# Altair MotionView 2019 Tutorials

MV-1025: Modeling Point-to-Curve (PTCV) Higher-Pair Constraint

MV-1025: Modeling Point-to-Curve (PTCV) Higher-Pair Constraint

In this tutorial, you will learn how to:

- Model a PTCV (point-to-curve) joint

A PTCV (point-to-curve) joint is a higher pair constraint. This constraint restricts a specified point on a body to move along a specified curve on another body. The curve may be open or closed, planar or in 3-d space. The point may belong to a rigid, flexible or point body. This constraint can help avoid modeling contact in some systems. It may prove advantageous since proper contact modeling (refer tutorial MV-1010) in many cases involves fine-tuning of contact parameters. One good example for such a system is a knife-edge cam follower mechanism. One can avoid modeling the contact between the cam and follower by defining a PTCV joint: the curve being the cam profile and the point being the tip of the follower.
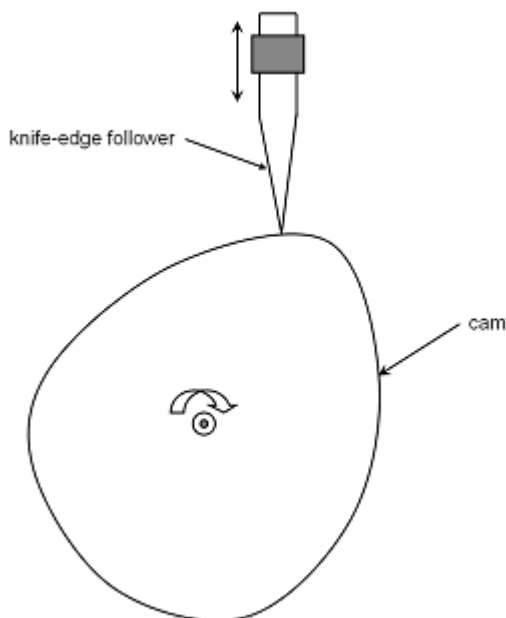
A Knife-edge Cam Follower Mechanism

In this tutorial, we will model a knife-edge cam follower mechanism with the help of a PTCV joint.

Exercise

Copy all the files from the `mbd_modeling\interactive` folder to your `<Working directory>`.

Step 1: Creating Points.

Let's start with creating points that will help us locate the bodies and joints as required. We will define points for center of mass of the bodies and joint locations.

1. Start a new MotionView Session. We will work with the default units (kg, mm, s, N).

2. From the **Project Browser** right-click on *Model* and select *Add Reference Entity > Point* (or right-click the *Points* icon ⬤ on the **Model-Reference** toolbar).

    The **Add Point or PointPair** dialog is displayed.

3. For **Label**, enter `PivotPoint`.

4. Accept the default **Variable** name and click *OK*.

5. Click on the **Properties** tab and specify the coordinates as **X** = 0.0 , **Y** = 0.0, and **Z** = 0.0.

6. Follow the same procedure and create the points specified in the following table:

Point	X	Y	Z
FollowerCM	0.0	65.557	0.0
FollowerPoint	0.0	25.0	0.0
FollowerJoint	0.0	85.0	0.0
CamCM	0.0	-14.1604	0.0

Step 2: Creating Bodies.

We will have two bodies apart from the ground body in our model visualization; the cam and the follower. Pre-specified inertia properties will be used to define the bodies.

1. From the **Project Browser** right-click on *Model* and select *Add Reference Entity > Body* (or right-click the *Body* icon ⊕ on the **Model-Reference** toolbar).

    The **Add Body or BodyPair** dialog is displayed.

2. For **Label**, enter `Cam` and click *OK*.

3. From the **Project Browser** right-click on *Model* and select *Add Reference Entity > Body* (or right-click the *Body* icon ⊕ on the **Model-Reference** toolbar).

    The **Add Body or BodyPair** dialog is displayed.

4. For **Label**, enter `Follower` and click *OK*.

5. From the **Properties** tab, specify the following for the two bodies:

Body	Mass	Ixx	Iyy	Izz	Ixy	Iyz	Izx
Cam	0.174526	60.3623	63.699	123.276	0.0	0.0	0.0
Follower	0.0228149	7.10381	0.219116	7.22026	0.0	0.0	0.0

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6. For the **Cam** body, under the **CM Coordinates** tab, check the ***Use center of mass coordinate system*** box.

7. Double click on ***Point***.

   The **Select a Point** dialog is displayed. Choose ***CamCM*** and click ***OK***.

8. Accept defaults for axes orientation properties.

9. For the **Follower** body, under the **CM Coordinates** tab, check the ***Use CM Coordsys*** box.

10. Double click on ***Point***.

    The **Select a Point** dialog is displayed. Choose ***FollowerCM*** and click ***OK***.

11. Accept defaults for axes orientation properties.

Step 3: Creating Joints.

Here, we will define all the necessary joints except the PTCV joint which will be defined as an advanced joint later. We require two joints for the model. The first of them is the revolute joint between the cam and ground body. The second joint we need is a translational joint between the follower and ground body.

1. From the **Project Browser** right-click on ***Model*** and select ***Add Constraint > Joint*** (or right-click the ***Joints*** icon on the **Model-Constraint** toolbar).

   The **Add Joint or JointPair** dialog is displayed.

2. For **Label**, enter `CamPivot`.

3. Select ***Revolute Joint*** as the **Type** and click ***OK***.

4. From the **Connectivity** tab, double-click on ***Body 1***.

   The **Select a Body** dialog is displayed. Choose ***Cam*** and click ***OK***.

5. From the **Connectivity** tab, double-click on ***Body 2***.

   The **Select a Body** dialog is displayed. Choose ***Ground Body*** and click ***OK***.

6. From the **Connectivity** tab, double-click on ***Point***.

   The **Select a Point** dialog is displayed. Choose ***PivotPoint*** and click ***OK***.

7. For **Axis** click on the arrow and choose ***Vector***. Now click on ***Vector***.

   The **Select a Vector** dialog is displayed. Choose ***Global Z*** and click ***OK***.

8. From the **Project Browser** right-click on ***Model*** and select ***Add Constraint > Joint*** (or right-click the ***Joints*** icon on the **Model-Constraint** toolbar).

   The **Add Joint or JointPair** dialog is displayed.

9. For **Label**, enter `FollowerJoint`.

10. Select ***Translational Joint*** as the **Type** and click ***OK***.

11. From the **Connectivity** tab, double-click on ***Body 1***.

    The **Select a Body** dialog is displayed. Choose ***Follower*** and click ***OK***.

12. From the **Connectivity** tab, double-click on ***Body 2***.

    The **Select a Body** dialog is displayed. Choose ***Ground Body*** and click ***OK***.

13. From the **Connectivity** tab, double-click on ***Point***.

    The **Select a Point** dialog is displayed. Choose ***FollowerJoint*** and click ***OK***.

14. For **Axis** click on the arrow and choose ***Vector***. Now click on ***Vector***.

    The **Select a Vector** dialog is displayed. Choose ***Global Y*** and click ***OK***.


Step 4: Creating Markers.

Now, we will define some markers required for the definition of the PTCV joint. We need two markers, one associated with the cam (for the curve) and the other associated with the follower (for the point).

1. From the **Project Browser** right-click on ***Model*** and select ***Add Reference Entity > Marker*** (or right-click the ***Markers*** icon ⅄ on the **Model-Reference** toolbar).

   The **Add Marker or MarkerPair** dialog is displayed.

2. For **Label**, enter `CamMarker` and click ***OK***.

3. From the **Properties** tab, double-click on ***Body***.

4. The **Select a Body** dialog is displayed. Choose ***Cam*** and click ***OK***.

5. From the **Properties** tab, double-click on ***Point***.

6. The **Select a Point** dialog is displayed. Choose ***PivotPoint*** and click ***OK***.

7. Accept the defaults for axes orientation.

8. Add another marker by right-clicking on ***Model*** in the **Project Browser** and selecting ***Add Reference Entity > Marker*** (or right-click the ***Markers*** icon ⅄ on the **Model-Reference** toolbar).

   The **Add Marker or MarkerPair** dialog is displayed.

9. For **Label**, enter `FollowerMarker` and click ***OK***.

10. From the **Properties** tab, double-click on ***Body***.

11. The **Select a Body** dialog is displayed. Choose ***Follower*** and click ***OK***.

12. From the **Properties** tab, double-click on ***Point***.

13. The **Select a Point** dialog is displayed. Choose ***FollowerPoint*** and click ***OK***.

14. Accept the defaults for axes orientation.

Step 5: Creating Graphics.

Graphics for the cam and follower have been provided as h3d files. We need to associate the h3ds with bodies defined in our model. To make visualization better, we will also create some graphics for the joints.

1. From the **Project Browser** right-click on **Model** and select **Add Reference Entity > Graphic** (or right-click the **Graphics** icon on the **Model-Reference** toolbar).

   The **Add Graphics or GraphicPair** dialog is displayed.

2. For **Label**, enter `Cam`.

3. Choose **File** from the drop-down menu.

4. Click on the file browser icon and select `CamProfile.h3d` from the model folder.

5. Click **Open** and then **OK**.

6. From the **Connectivity** tab, double-click on **Body**.

   The **Select a Body** dialog gets displayed. Choose **Cam** and click **OK**.

7. Add another graphic by right-clicking on **Model** in the **Project Browser** and selecting **Add Reference Entity > Graphics** (or right-click the **Graphics** icon on the **Model-Reference** toolbar).

   The **Add Graphics or GraphicPair** dialog is displayed.

8. For **Label**, enter `Follower`.

9. Choose **File** from the drop-down menu and click **OK**.

10. Click on the browser icon and select `FollowerProfile.h3d` from the model folder.

11. Click **Open**.

12. Under the **Connectivity** tab, double-click on **Body**.

    The **Select a Body** dialog gets displayed. Choose **Follower** and click **OK**.

Next, we will add some joint graphics for better visualization and aesthetics.

1. From the **Project Browser** right-click on **Model** and select **Add Reference Entity > Graphic** (or right-click the **Graphics** icon on the **Model-Reference** toolbar).
   The **Add Graphics or GraphicPair** dialog is displayed.

2. For **Label**, enter `PivotGraphicOne` (the first graphic to show the cam pivot).

3. Choose **Cylinder** from the drop-down menu and click **OK**.

4. From the **Connectivity** tab, double-click on *Body*.

    The **Select a Body** dialog gets displayed. Choose *Ground Body* and click *OK*.

5. Double click on *Point*.

    The **Select a Point** dialog is displayed. Choose *PivotPoint* and click *OK*.

6. Click on the arrow below **Direction** and select the *Vector* option.

7. Click on *Vector*.

   The **Select a Vector** dialog is displayed. Choose *Global Z* and click *OK*.

8. From the **Properties** tab, specify the following values:

Property	Value
Length	7.5
Offset	-3.75
Radius 1	4.000
Radius 2	4.000

9. For the **Cap** properties, choose *Cap Both Ends*.

10. Add another graphic by right-clicking on *Model* in the **Project Browser** and selecting *Add Reference Entity > Graphics* (or right-click the *Graphics* icon 🌐 on the **Model-Reference** toolbar).

    The **Add Graphics or GraphicPair** dialog is displayed.

11. For **Label**, enter `PivotGraphicTwo` (the second graphic to show the cam pivot).

12. Choose *Cylinder* from the drop-down menu and click *OK*.

13. Under the **Connectivity** tab, double-click on *Body*.

    The **Select a Body** dialog gets displayed. Choose *Cam* and click *OK*.

14. Double click on *Point*.

    The **Select a Point** dialog is displayed. Choose *PivotPoint* and click *OK*.

15. Click on the arrow below **Direction** and select the *Vector* option.

16. Click on *Vector*.

    The **Select a Vector** dialog is displayed. Choose *Global Z* and click *OK*.

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17. From the **Properties** tab, specify the following values:

Property	Value
Length	7.6
Offset	-3.8
Radius 1	2.000
Radius 2	2.000

18. For the **Cap** properties, choose *Cap Both Ends*.

19. Add another graphic by right-clicking on *Model* in the **Project Browser** and selecting *Add Reference Entity > Graphics* (or right-click the *Graphics* icon on the **Model-Reference** toolbar). *Add*.

    The **Add Graphics or GraphicPair** dialog is displayed.

20. For **Label**, enter `FollowerJointGraphic` (the graphic for the follower translational joint).

21. Choose *Box* from the drop-down menu and click *OK*.

22. From the **Connectivity** tab, double-click on *Body*.

    The **Select a Body** dialog gets displayed. Choose *Ground Body* and click *OK*.

23. For **Type**, choose *Center* from the drop-down menu.

24. Double-click on *Point*.

    The **Select a Point** dialog gets displayed. Choose *FollowerJoint* and click *OK*.

25. For axis orientation, use the vector *Global Z* as the *Z-axis* and the vector *Global X*, to define the *ZX plane*.

26. From the **Properties** tab, specify the following properties:

Property	Value
Length X	15
Length Y	10
Length Z	10

At the end of this step, your model should look like the one shown in the figure below:
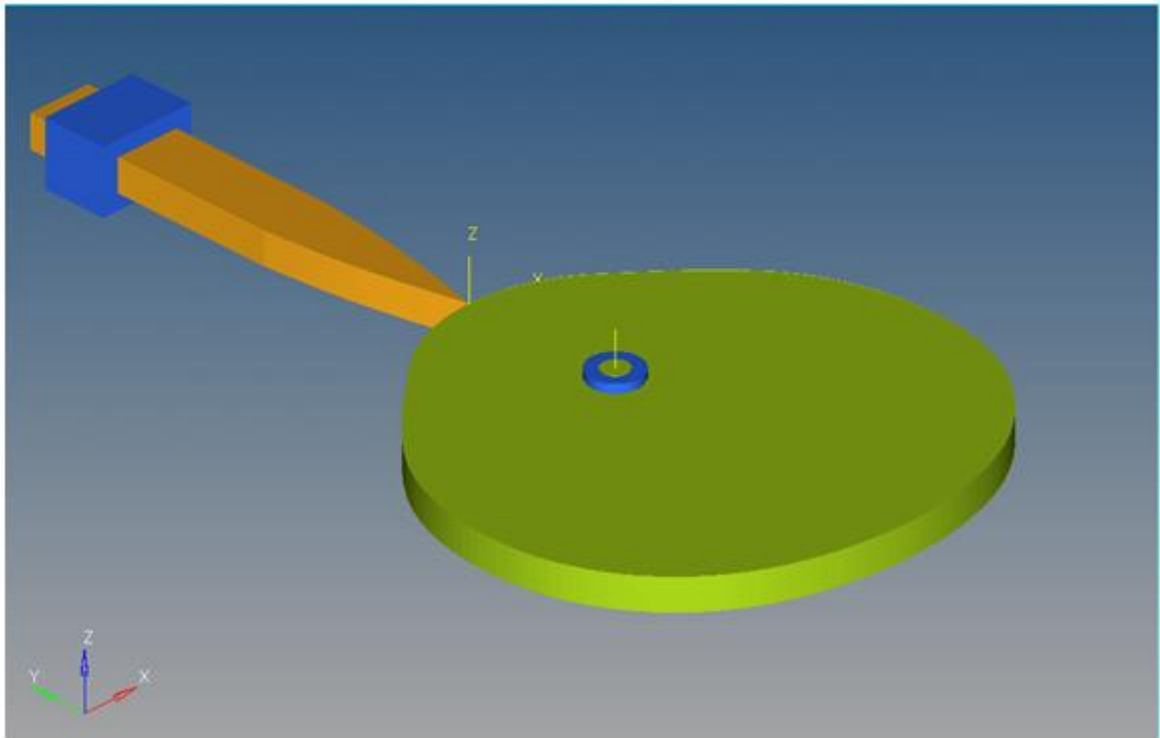
A Knife-edge Cam Follower Mechanism in MotionView

Step 6: Creating the Curve.

The curve that we will use here is the curve that defines the profile of the cam. The data for this curve has been provided in `.csv` format. We need to define the curve using the data in the given file.

1. From the **Project Browser** right-click on *Model* and select *Add Reference Entity > Curve* (or right-click the *Curves* icon ✝ on the **Model-Reference** toolbar).

   The **Add Curve** dialog is displayed.

2. For **Label**, enter `CamProfile` and click *OK*.

3. From the **Properties** tab, use the first drop-down menu to change the curve from *2D Cartesian* to *3D Cartesian*.

4. From the **Properties** tab, click on the *x* radio button.

5. Click on the file browser icon 📂 and select `CamProfile.csv`. Click *Open*.

6. Choose the properties of the curve as shown in the figure below:
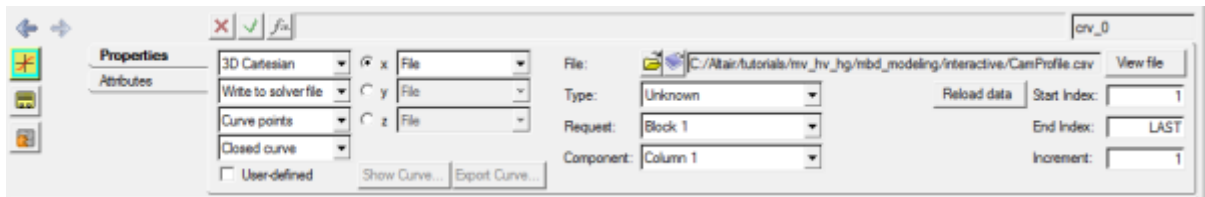
7. From the **Properties** tab, click on the **y** radio button.

8. Click on the file browser icon 📂 and select `CamProfile.csv`. Click **Open**.

9. Choose the properties of the curve as shown in the figure below:
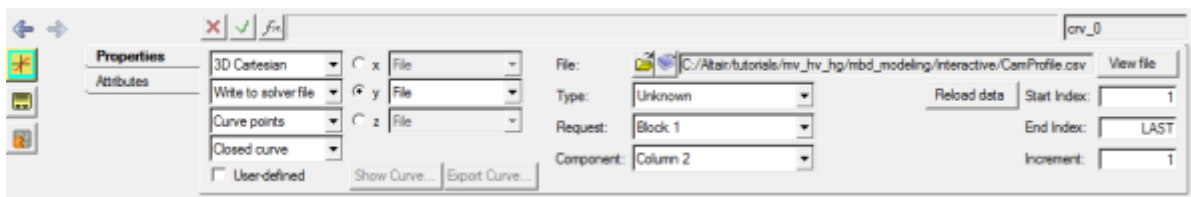
10. From the **Properties** tab, click on the **z** radio button.

11. Click on the file browser icon 📂 and select `CamProfile.csv`. Click **Open**.

12. Choose the properties of the curve as shown in the figure below:
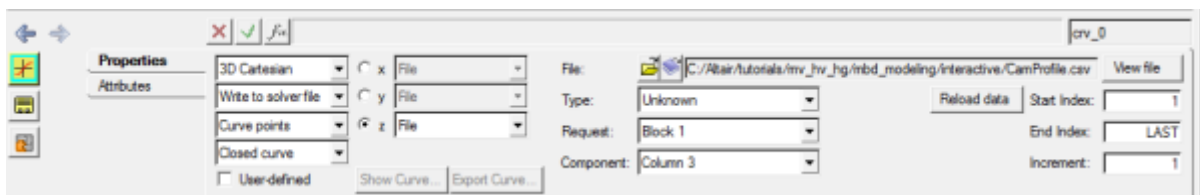
Notice the different column numbers used for **x**, **y**, and **z** properties.

13. From the **Properties** tab, use the fourth drop-down menu to set the curve type to **Closed Curve**.

Step 7: Creating the PTCV Joint.

Now, we will create the PTCV joint.

1. From the **Project Browser** right-click on **Model** and select **Add Constraint > Advanced Joint** (or right-click the **Advanced Joints** icon 🔘 on the **Model-Constraint** toolbar).

   The **Add AdvJoint** dialog is displayed.

2. For **Label**, enter `PTCV`.

3. Choose **PointToCurveJoint** from the drop-down menu and click **OK**.

4.   From the **Connectivity** tab, double-click on ***Body 1***.

   The **Select a Body** dialog gets displayed. Choose ***Follower*** and click ***OK***.

5.   From the **Connectivity** tab, double-click on ***Point***.

   The **Select a Point** dialog gets displayed. Choose ***FollowerPoint*** and click ***OK***.

6.   From the **Connectivity** tab, double-click on ***Curve***.

   The **Select a Curve** dialog gets displayed. Choose ***CamProfile*** and click ***OK***.

7.   From the **Connectivity** tab, double-click on ***Ref Marker***.

   The **Select a Marker** dialog gets displayed. Choose ***CamMarker*** and click ***OK***.

Step 8: Specifying the Cam Motion.

After we have the topology and constraints specified, we need to provide the cam motion. The most natural choice here is a uniform motion imposed on the revolute joint.

1.   From the **Project Browser** right-click on ***Model*** and select ***Add Constraint >*** ***Motions*** (or right-click the ***Motions*** icon 上~ on the **Model-Constraint** toolbar).

   The **Add Motion or MotionPair** dialog is displayed.

2.   For **Label**, enter `CamMotion` and click ***OK***.

3.   From the **Connectivity** tab, double-click on ***Joint***. Choose ***CamPivot*** and click ***OK***.

4.   From the **Properties** tab, specify the properties as `10*TIME`.
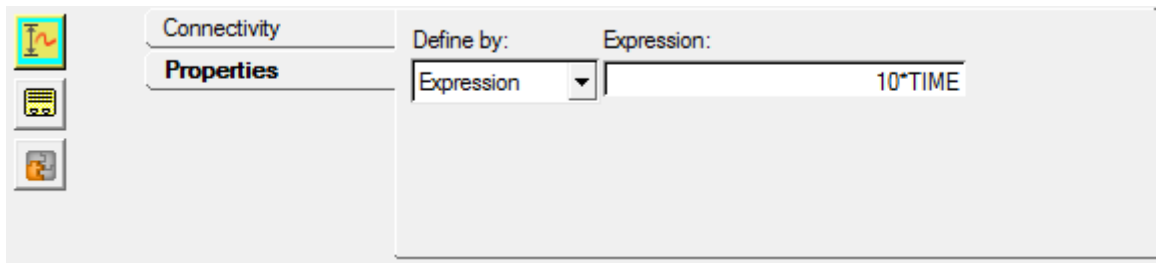
Step 9: Specifying Gravity.

Since our shaft is along the Y-axis, we want the gravity to be in the negative Y direction. To specify this:

1. Click the *Forms* icon ▦ on the **Model-General** toolbar.

    The **Forms** panel is displayed.

2. Select *Gravity* and specify the following values:

Direction	Value
X	0
Y	-9810
Z	0

Step 10: Specifying Output Requests.

We would like to monitor the reaction on PTCV joint since it can help us verify the correctness of our results. This will be discussed in detail towards the end of the tutorial when the topic of 'lift-offs' will be discussed.

1. From the **Project Browser** right-click on *Model* and select *Add General MDL Entity > Output* (or right-click the *Outputs* icon ⋙ on the **Model-General** toolbar).

    The **Add Output** dialog is displayed.

2. For **Label**, enter PTCV Reaction and click *OK*.

3. From the **Properties** tab, choose *Expressions* from the drop-down menu.

4. Click in the *F2* expression box.

5. Click on the $f*$ button.

    The **Expression Builder** dialog is displayed.

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6. Populate the expression as `'PTCV({aj_0.idstring},0,2,0)'`.
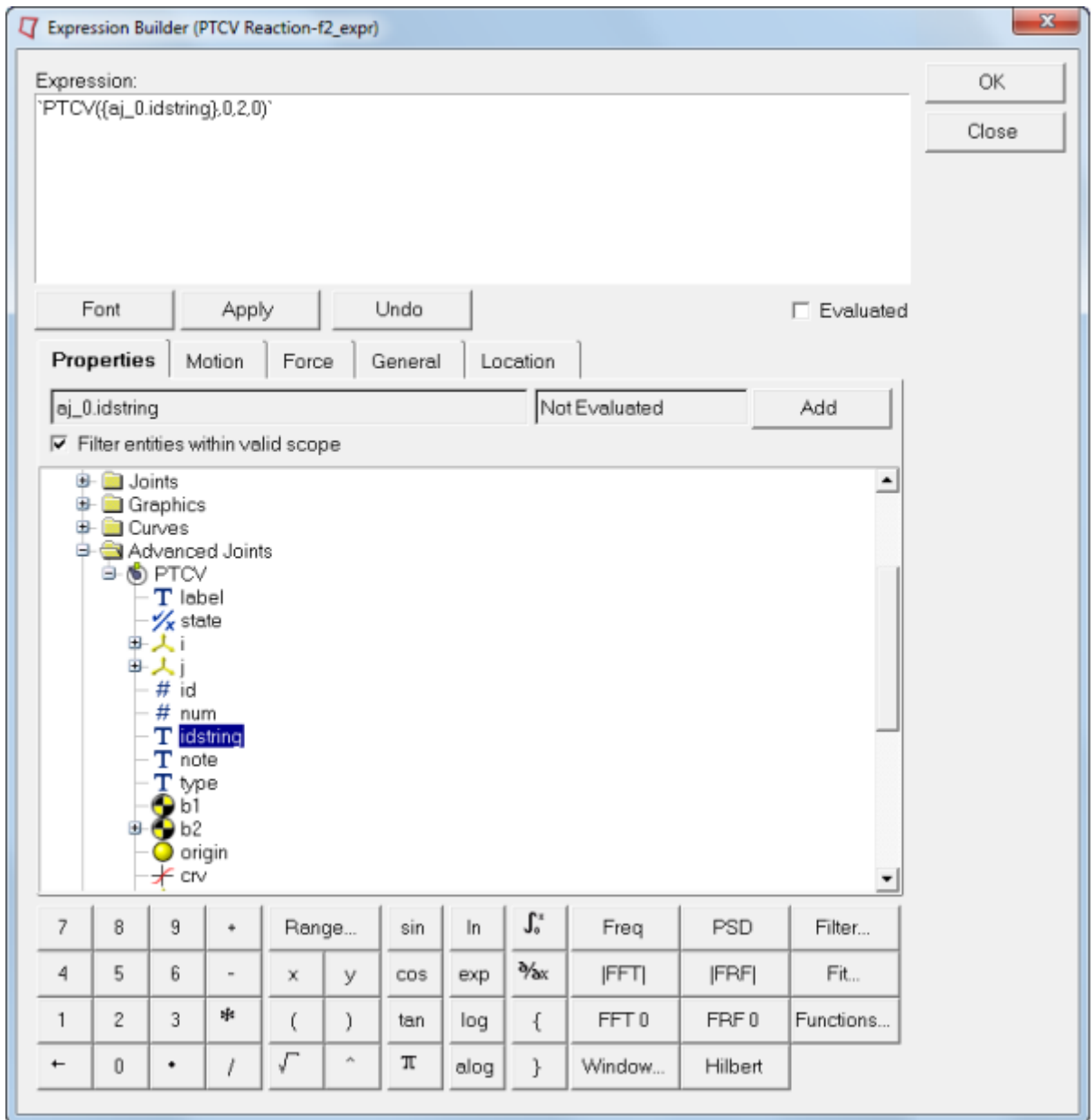
7. Click **OK**.

8. Repeat the process for **F3**, **F4**, **F6**, **F7**, and **F8** by changing the 3rd parameter to **3**, **4**, **6**, **7**, and **8** accordingly.

    The PTCV(`id`, `jflag`, `comp`, `ref_marker`) function returns the reaction on the PTCV joint:

`id`	ID of the PTCV joint
`jflag`	0 gives reaction on the I-marker and 1 on J-marker
`comp`	component of the reaction
`ref_marker`	reference marker (0 implies Global Frame)

Step 11: Running the Model.

We now have the model defined completely and it is ready to run.

1. Click the **Run** icon ![RUN] on the toolbar.

    The **Run** panel is displayed.

2. From the **Main** tab, specify values as shown below:
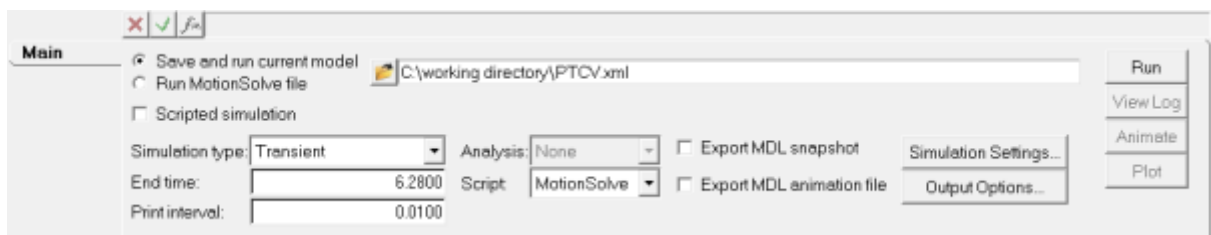
3. Choose the **Save and run current model** radio button.

4. Click on the browser icon 📂 and specify a file name of your choice.

5. Click **Save**.

6. Click **Check Model** button ![check] on the **Model Check** toolbar to check the model for errors.

7. To run the model, click the **Run** button on the panel.

   The solver will get invoked here.

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Step 12: Viewing the Results.

1. Once the solver has finished its job, the **Animate** button will be active. Click on
   Animate.

   The ▶ icon can be used to start the animation, and the ⏸ icon can be used to
   stop/pause the animation.

   One would also like to inspect the displacement profile of the follower in this
   mechanism. For this, we will plot the Y position of the center of mass of the follower.

2. Use the *Page Layout* drop-down menu ▢▾ on the **Page Controls** toolbar to
   select the three-window layout ▢.

3. Highlight the lower right window and use the **Select application** drop-down menu
   to change the application from *MotionView* 🌑 to *HyperGraph 2D* 📊.

4. Click the *Build Plots* 📖 icon on the **Curves** toolbar.

5. Click on the browser icon 📂 and load the `result.abf` file.

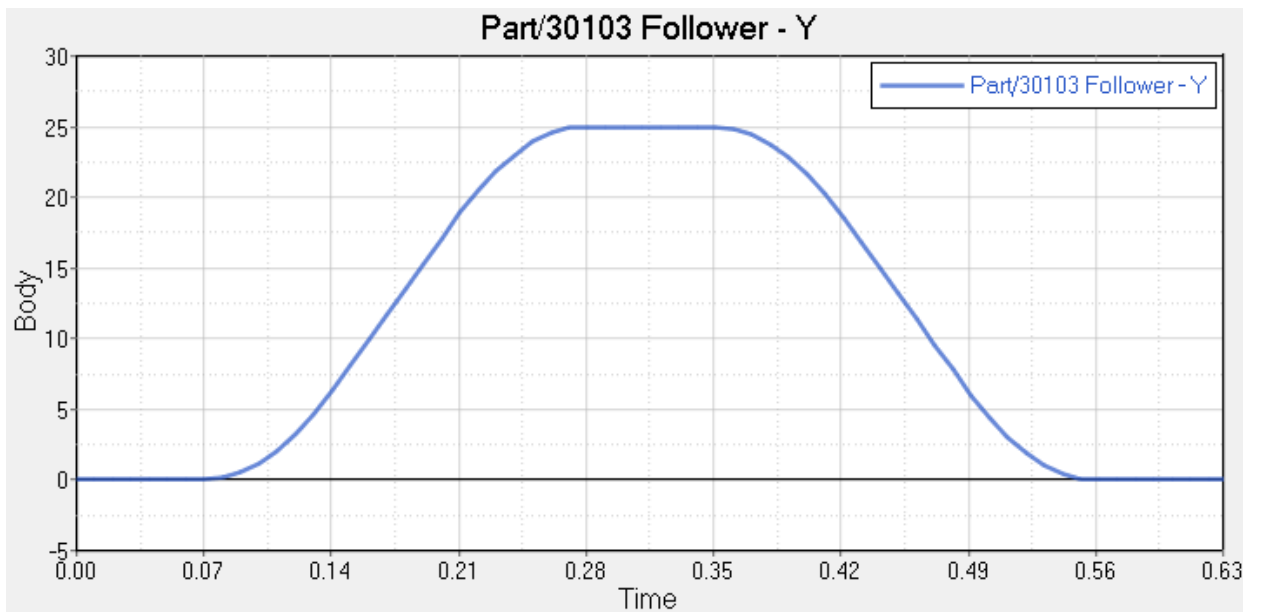6. Make selections for the plot as shown below:
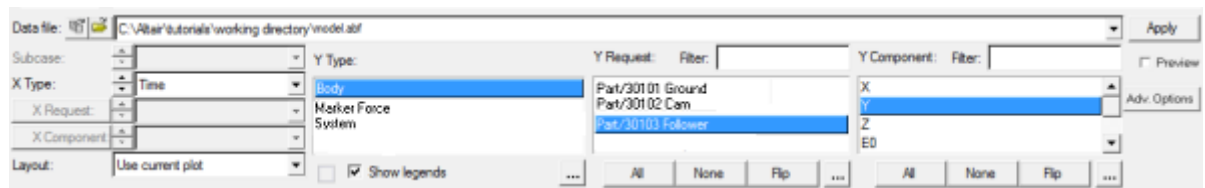
   We are plotting the Y profile of the center of mass of the follower.

7. Click *Apply*.

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8. The profile for the Y-displacement of the follower should look like the one shown below:
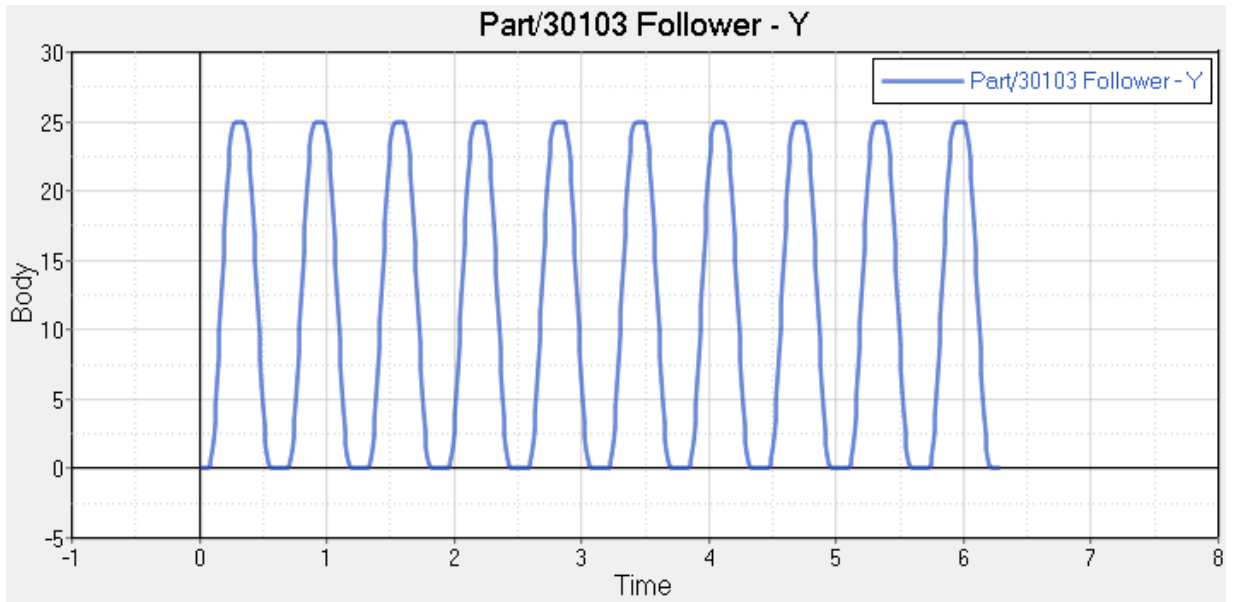
9. If we set the X-axis properties to zoom in on one cycle, the profile looks as shown below:


The profile of the cam has been designed to obtain the above Y-profile for the follower.

Now, we come to the discussion regarding 'lift-offs'. In some cases, the dynamics of the system may cause the follower to lose contact with the cam. This is called 'lift-off'. In such cases, modeling the system using a PTCV joint will give us incorrect results. This is because the PTCV joint constrains the follower point to be always on the curve and hence cannot model lift-offs. For such cases, contact modeling has to be used (refer tutorial MV-1010 for contact modeling). However, one would like to start with a PTCV model since modeling a PTCV joint is a lot easier than modeling contact. Given this scenario, the following modeling steps should be followed:

1. Model the system using a PTCV joint.

2. Monitor the PTCV joint reaction. If the reaction on the follower is a 'pulling' reaction, it means lift-off would have occurred and one needs to go for a contact model. Otherwise, the PTCV model is good enough.

    Now, let's check if our PTCV model is good enough. For this, we need to plot the reaction profile on the follower. Since the follower is moving along the Y-axis, any negative reaction along the Y-axis is a 'pulling' reaction. So, let's plot the Y-reaction on the follower. For this:
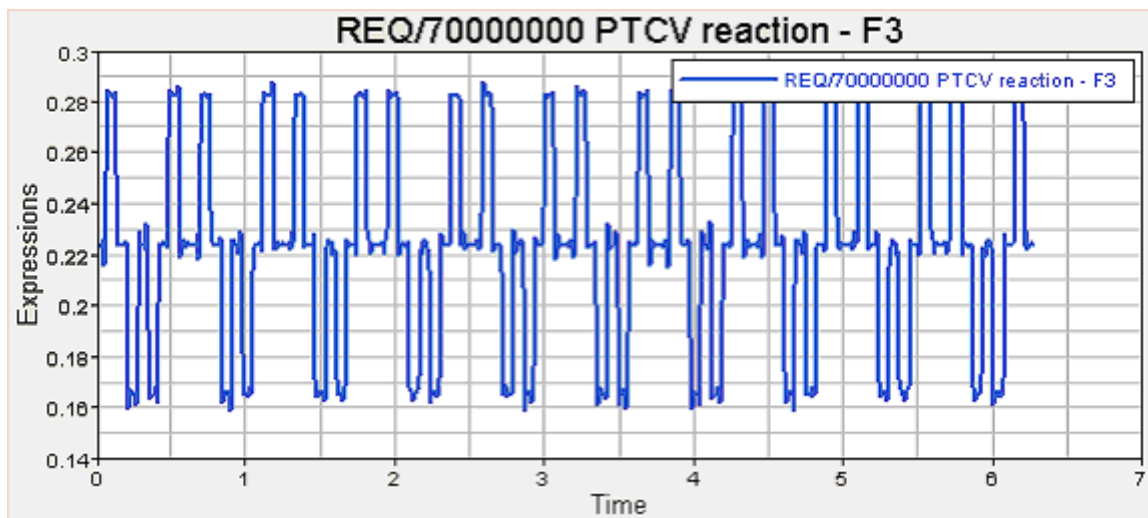
3. Add a new page to the session by clicking on the ***Add Page*** icon.

4. Choose ***HyperGraph 2D*** and click on ***Build Plots***.

5. Click on the browser icon and load the `result.abf` file.

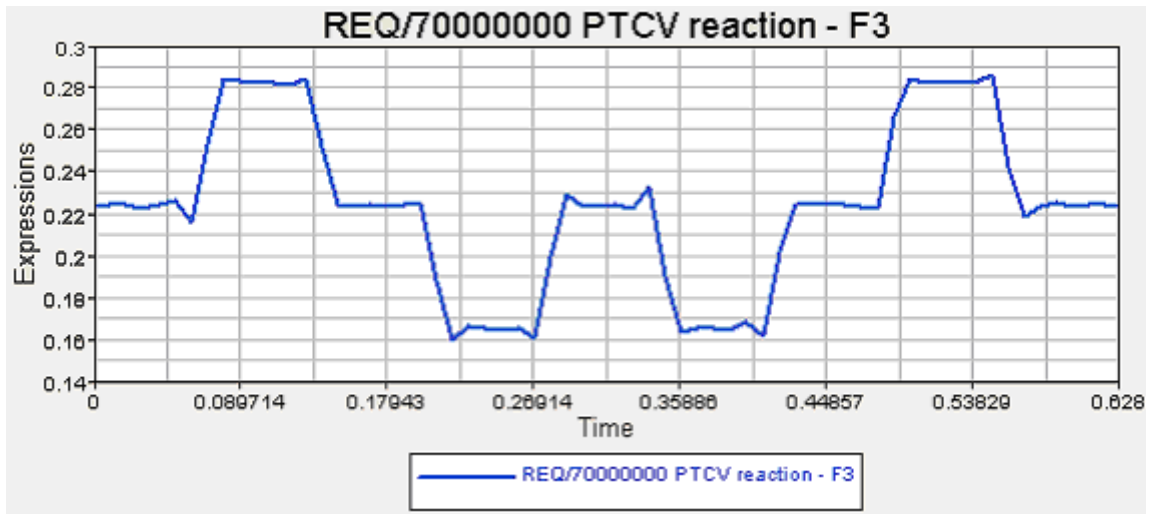6. Make selections for the plot as shown below:
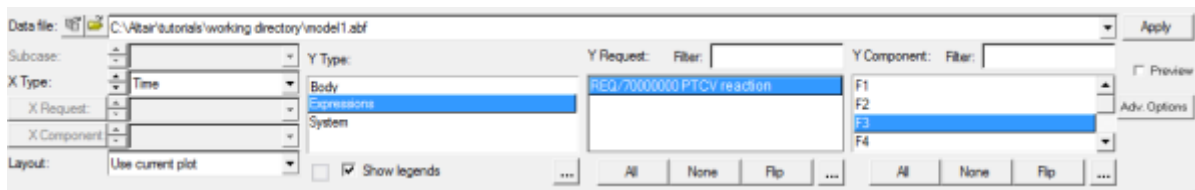
    We are plotting the Y profile of the PTCV reaction on the follower.

7. Click ***Apply***.

    The profile should look like the one shown below:

If we zoom in on one cycle by scaling the X-axis, the profile looks like this:

We see that the Y component of the PTCV reaction on the follower is always positive and hence it is never a 'pulling' reaction. Thus, our PTCV model is good enough to model the dynamics since there is no expected lift-off.

In this tutorial, we learned how to model a PTCV joint and use it to model a cam-follower mechanism. We also discussed lift-offs and ways of verifying the suitability of a PTCV joint model for modeling the dynamics of a particular system.