Altair

HyperWorks

Altair MotionView 2019 Tutorials

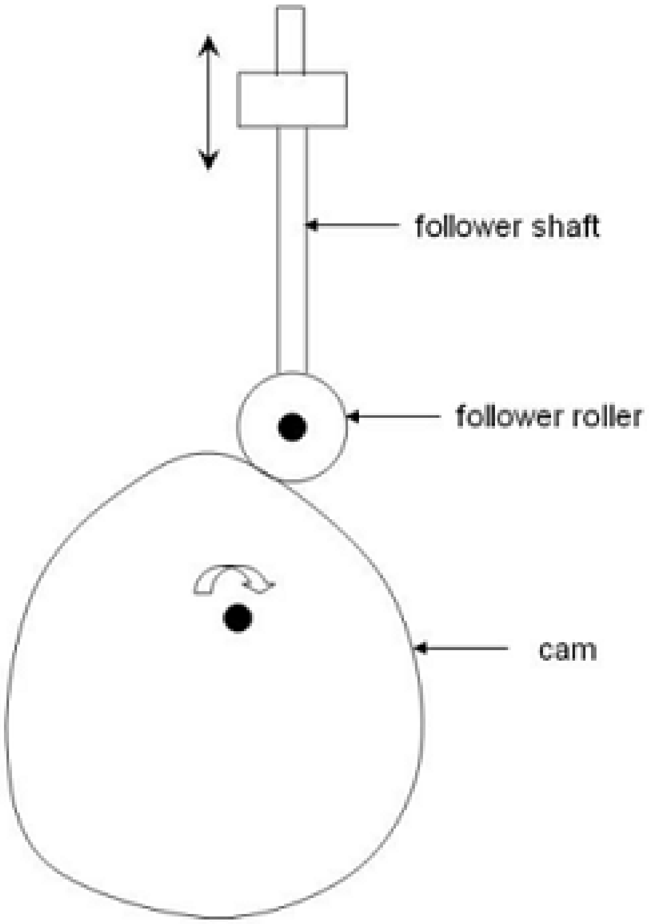
MV-1026: Modeling Curve-to-Curve (CVCV) Higher-Pair Constraint

MV-1026: Modeling Curve-to-Curve (CVCV) Higher-Pair Constraint

In this tutorial, you will learn how to:

- Model a CVCV (curve-to-curve) joint

A CVCV (curve-to-curve) joint is a higher pair constraint. The constraint consists of a planar curve on one body rolling and sliding on a planar curve on a second body. The curves are required to be co-planar. This constraint can act as a substitute to contact modeling in many cases where the contact occurs in a plane. One such case is the cam-follower system, in which the follower is in the form of a roller. Instead of modeling the contact between the cam and the follower, we can specify a CVCV constraint between their profiles.



A cam roller mechanism

In this tutorial, we will model a roller type cam-follower mechanism with the help of a CVCV constraint.

Exercise

Copy the files `CamProfile.h3d` and `CamProfile.csv` , located in 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 that we would like to. We will define points for center of mass of the bodies and joint locations.

1. Start a new MotionView Session. We will work in 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 for the points specified in the following table:

Point	*X*	*Y*	*Z*
FollowerShaftCM	0.0	67.5	0.0
FollowerTransJoint	0.0	85.0	0.0
FollowerRevJoint	0.0	30.0	0.0
CamCM	0.0	-14.1604	0.0

Step 2: Creating Bodies.

We will have three bodies apart from the ground body in our model visualization: the cam, the follower shaft and the follower roller. 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. Right-click on ***Bodies*** in the **Project Browser** and select ***Add Body*** to define a second body.

   The **Add Body or BodyPair** dialog is displayed.
4. For **Label**, enter `FollowerShaft` and click ***OK***.
5. Right-click on ***Bodies*** in the **Project Browser** and select ***Add Body*** to define a third body.

   The **Add Body or BodyPair** dialog is displayed.
6. For ***Label***, enter `FollowerRoller` and click ***OK***.

7. From the **Properties** tab, specify the following for the three bodies:

Body	*Mass*	*Ixx*	*Iyy*	*Izz*	*Ixy*	*Iyz*	*Izx*
Cam	0.1724	59.339	62.6192	121.240	0.0	0.0	0.0
FollowerShaft	0.0072	3.4270	0.0144	3.4270	0.0	0.0	0.0
FollowerRoller	0.0030	0.0251	0.0251	0.0375	0.0	0.0	0.0

8. For the **Cam** body, under the **CM Coordinates** tab, check the ***Use CM Coordsys*** box.
9. Double click on ***Point***.

   The **Select a Point** dialog is displayed.

   – Choose ***CamCM*** and click ***OK***.
10. Accept defaults for axes orientation properties.
11. For the **FollowerShaft** body, under the **CM Coordinates** tab, check the ***Use CM Coordsys*** box.
12. Double click on ***Point***.

   The **Select a Point** dialog is displayed.

   – Choose ***FollowerShaftCM*** and click ***OK***.
13. Accept defaults for axes orientation properties.
14. For the **FollowerRoller** body, under the ***CM Coordinates*** tab, check the ***Use CM Coordsys*** box.
15. Double click on ***Point***.

   The **Select a Point** dialog is displayed.

   – Choose ***FollowerRevJoint*** and click ***OK***.
16. Accept defaults for axes orientation properties.

Step 3: Creating Joints.

Here, we will define all the necessary joints except the CVCV joint which will be defined as a advanced joint later. We require three 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 shaft and ground body and the third joint is the revolute joint that connects the roller to the shaft.

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. Again 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. Right-click on ***Joints*** in the **Project Browser** and select ***Add Joint*** to define a second joint.

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

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

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 ***FollowerShaft*** 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. Again from the **Connectivity** tab, double-click on ***Point***.

    The **Select a Point** dialog is displayed.

    – Choose ***FollowerTransJoint*** 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***.

15. Right-click on ***Joints*** in the **Project Browser** and select ***Add Joint*** to define a third joint.

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

16. For **Label**, enter `FollowerRollerJoint`.

17. Select ***Revolute Joint*** as the type and click ***OK***.

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

    The **Select a Body** dialog is displayed.

    – Choose ***FollowerRoller*** and click ***OK***.

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

    The **Select a Body dialog** is displayed.

    – Choose ***FollowerShaft*** and click ***OK***.

20. Again from the **Connectivity** tab, double-click on ***Point***.

    The **Select a Point** dialog is displayed.

    – Choose ***FollowerRevJoint*** and click ***OK***.

21. 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***.

Step 4: Creating Markers.

Now, we will define markers required for the definition of the CVCV joint. We need two markers, one associated with the cam and the other associated with the follower roller.

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).
2. For **Label**, enter `CamMarker` and click ***OK***.
3. From the **Properties** tab, double-click on ***Body***.

   The **Select a Body** dialog is displayed.

   – Choose ***Cam*** and click ***OK***.
4. From the **Properties** tab, double-click on ***Point***.

   The **Select a Point** dialog is displayed.

   – Choose ***PivotPoint*** and click ***OK***.
5. Accept the defaults for axes orientation.
6. Right-click on ***Markers*** in the **Project Browser** and select ***Add Marker*** to define a second marker.

   The **Add Marker or MarkerPair** dialog is displayed.
7. For **Label**, enter `FollowerMarker` and click ***OK***.
8. From the **Properties** tab, double-click on ***Body***.

   The **Select a Body** dialog is displayed.

   – Choose ***FollowerRoller*** and click ***OK***.

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

   The **Select a Point** dialog is displayed.

   – Choose ***FollowerRevJoint*** and click ***OK***.

10. Accept the defaults for axes orientation.

Step 5: Creating Graphics.

Graphics for the cam have been provided as an h3d file. We need to associate the h3d with the cam body defined in our model. The follower shaft and roller can be represented using primitive graphics. To make the 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 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 is displayed.

   – Choose ***Cam*** and click ***OK***.

7. Right-click on ***Graphics*** in the **Project Browser** and select ***Add Graphic*** to define a second graphic.

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

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

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

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

    The **Select a Body dialog** is displayed.

    – Choose ***FollowerShaft*** and click ***OK***.

11. Double click on ***Point***.

    The **Select a Point** dialog is displayed.

    – Choose ***FollowerShaftCM*** and click ***OK***.

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

13. Click on ***Vector***.

    The **Select a Vector** dialog is displayed.

    – Choose ***Global Y*** and click ***OK***.

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

Property	Value
Length	75
Offset	-37.5
Radius 1	2.000
Radius 2	2.000

15. For the **Cap** properties, choose ***Cap Both Ends***.
16. Right-click on ***Graphics*** in the **Project Browser** and select ***Add Graphic*** to define a third graphic.

    The **Add Graphics or GraphicPair** dialog is displayed.
17. For **Label**, enter `FollowerRoller`.
18. Choose ***Cylinder*** from the drop-down menu and click ***OK***.
19. From the **Connectivity** tab, double-click on ***Body***.

    The **Select a Body** dialog is displayed.

    – Choose ***FollowerRoller*** and click ***OK***.
20. Double click on ***Point***.

    The **Select a Point** dialog is displayed.

    – Choose ***FollowerRevJoint*** and click ***OK***.
21. Click on the arrow below ***Direction*** and select the ***Vector*** option.
22. Click on ***Vector***.

    The **Select a Vector** dialog is displayed.

    – Choose ***Global Z*** and click ***OK***.
23. From the **Properties** tab, specify the following values:

Property	Value
Length	5.0
Offset	-2.5
Radius 1	5.000
Radius 2	5.000

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

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

1. Right-click on ***Graphics*** in the **Project Browser** and select ***Add Graphic*** to define another graphic.

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

2. For **Label**, enter `CamPivotGraphicOne` (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 is 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. Right-click on ***Graphics*** in the **Project Browser** and select ***Add Graphic*** to define another graphic.

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

11. For **Label**, enter `CamPivotGraphicTwo` (second graphic to show the cam pivot).
12. Choose ***Cylinder*** from the drop-down menu and click ***OK***.
13. From the **Connectivity** tab, double-click on ***Body***.

    The **Select a Body** dialog is 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***.
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***.

    Repeat this process for the **FollowerRevJoint** and label the graphics as:

    – `RollerPivotGraphicOne` on **FollowShaft** with a length of ***7.5*** and radius of ***2***.

    and

    – `RollerPivotGraphicTwo` on **FollowRoller** with a length of ***7.6*** and radius of ***1***.
19. Right-click on ***Graphics*** in the **Project Browser** and select ***Add Graphic*** to define another graphic.

    The **Add Graphics or GraphicPair** dialog is displayed.
20. For **Label**, enter `FollowerTransJointGraphic` (the graphic for the 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 is displayed.

    – Choose ***Ground Body*** and click ***OK***.
23. For **Type**, choose ***Center*** from the drop-down menu.
24. Double-click on ***Point***.

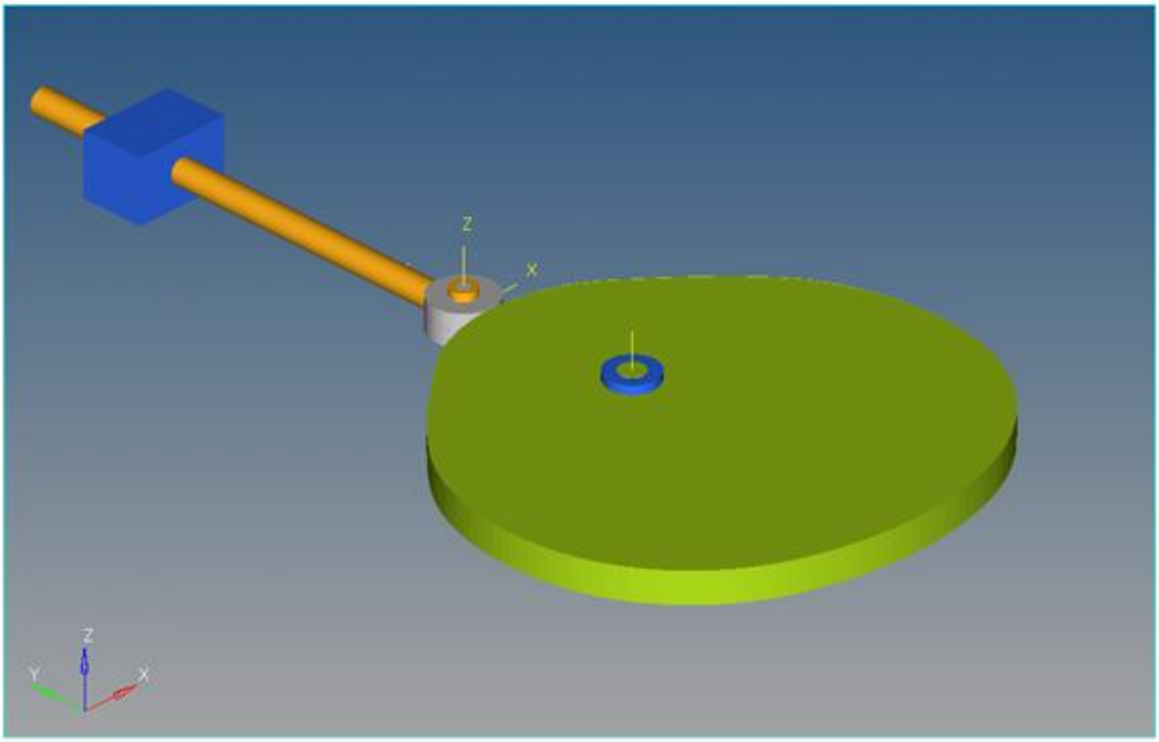
    The **Select a Point** dialog is displayed.

    – Choose ***FollowerTransJoint*** 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:



Step 6: Creating the Curves.

The curves that we will use here are the curves that define the profile of the cam and the roller. The data for the cam profile curve has been provided in `csv` format. Since the roller profile is circular - it can be defined using mathematical expressions.

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.

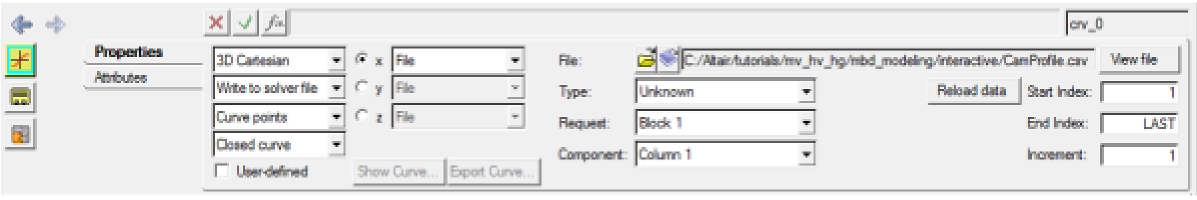
2. For **Label**, enter `CamProfile` and click ***OK***.

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***.

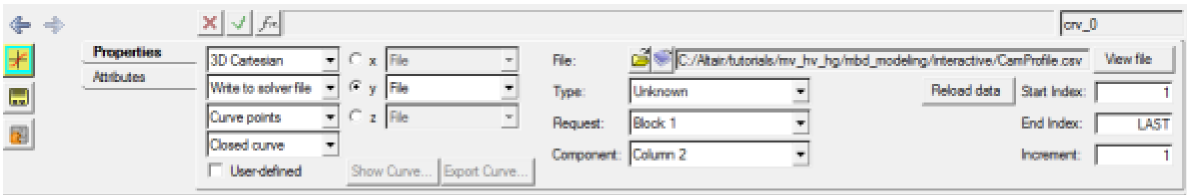
6. Choose the properties of the curve as shown in the figure below:



7. From the **Properties** tab, click on the ***y*** radio button.

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

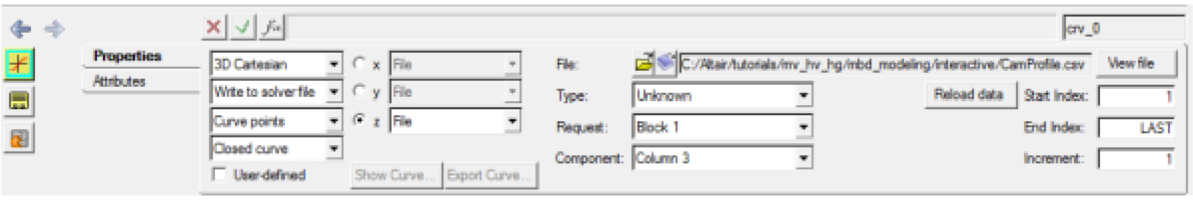
9. Choose the properties of the curve as shown in the figure below:



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 the ***x***, ***y*** and ***z*** properties.

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

14. Right-click on ***Curves*** in the **Project Browser** and select ***Add Curve*** to define another curve.

    The **Add Curve** dialog is displayed.

15. For ***Label***, enter `FollowerRollerProfile` and click ***OK***.

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

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

18. Select ***Math*** from the second drop-down menu on the left.

19. Enter `5*sin(2*PI*(0:1:0.01))` in the **Expression Builder**.

20. From the **Properties** tab, click on the ***y*** radio button.
21. Select ***Math*** from the second drop-down menu on the left.
22. Enter `5*cos(2*PI*(0:1:0.01))` in the **Expression Builder**.
23. From the **Properties** tab, click on the ***z*** radio button.
24. Select ***Math*** from the second drop-down menu at the left.
25. Enter `0.0*(0:1:0.01)` in the **Expression Builder**.
26. From the **Properties** tab, use the fourth drop-down menu to change the curve from ***Open Curve*** to ***Closed Curve***.

    We now have both of the curves defined.

Step 7: Creating the CVCV Joint.

Now, we will create the CVCV 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 CVCV.
3. Choose ***CurveToCurveJoint*** from the drop-down menu and click ***OK***.
4. From the **Connectivity** tab, double-click on ***Curve 1***.

   The **Select a Curve** dialog is displayed.

   – Choose ***CamProfile*** and click ***OK***.
5. From the **Connectivity** tab, double-click on ***Curve 2***.

   The **Select a Curve** dialog is displayed.

   – Choose ***FollowerRollerProfile*** and click ***OK***.
6. From the **Connectivity** tab, double-click on ***Ref Marker 1***.

   The **Select a Marker** dialog is displayed.

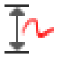
   – Choose ***CamMarker*** and click ***OK***.
7. Again from the **Connectivity** tab, double-click on ***Ref Marker 2***.

   The **Select a Marker** dialog is displayed.

   – Choose ***FollowerMarker*** and click ***OK***.

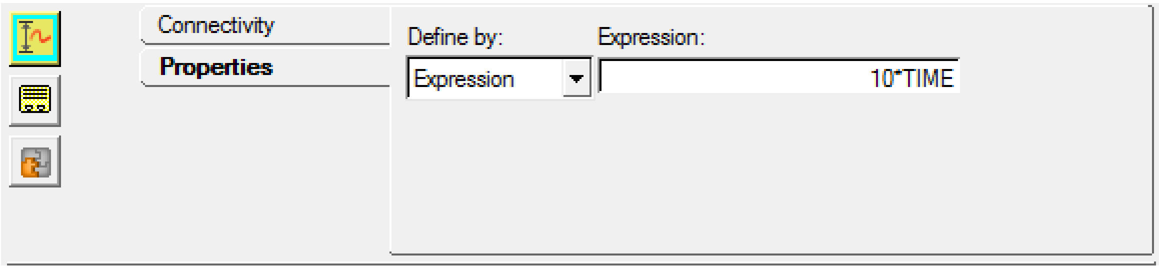
Step 8: Specifying the Cam Motion.

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. Click the **Project Browser** right-click on ***Model*** and select ***Add Constraint >*** ***Motions*** (or right-click the ***Motions*** icon  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 CVCV joint since it can help us verify the correctness of our results. This will be discussed in detail towards the end of the tutorial where we will also discuss lift-offs.

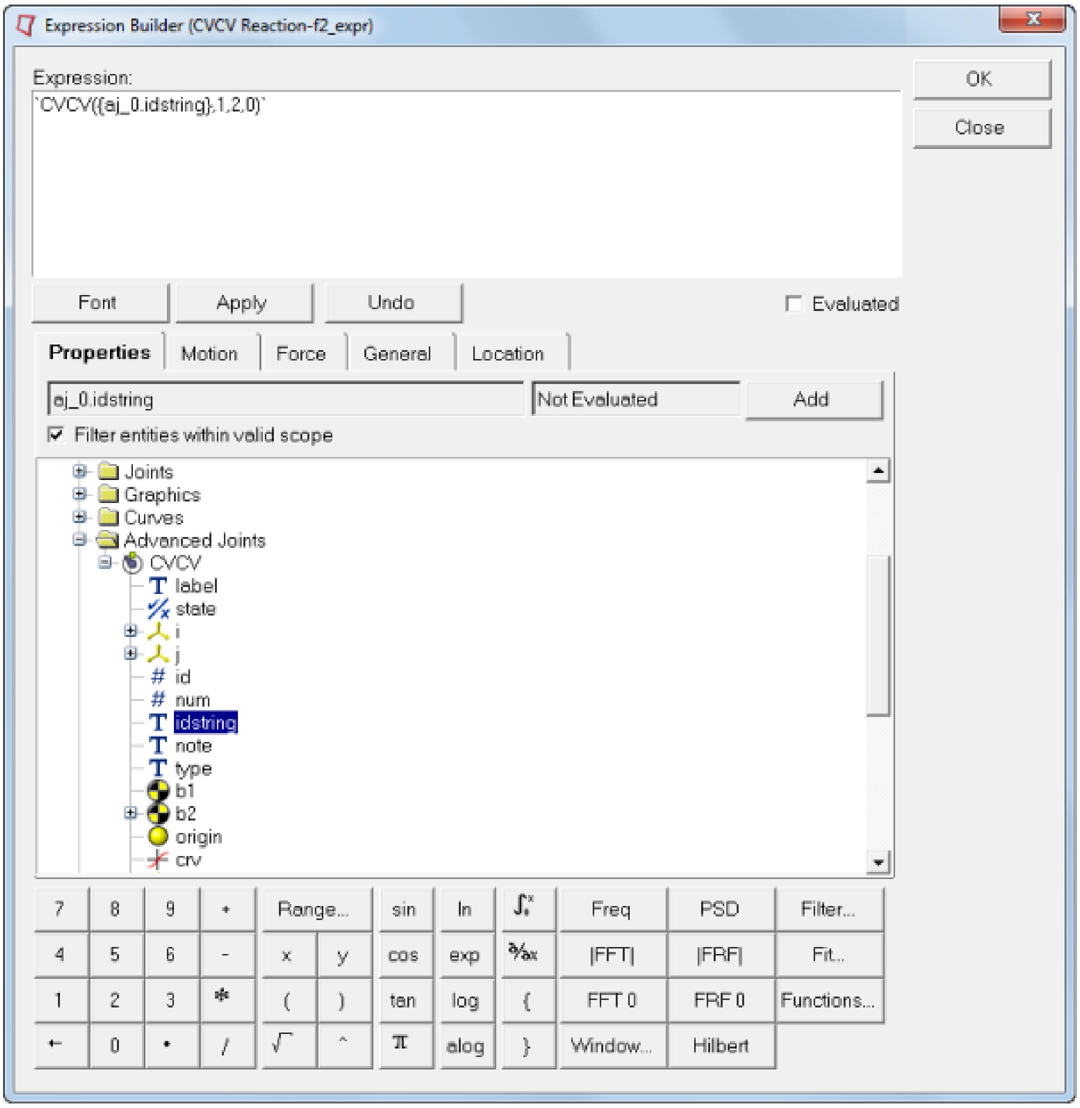
1. From the **Project Browser** right-click on ***Model*** and select ***Add General MDL Entity > Output*** (or right-click the ***Outputs*** icon on the **Model-General** toolbar).

   The **Add Output** dialog is displayed.

2. For ***Label***, enter `CVCV 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 button.

   The **Expression Builder** dialog is displayed.

6. Populate the expression as `'CVCV({aj_0.idstring},1,2,0)'`.



7. Click ***OK***.

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

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

`id`	ID of the CVCV 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)

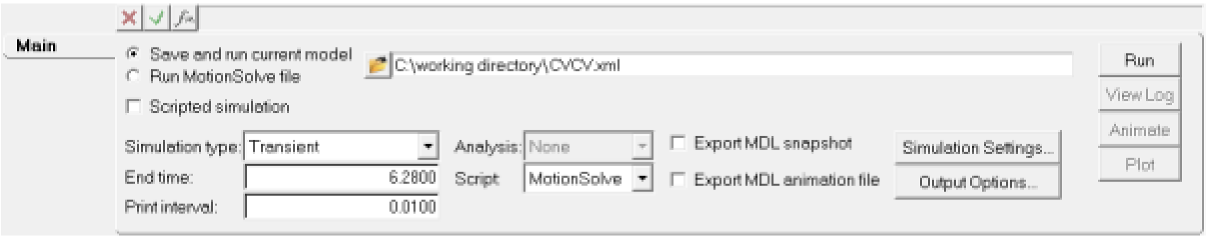
Step 11: Running the Model.

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

1. Click the ***Run*** icon on the **Model-Main** 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 the ***Check Model*** button 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.

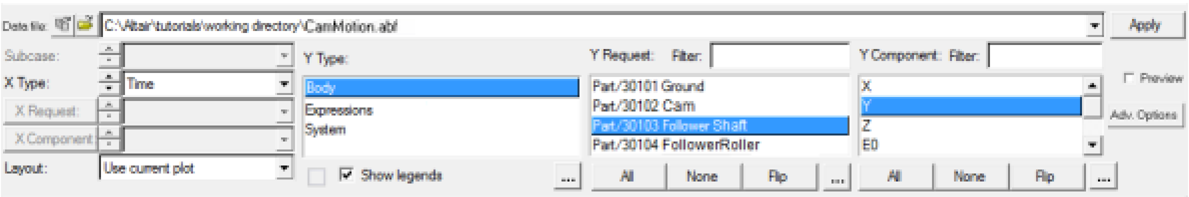
Step 12: Viewing the Results.

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.

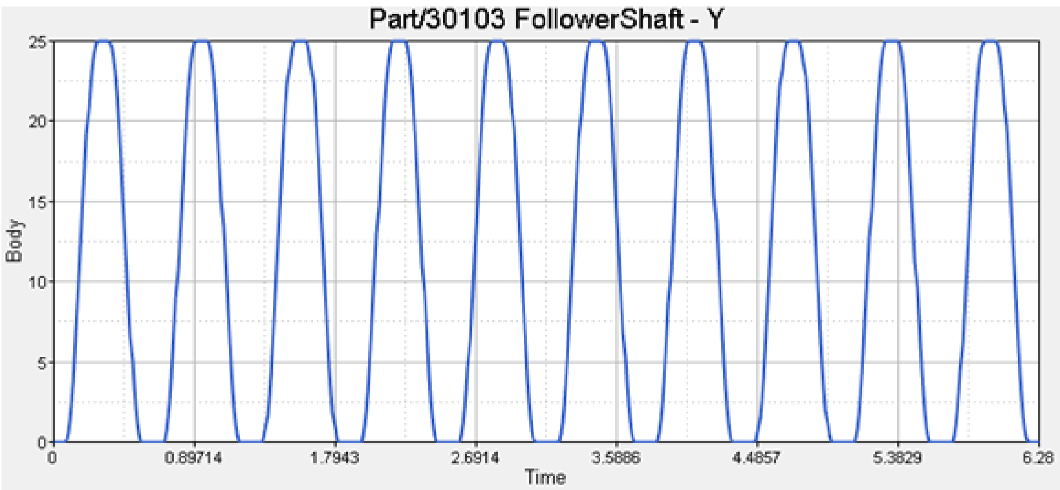
2. Use the **Page Layout** drop-down menu on the **Page Controls** toolbar to select the three-window layout .
3. Highlight the lower right window and use the **Select application** drop-down menu to change the application from ***MotionView*** to ***HyperGraph 2D*** .
4. Click the ***Build Plots*** 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:



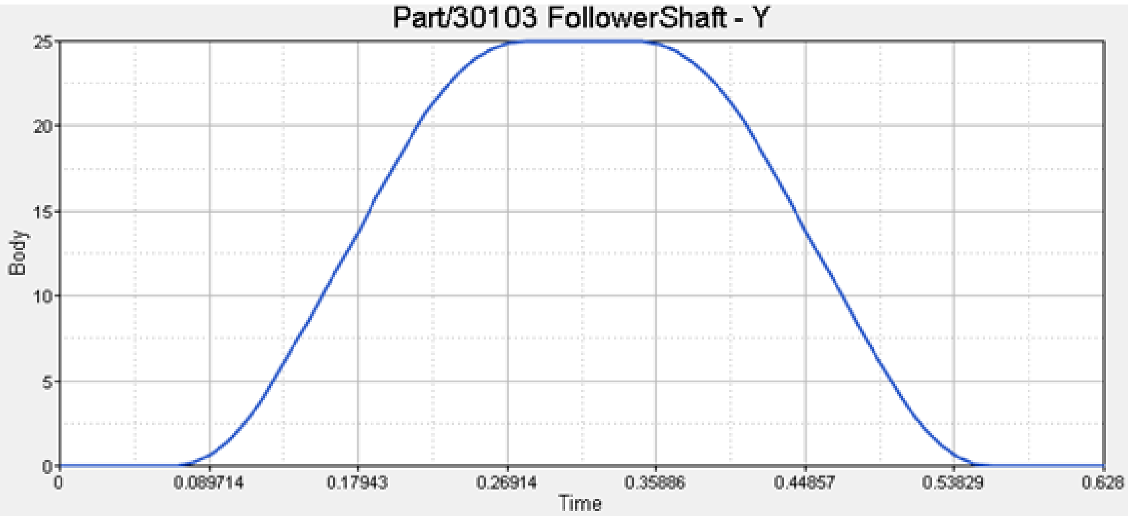
   We are plotting the Y profile of the center of mass of the follower.

7. Click ***Apply***.

   The profile for the Y-displacement of the follower should look like the one shown below:



If we set the X-axis properties to zoom in on one cycle, the profile will look as shown below:



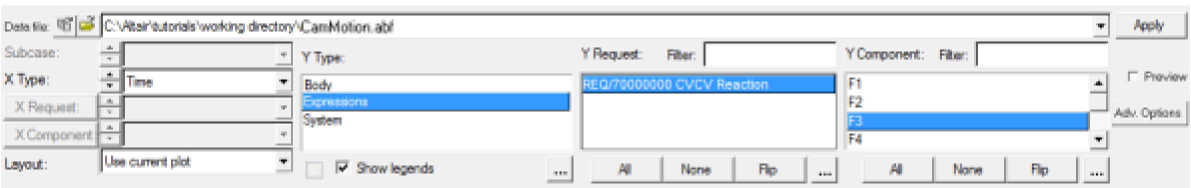
The profile of the cam has been designed to obtain the above Y-profile for the follower.

Now, we come to the discussion on '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 CVCV joint will give us incorrect results. This is because the CVCV joint constrains the follower point to be always on the curve. For such cases, contact modeling has to be used. However one would like to start with a CVCV model whenever applicable, since modeling a CVCV joint is a lot easier than modeling contact. Given this scenario, the following modeling steps should be followed:

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

   Now, let's check if our CVCV model is good enough. For this, we need to plot the reaction profile on the follower roller. 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 roller. For this:

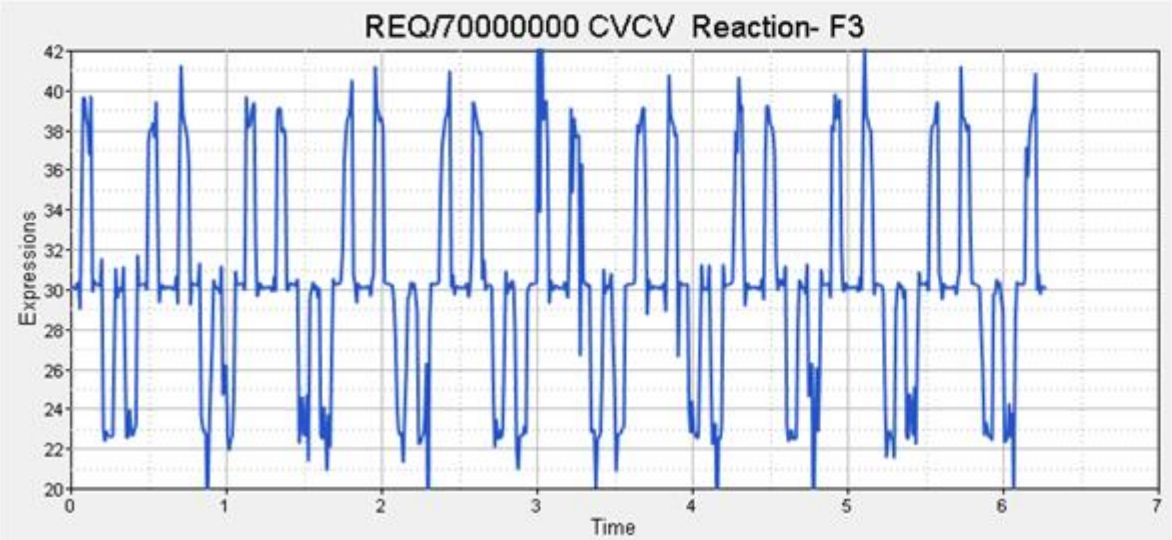
3. Add a new page to the session by clicking on the ***Add Page*** icon .
4. Choose ***HyperGraph 2D*** and click on ***Build Plots***.
5. Click on the browser icon and load the `result.abf` file.
6. Make selections for the plot as shown below:



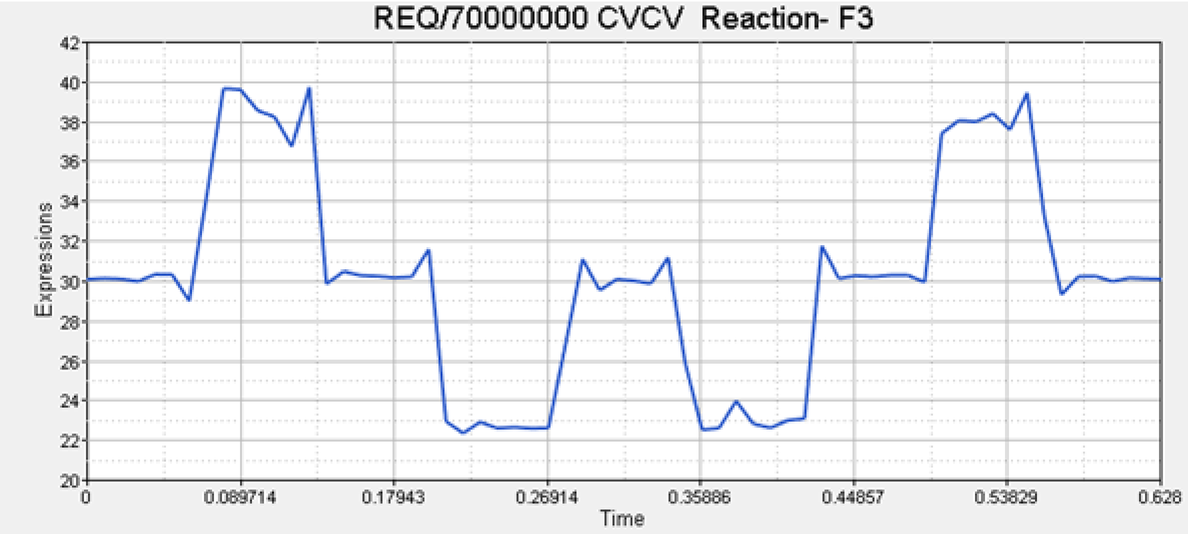
We are plotting the Y profile of the CVCV reaction on the follower roller.

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 CVCV reaction on the follower is always positive, and hence it is never a 'pulling' reaction. Thus, our CVCV model is good enough to model the dynamics since there is no expected lift-off.

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