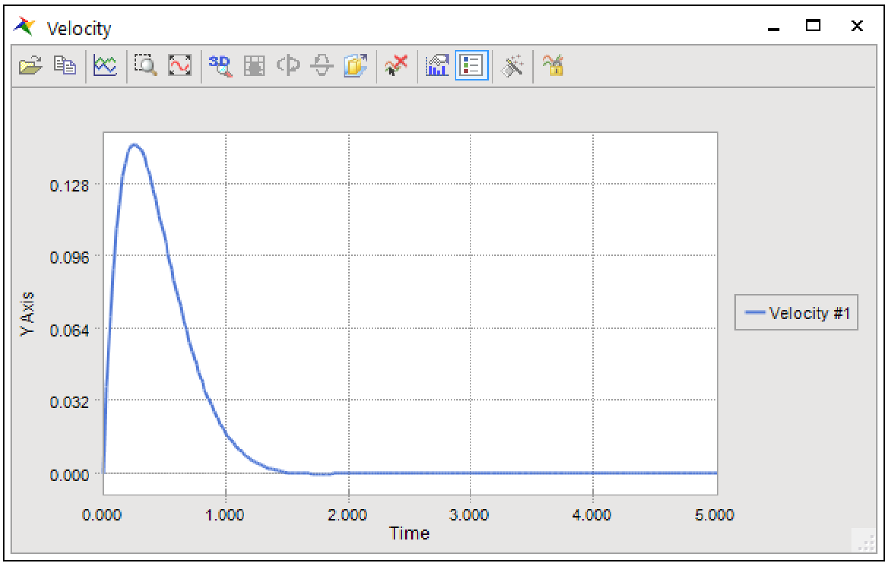
Simulate the model as before.

Tip: What if the Run arrow is grayed out?
On rare occasions the CoLink Run arrow stays grayed out. If that happens, simply save the CoLink model, close CoLink, restart CoLink and reload the model.

To view the results:

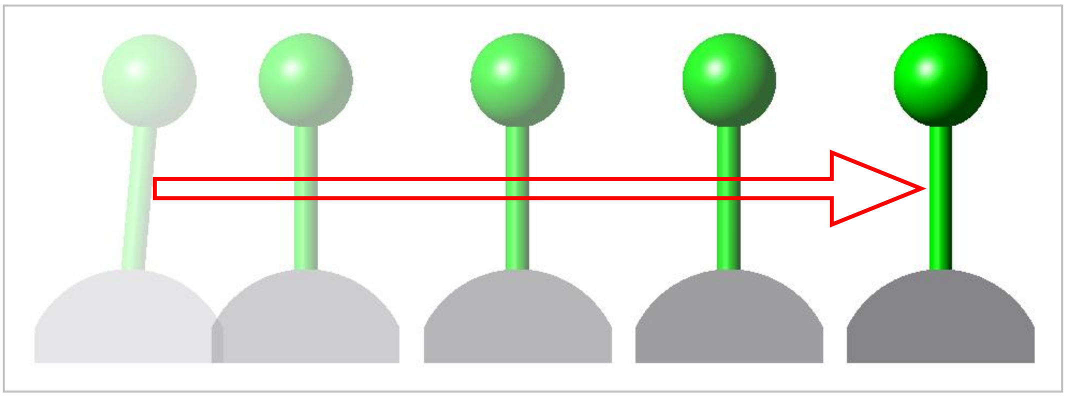
1. Double-click on the Position and Velocity scopes. You should see the following results:





It appears that the results are much better, as both the angular position and velocity of the pendulum now converge to zero, instead of oscillating.

2. Return to the RecurDyn window.
3. Play the animation.



The animation shows that while the pendulum indeed stays upright, the entire system drifts off to the right. To reduce the drifting, you will add integral control in the next chapter.

Chapter

5

Adding Integral Control

Task Objective

In this chapter, you will modify the **CoLink** model to include integral control, thereby creating a Proportional-Integral-Derivative (PID) control system. You will then simulate the system and observe the results.

Estimated Time to Complete

5 minutes

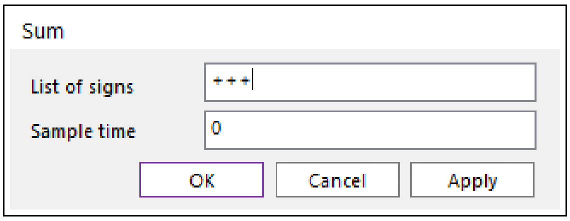
Adding Integral Control

You will first save the CoLink model to a different filename, and then modify it to include another feedback loop which will handle integral control.

To save the control system under a different name:

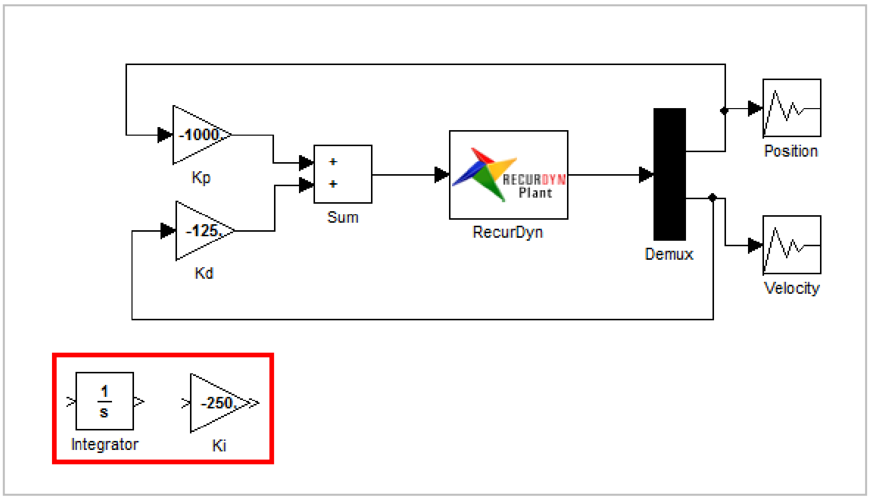
1. From the CoLink **File** menu, select **Save As**.
2. Save the file as **Pendulum_PID.clk**.

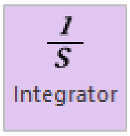
To add derivative control:



1. Double-click on the **Sum** block.
2. Enter **+++** for the List of signs. This will increase the number of inputs to the Sum block to three.
3. Click **OK**.

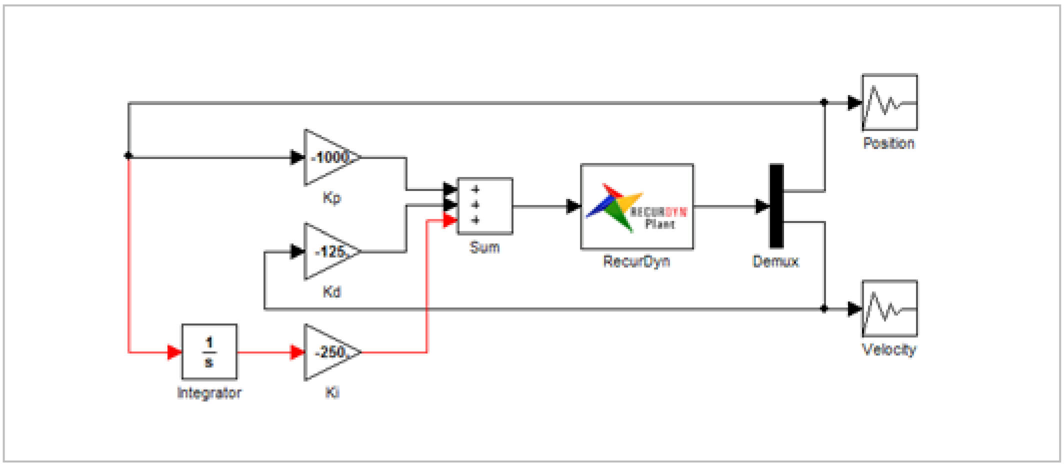
   Use the figure below to guide you through the next steps:





4. From the **Continuous** group in the **Continuous and Discrete** tab, click the **Integrator** block and then, click into the working window. Place it below and to the left of the **Kd** gain block.
5. Place another gain block in the model, below the **Kd** gain block.
   - Name the gain block **Ki**.
   - Change the gain value to **-250**.

6. Make the three connections shown below in red.



7. Press the Start button. You should be able to see run status in the RecurDyn Output window.

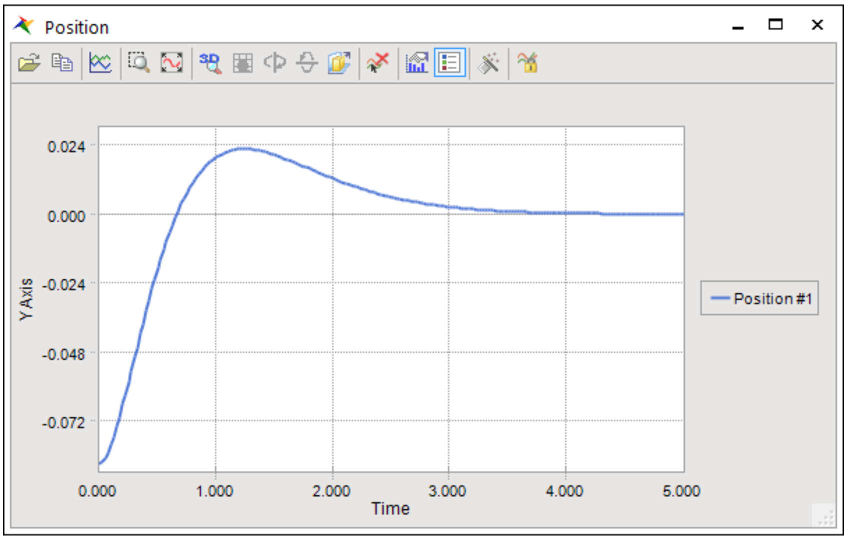
8. Save the control system.

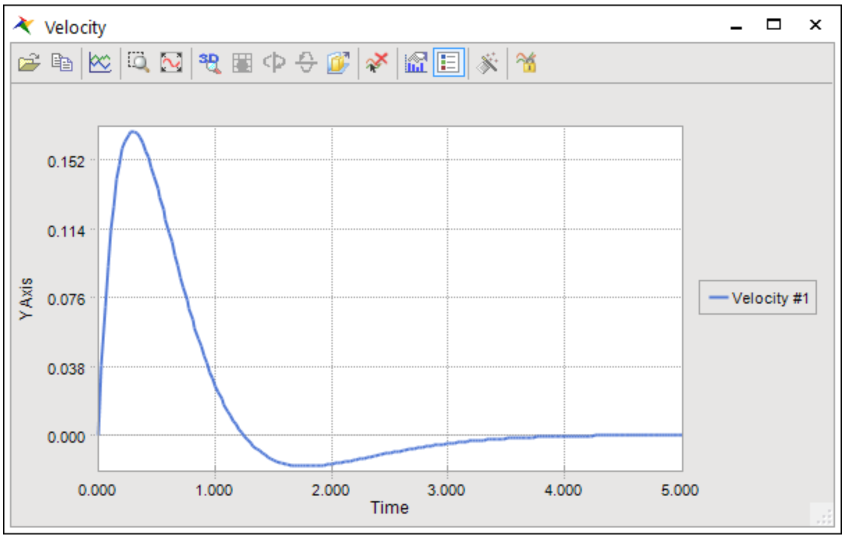
Simulating the Model with PID Control

Simulate the model as before.

To view the results:

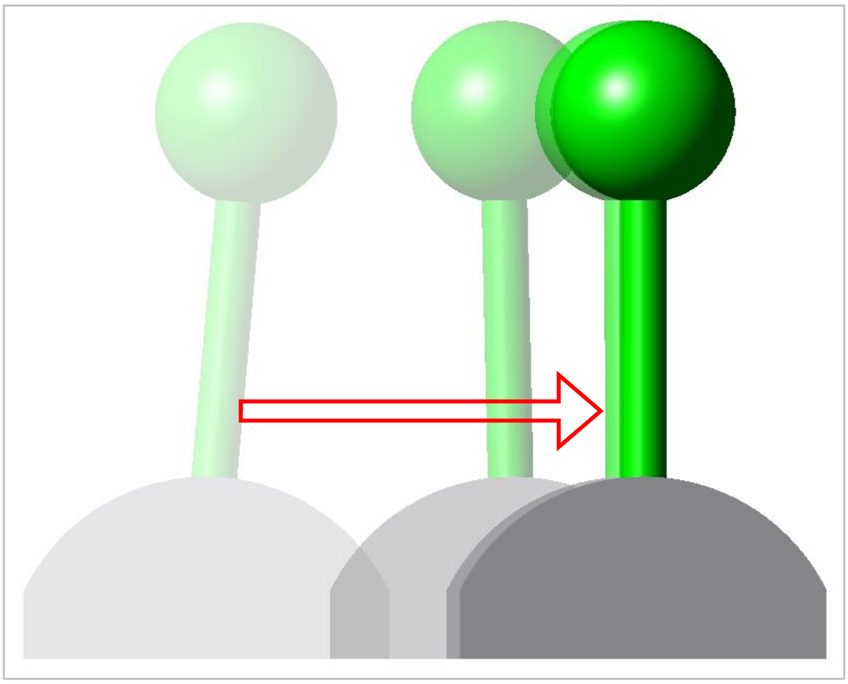
1. Double-click on the Position and Velocity scopes. You should see the following reslts:





There is now some overshoot in the positional response as it converges to zero.

2. Return to the RecurDyn window.
3. Play the animation.



The animation now shows that the pendulum stays upright, and the base comes to a near stop instead of sliding away as before. Therefore, with the addition of more types of control feedback loops, the control system becomes more adept at stabilizing the system.

Thanks for participating in this tutorial!