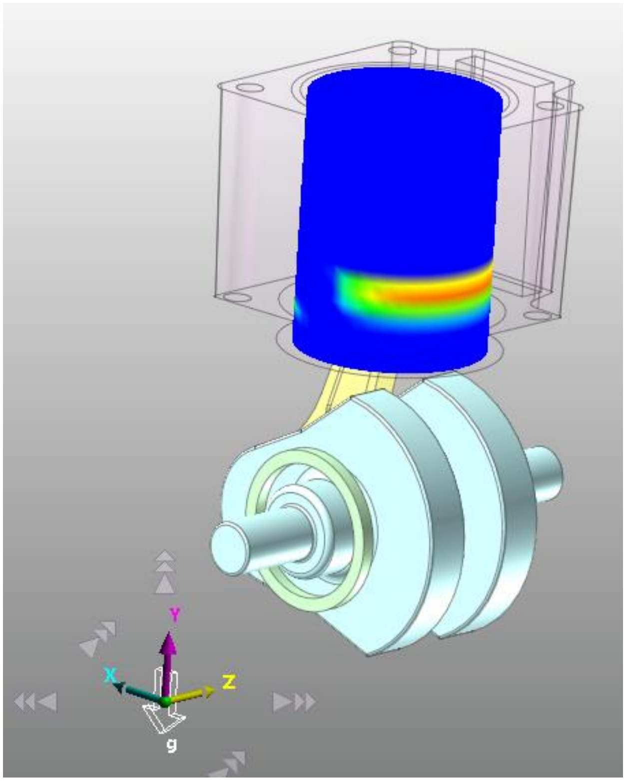
Piston Lubrication (EHD)



FunctionBay

Edition Note

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

Table of Contents

Chapter

1

Overview

Task Objectives

The objective of fluid lubrication is to penetrate into the contact area between solid objects, which generate friction, and to form a thin oil film to reduce abrasion and frictional heat caused by friction. This oil film separates two solid surfaces from directly contacting each other and reduces friction and heat between them to smooth their movement.

The history of the lubrication theory started with an equation derived from the fluid flow existing in the narrow gap between two solid objects. The equation was presented by O. Reynolds back in 1886. This equation, called the Reynolds equation named after him, established the basis of the lubrication theory.

In this tutorial, EHD (elastic, hydraulic, and dynamic) elements, which are developed based on the Reynolds equation, are used to model the lubrication action at the part where the cylinder and the piston in the engine system contact each other and to perform the dynamic analysis of the cylinder and the piston considering their lubrication characteristics.

- Configure the piston lubrication using the rigid model.
- Swap the rigid bodies with the RFlex bodies, perform the analysis of the piston lubrication, and check the result of the lubrication action.

Prerequisites

This tutorial is intended for users who have completed the basic tutorials provided with RecurDyn. If you have not completed these tutorials, then you should complete them before proceeding with this tutorial.

Task

This tutorial consists of the following tasks and the time required for each task is listed in the table below.

Procedures	Time (minutes)
Opening the initial Model	10
Analyzing Piston Lubrication with Rigid Bodies	30
Analyzing Piston Lubrication with RFlex Bodies	30
Analyzing the Results	10
Modifying Piston Profile and Analyzing Piston Lubrication	10
Total	90

Estimated Time to Complete this Task

90 minutes

Chapter 2

Opening the Initial Model

Task Objectives

To open and observe the initial model.

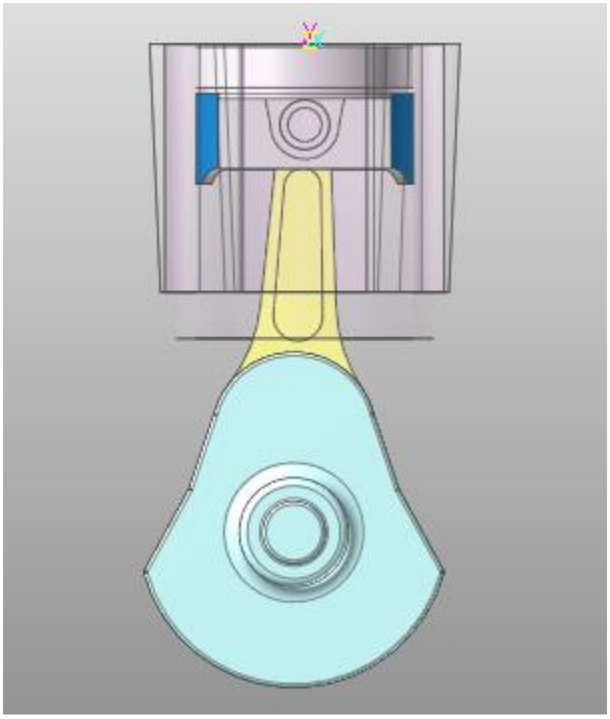
Estimated Time to Complete This Task

10 minutes

Opening the RecurDyn Model

To run RecurDyn and open the initial model

1. On the **Desktop**, double-click the **RecurDyn** icon to open **RecurDyn**.
2. When the **Start RecurDyn** dialog window appears, close it.
3. In the **File** menu, click **Open**.
4. Navigate to the tutorial folder and select **PistonLubricationEHD_Start.rdyn**. (File path: <Install Dir>\Help\Tutorial\Toolkit\EHD\PistonLubrication).
5. Click the **Open** button. to open the model shown in the following figure.



The following explains the configuration of the model.

An engine block consists of a cylinder, a piston, a piston pin, a connecting rod and a crank. The piston moves via the translation force defined with the spline of gas force according to the crank angle. The piston and the cylinder are joined by a translation joint, which makes the piston only move up and down.

To save the model:

1. In the **File** menu, click **Save As**.

(You cannot perform the simulation if the model is in the tutorial path, so you must save the model in a different path.)

Performing Simulation

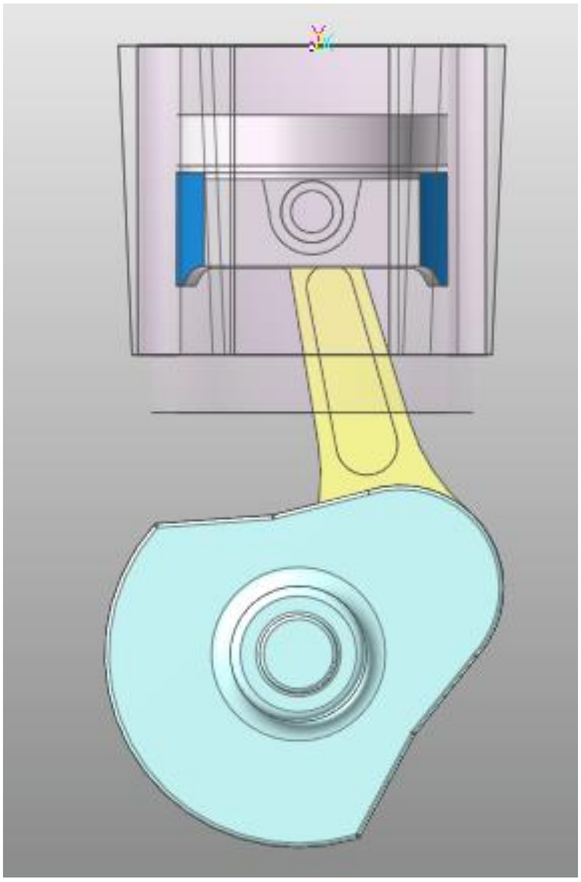
This section teaches you how to perform an initial simulation using the model in order to understand its behavior.

To perform the initial simulation:

1. On the **Analysis** tab, in the **Simulation Type** group, click the **Dyn/Kin** icon.
2. The Dynamic/Kinematic Analysis dialog window appears.
3. After verifying the simulation conditions, click **Simulation**.

To view the result:

Under the **Analysis** tab, in the **Animation Control** group, press the **Play** button to check if the connecting rod moves as shown in the figure below.



Chapter

3

Analyzing Piston Lubrication with Rigid Bodies

Task Objectives

For the lubrication analysis using EHD, you should define the cylinder and the piston of the engine system as the piston lubrication force. In this chapter, we will keep the modeling elements, such as joint and force, configured in the previously opened model as is, and define the piston lubrication to simulate and analyze the lubrication action of the rigid bodies.

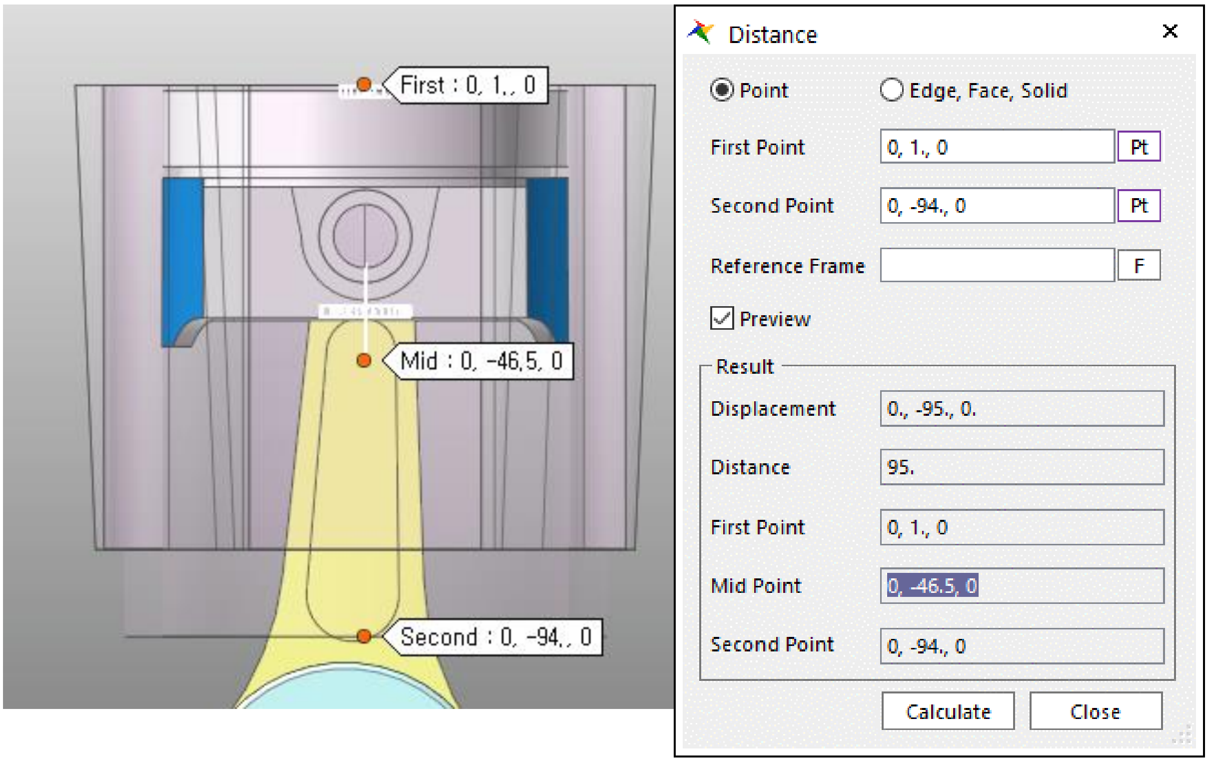
Estimated Time to Complete This Task

30 minutes

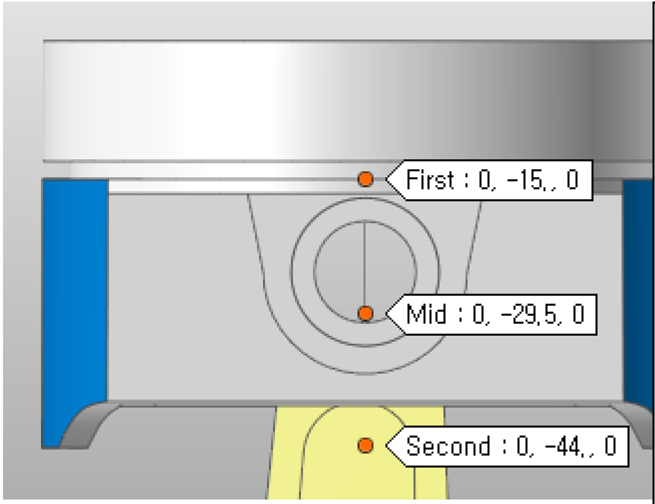
Creating piston lubrication

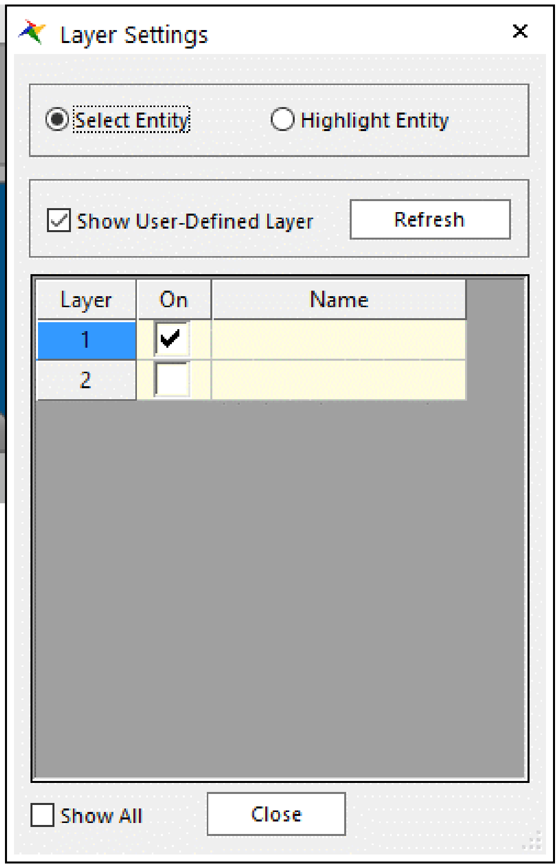
1. From the previous model, delete **TraJoint1** which was defined for movement.

2. Under the **Toolkit** tab, in the **Toolkit** group, click the **Piston Lubrication** icon.
3. For the Creation Method, select Body, Point, Direction, Direction, Body, Point, Direction and Direction.
4. For the first body, select **Cylinder**, which is to be the **Base Body**, and click "**0,-46.5,0**", which is the middle part of the entire cylinder.
   - Use the **Distance Measure** function to check it.



5. Enter "**0,1,0**" for the axis on which the base body moves, and "**1,0,0**" for its direction of rotation.
6. For the second body, select **Piston**, which is to be the **Action Body**, and click "**0,-29.5,0**", which is the middle part of the area contacting the cylinder.
   - From the Layer Settings window, uncheck Show All and uncheck the layer to which the cylinder body belongs so that you can select the piston body easily.



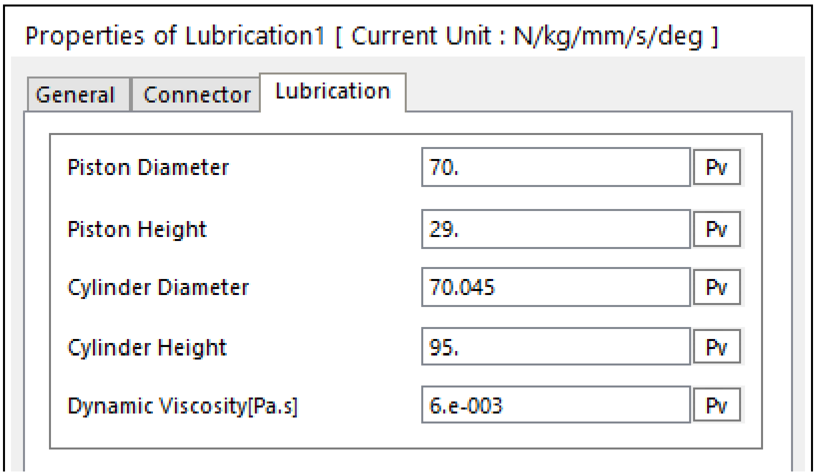


7. Enter "**0,1,0**" for the axis on which the action body moves, and "**1,0,0**" for its direction of rotation. You should set directions the same as those set for the cylinder body.
8. Make sure that the forces have been created in the **Database Window**.

Defining Piston Lubrication

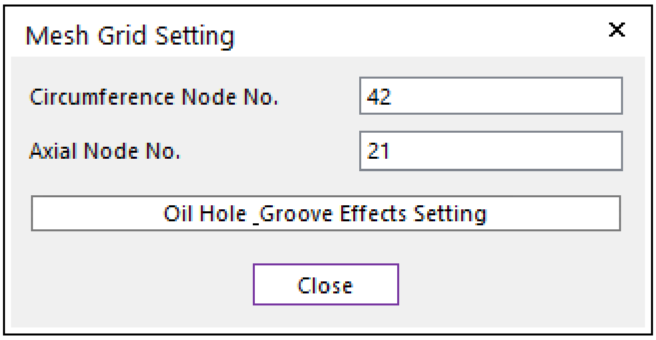
In the piston lubrication created just before, we set the default values without considering the actual geometry of the cylinder and the piston. Now you should set them with the values of the geometry again.

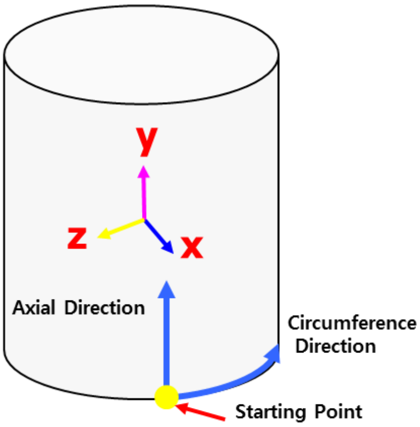
1. Right-click **Lubrication1** and select **Properties** in the context menu.
2. Enter **70** in the **Piston Diameter** field, **29** in the **Piston Height** field, **70.045** in the **Cylinder Diameter** field and **95** in the **Cylinder Height** field.
   - The value of the initial gap between the cylinder and the piston is the difference between both diameters divided by 2. In this tutorial, it is 0.0225.



3. Click **Mesh Grid Setting** to adjust the mesh size. Enter **42** in the **Circumference Node No.** field and **21** in the **Axial Node No.** field.

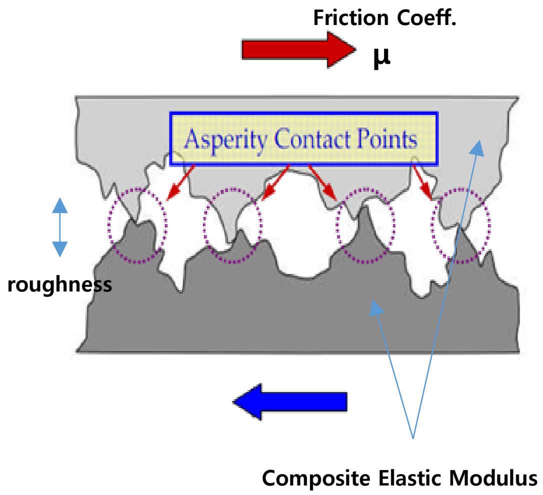
   - For each direction, refer to the figure at the right.



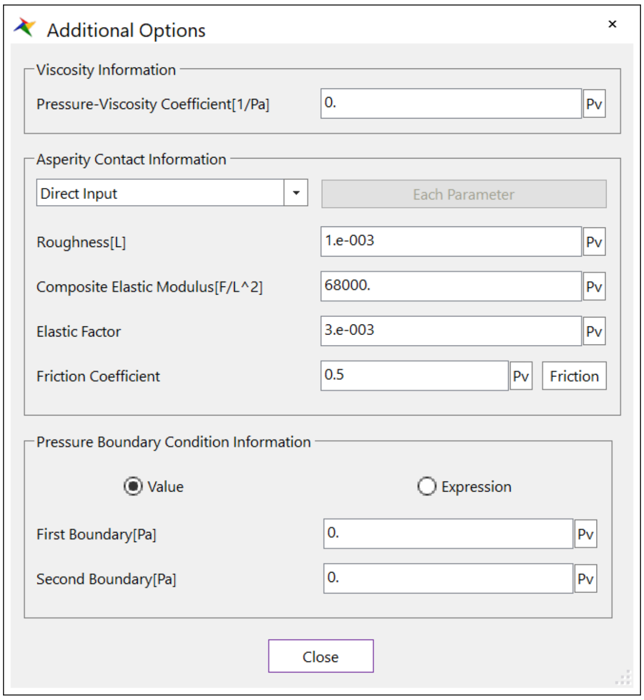


   - If the circumferential and axial directions have similar mesh grid sizes, you can perform the EHD analysis more efficiently.
   - In this tutorial, the sum of the circumferential length is 70.045*π = 220.05 and its height is 95. Therefore, if you want to use the mesh grid of the size of about 5 mm, the appropriate quantity in the circumferential direction is 44 and that in the axial direction is 19.

4. For the asperity contact, click **Additional Options** to configure additional settings. If the thickness of the oil film becomes less than the roughness multiplied by 4 during the lubrication action, the asperity contact occurs.



5. Enter values for the parameters to calculate the asperity contact as follows:
   - **Roughness: 0.001**
   - **Composite Elastic modulus: 68000**
   - **Elastic Factor: 0.003**
   - **Friction Coefficient: 0.5**



6. Click the **Close** button to close the window and click the **OK** button in the **Properties** dialog window for **Lubrication1** to close it.

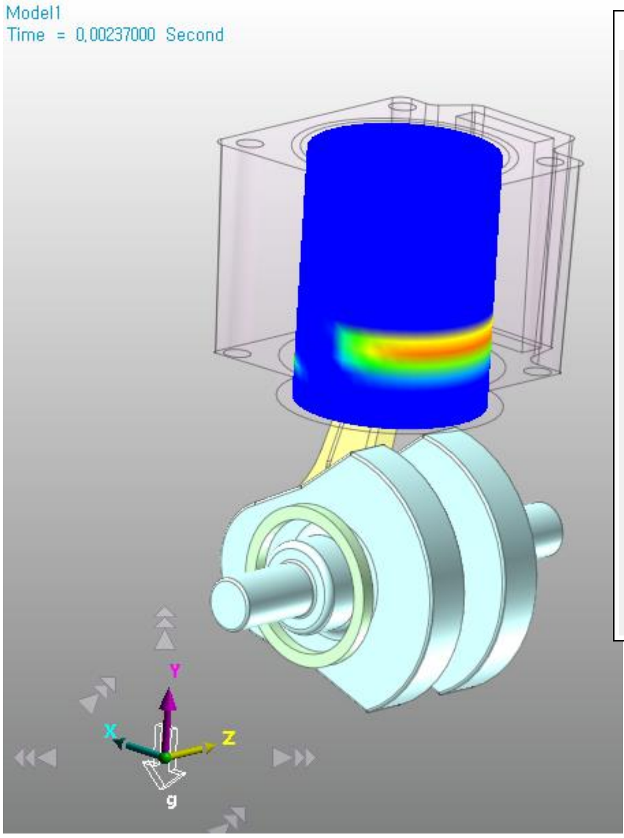
Performing Dynamic Analysis on Piston Lubrication and Checking Its Result

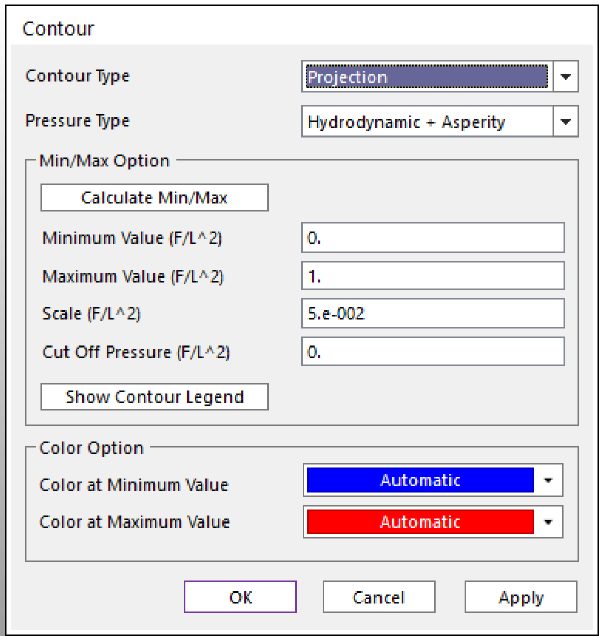
To run the simulation for piston lubrication:

1. Save the model as **PistonLubricationEHD _Rigid.rdyn**.
2. On the **Analysis** tab, in the **Simulation Type** group, click the **Dyn/Kin** icon.
3. The **Dynamic/Kinematic Analysis** dialog window appears.
4. After verifying the simulation conditions, click **Simulation**.

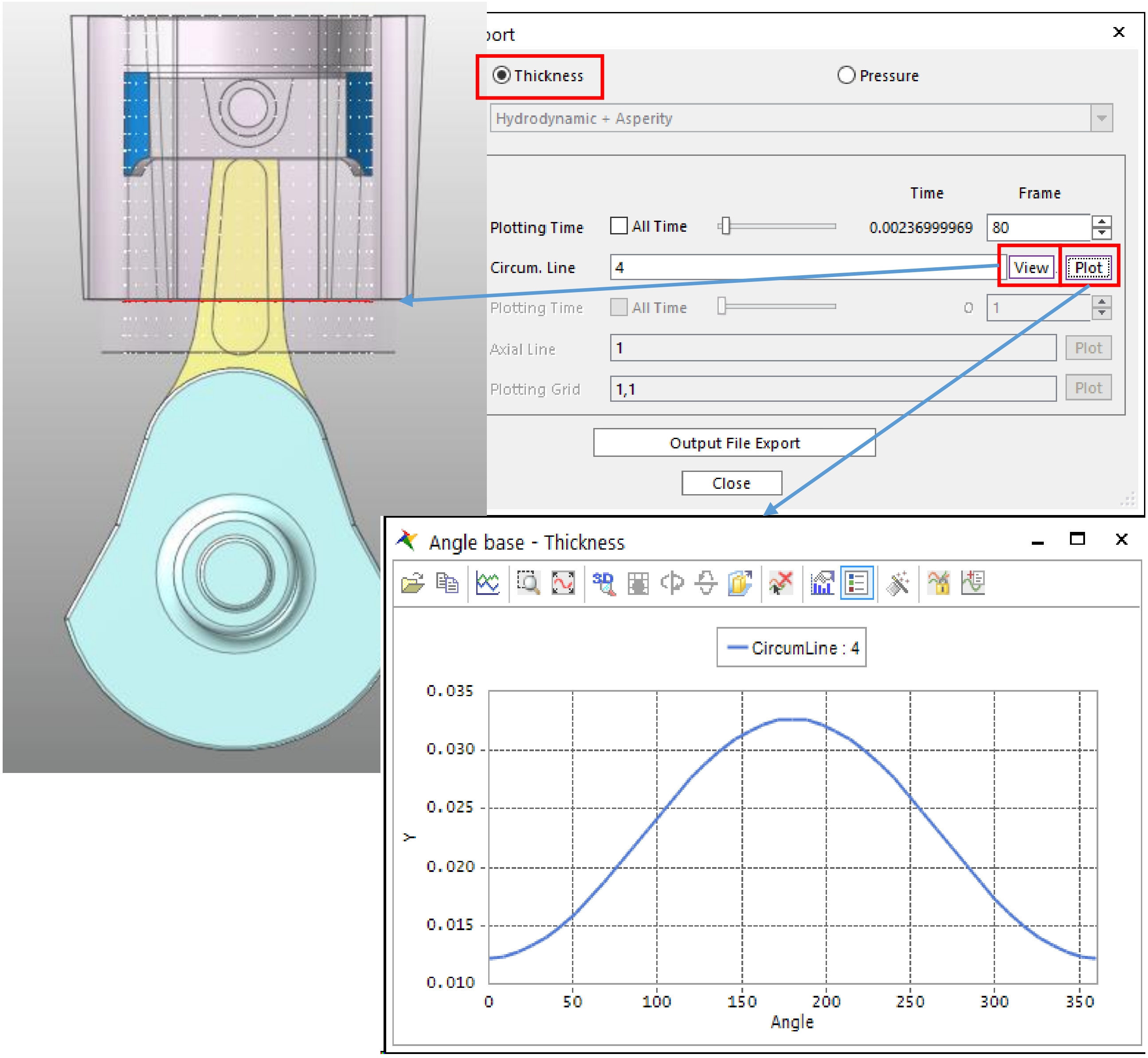
To view the result:

1. On the **Analysis** tab, in the **Animation Control** group, click the **Play** button to view the animation.
2. Right-click **Lubrication1** and select **Property** in the context menu.
3. Click **Contour Setting** and select **Hydrodynamic + Asperity** for **Pressure Type**.
   - You will be able to check the total lubrication force.
4. Change the **Maximum Value** field to **1** and click the **OK** button to close the window.
   - Play the animation again to see that the maximum values appear at both sides of the piston.

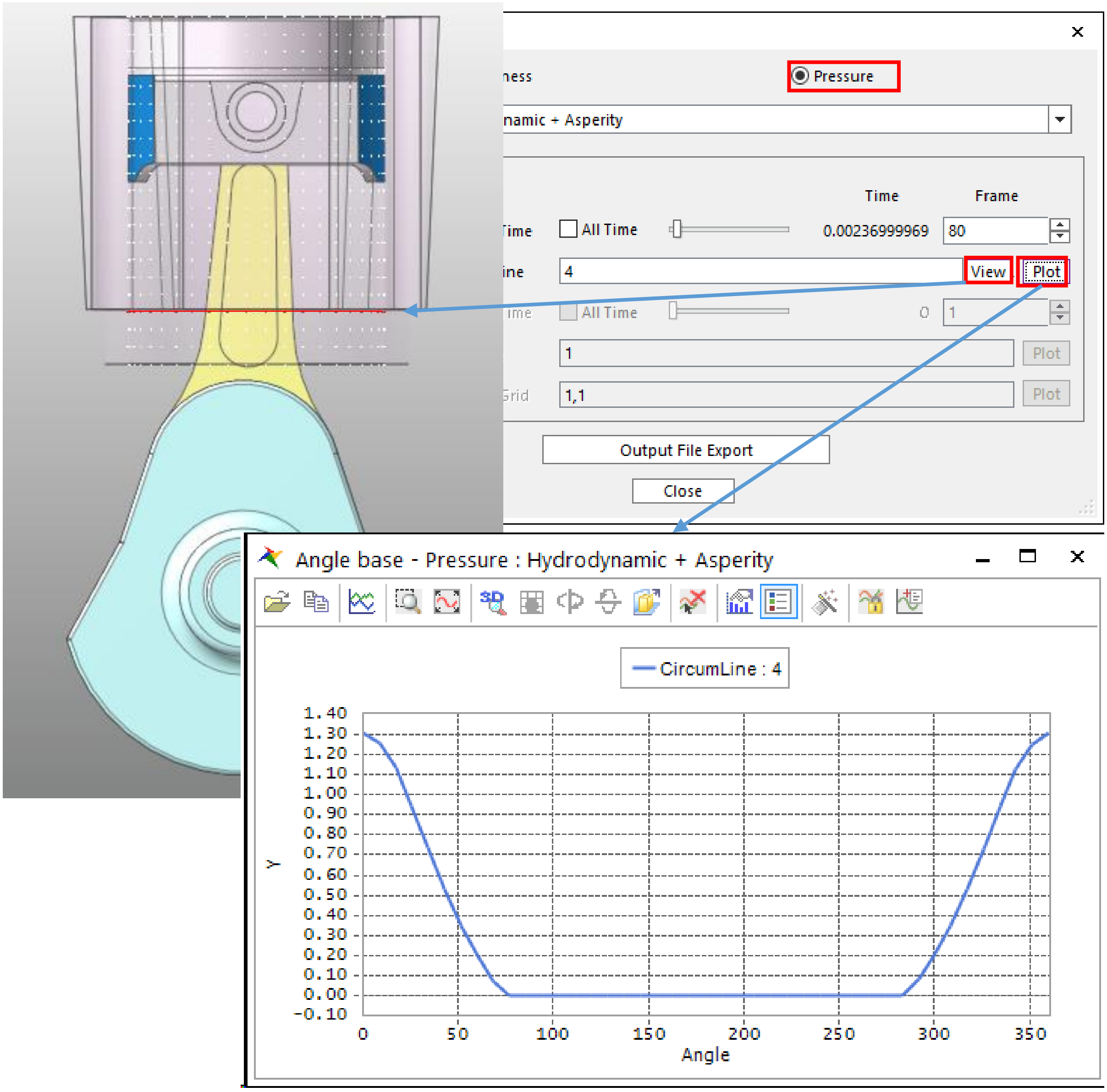




5. Click the **Output Data Export** button in the **Properties** dialog window for **Lubrication1**.
6. You can view the lubrication thickness and pressure from the top using a graph.
   a. Select **Thickness**. In **Angle base**, enter **80** in the **Frame** for **Plotting Time** field and **4** in the **Circum. Line** field.
   b. Click the **View** button to check Circumference **Line** and click the **Plot** button.



   c. You can see that the thickness of the oil film changes along the 4th line.
   d. Select **Pressure** and click the **Plot** button under the same state as before.



e. You can see that the pressure increases at the point where the oil film is thin.

Chapter 4

Analyzing Piston Lubrication with RFlex Bodies

Task Objectives

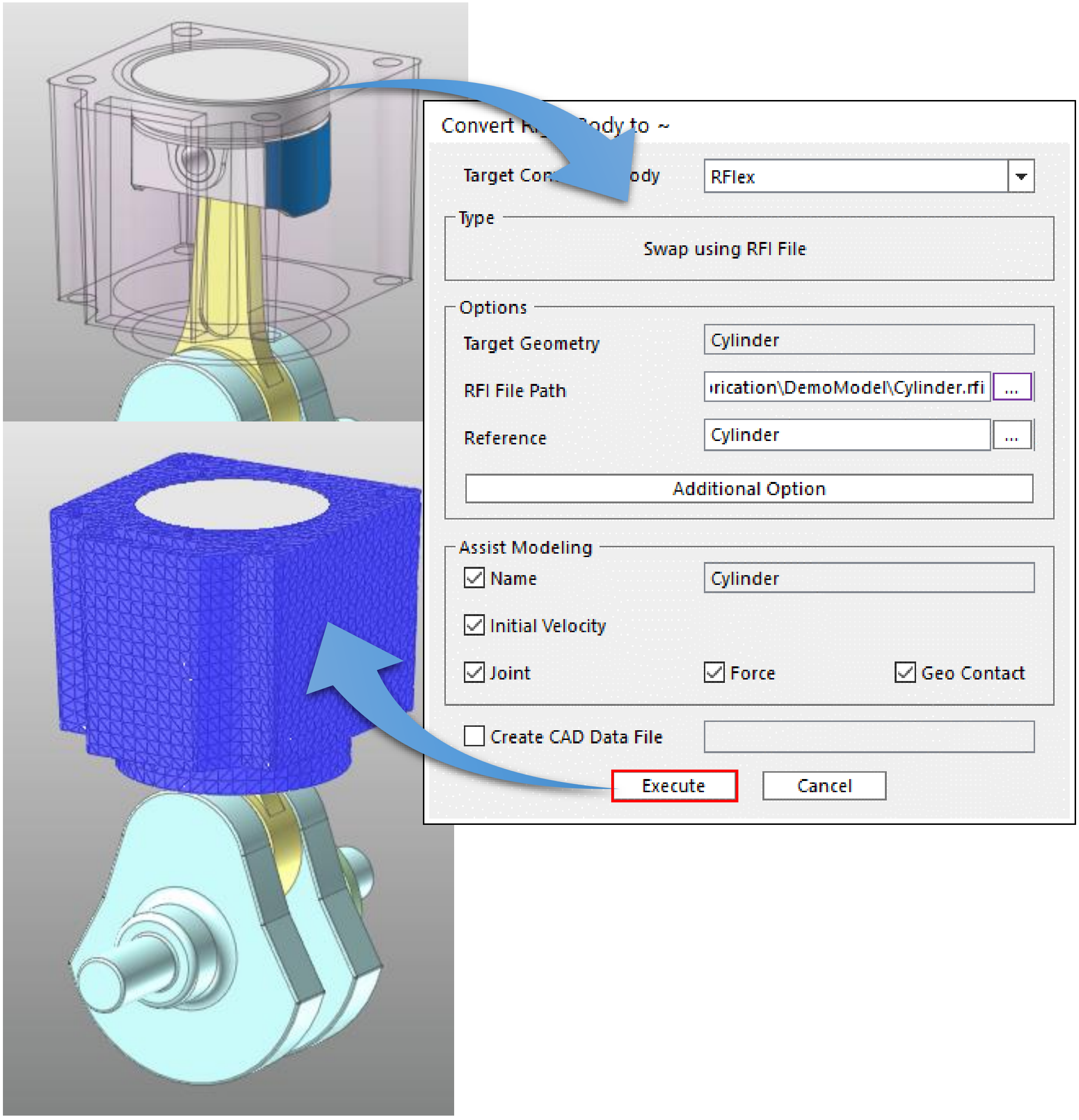
In this chapter, the cylinder and the piston in the previously defined rigid model are defined as RFlex bodies and the piston lubrication is analyzed considering the deformation.

Estimated Time to Complete This Task

30 minutes

Creating RFlex Bodies

1. Click the **G-Manager** icon in the **G-Manger** group under the **Flexible** tab.
2. From the **Working Window**, select **Cylinder Body** to display the **G-Manager** dialog window.
3. Select RFlex for the **Target Converting Body** field and set the **Type** field to **Swap** using RFI File.
   - For the purpose of this tutorial, the RFI file is provided in the <Install Dir>\Help\Tutorial\Toolkit\EHD folder.
4. Set the **RFI File Path** field to **Cylinder.rfi**.
5. Use **Cylinder** for the **Reference** field.
6. Click the **Execute** button in the **G-Manager** dialog window. The **Cylinder** will be replaced with that of an **RFlex Body** as shown in the following figure.

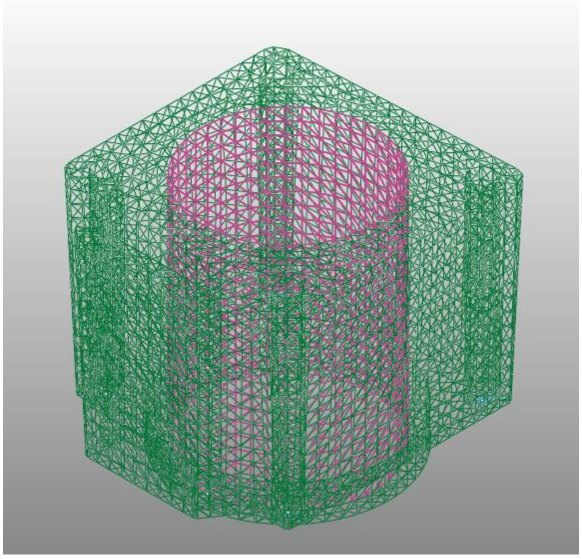


7. Also, for the **Piston**, use the **Piston.rfi** file and replace the piston with that of an **RFlex Body** in the same way as above.

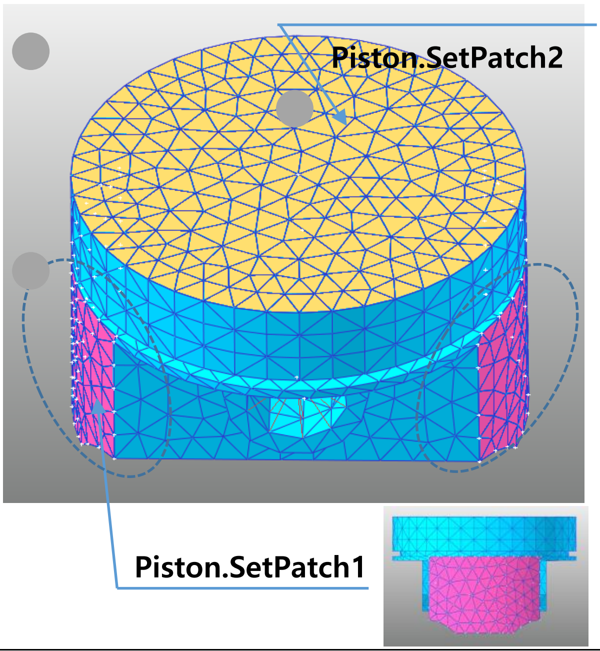
Creating PatchSet

1. From the **Working Window**, select the **Cylinder Body** and double-click it.

2. When you entered the **Flex Edit Mode**, click the **Patch Set** icon in the **Set** group under the **RFlex Edit** tab to create a PatchSet.



3. From the **Patch Set** dialog window, click the **Add/Remove (Continuous)** button and select one of patches placed at the inner side of the cylinder body.
4. Click **Finish Operation** from the context menu that appears when you right-click, press the **OK** button to close the **Patch Set** dialog window. You will see that **SetPatch1** is created.
5. Click the **Exit** icon to return to the **Assembly Mode**, select the **Piston Body** again and double-click it.
6. To create a **PatchSet**, click the **Patch Set** icon in the **Set** group under the **RFlex Edit** tab.
7. For the **Piston Body**, create two patch sets, one at the top where the gas explosion pressure will be applied and the other for piston lubrication.

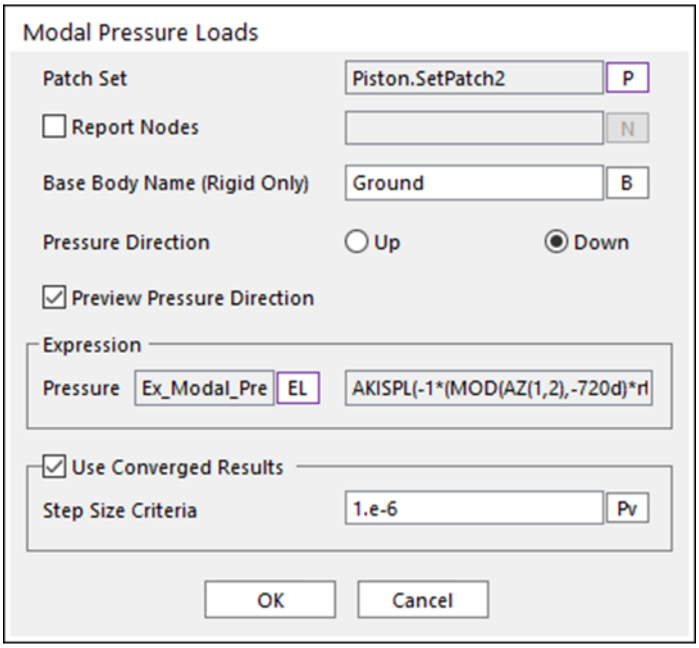


8. Click the **Exit** icon to return to the **Assembly Mode**.

Defining Modal Pressure Load to Piston

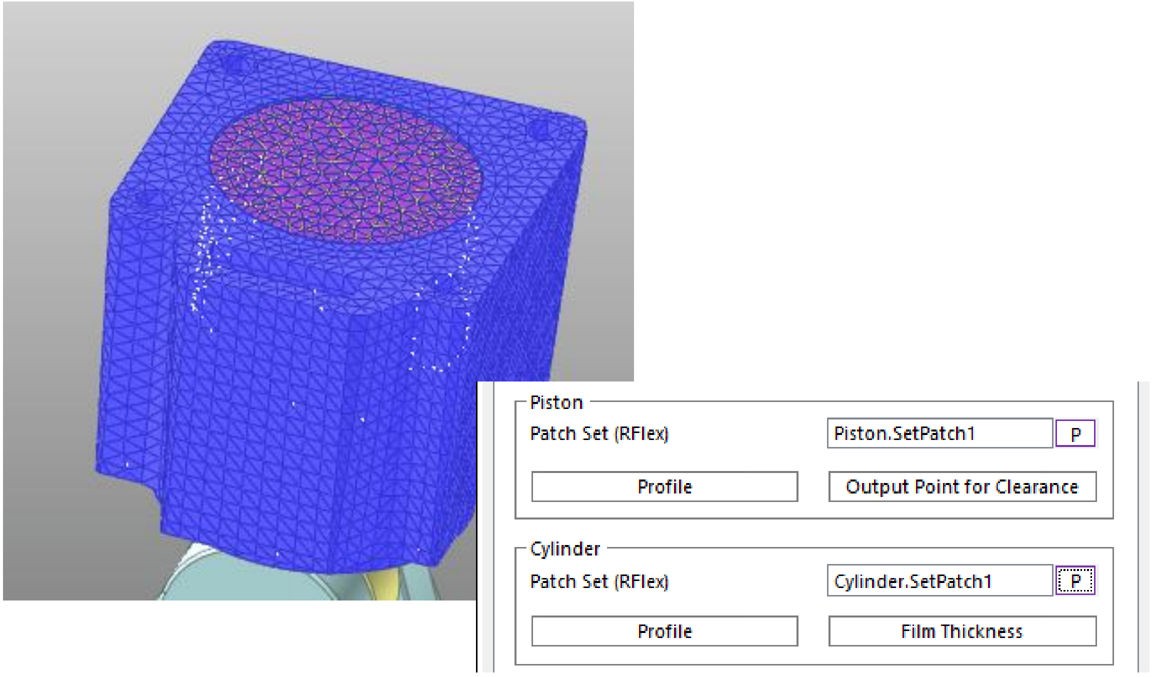
1. Delete **Translational1** used for the rigid body model.

2. Click the **Modal Pressure Load** icon in the **RFlex** group under the **Flexible** tab.
3. For the patch set, select **Piston.SetPatch2 (PatchSet at the top of the piston)**, which was previously created, from the **Modal Pressure Loads** dialog window.
4. Change the **Pressure Direction** option to **Down** so that the pressure is applied to the piston.
5. Click the **EL** button. From the **Expression List** dialog window, select the **EX_Modal_Pressure** field and set the pressure value.



Configuring RFlex Body PatchSets for Piston Lubrication

1. Open the **Properties** dialog window for **Lubrication1**.
2. Enter **Patch Sets** for the cylinder and the piston respectively.

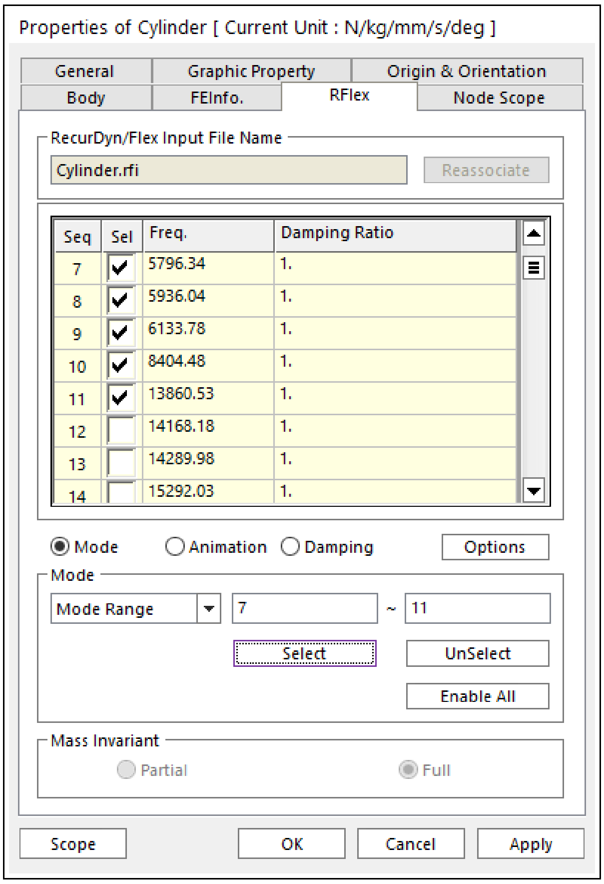


Performing Dynamic Analysis on Piston Lubrication and Checking Its Result

To reduce the number of RFlex body modes:

10 or more modes exist for each Rflex body. To shorten the analysis time, use only 5 modes for each body.

1. Right-click **Cylinder Body** and select **Property** in the context menu.
2. Select the **Mode** option under the **RFlex** tab in the **Properties** dialog window for **Cylinder Body**.
3. Select **Mode Type** for the **Mode Range** and click the **UnSelect** button to deselect all the modes.
4. Enter **7 - 11**, click the **Select** button and make sure that 5 consecutive modes are checked starting from the mode no. 7.
5. Also, for the **Piston Body**, select only 5 modes in the same way as above.



To run the simulation for piston lubrication:

1. Save the model as PistonLubricationEHD _RFlex.rdyn.
2. On the **Analysis** tab, in the **Simulation Type** group, click the **Dyn/Kin** icon.
3. The **Dynamic/Kinematic Analysis** dialog window appears.
4. Change the **End Time** field to **0.03** and the **Step** field to **1000** and click the **Simulation** button.
    - It will take approximately 34 minutes for the analysis.

Chapter 5

Analyzing the Results

Task Objectives

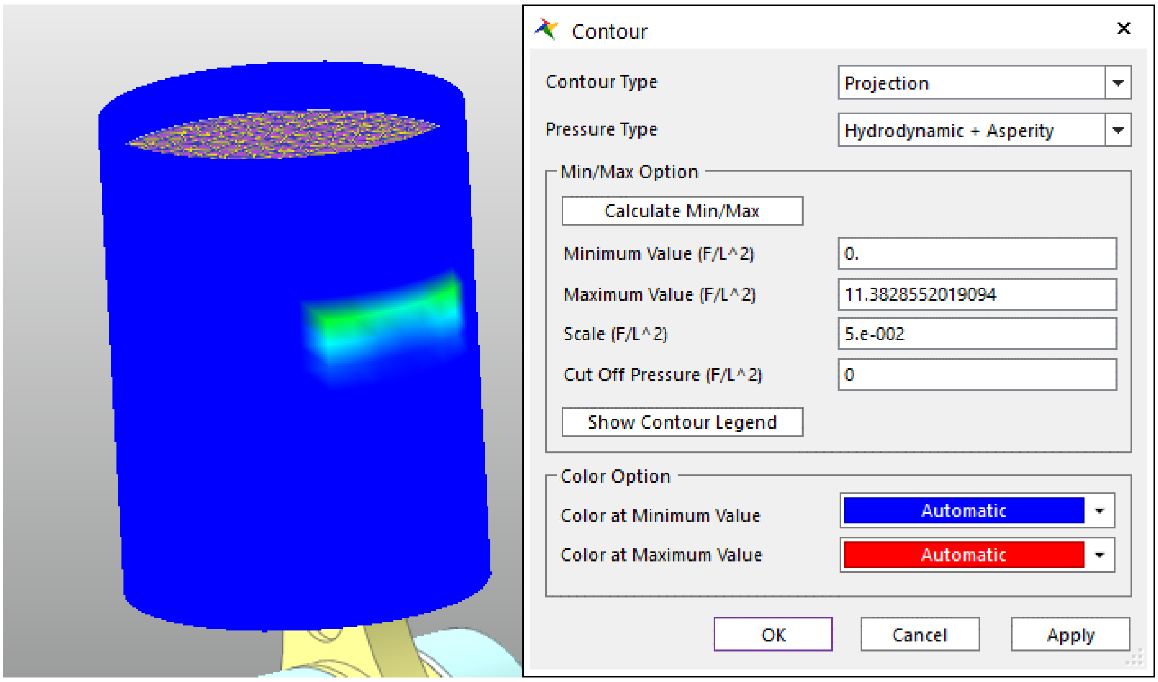
In this chapter, we will check the results of an analysis performed on the previously defined model.

Estimated Time to Complete This Task

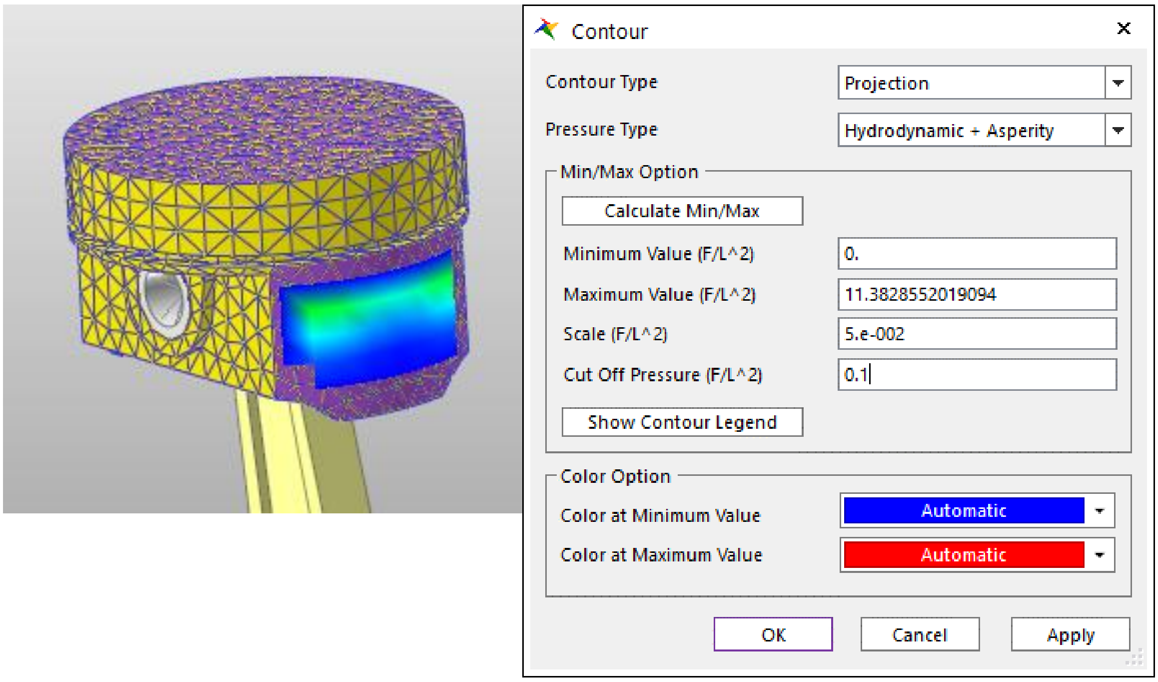
10 minutes

Viewing Contour Result

1. Uncheck the **Show All** option in the **Layer Settings** dialog window to hide the cylinder and display only **Layer 1**.
2. Right-click **Lubrication1** and select **Property** in the context menu.
3. Check the **Show Pressure Contour** option and click the **Contour Setting** button.
4. Select **Hydrodynamic + Asperity** for the **Pressure Type** field to check all the forces of the lubrication and click the **Apply** button to check the **Contour**.

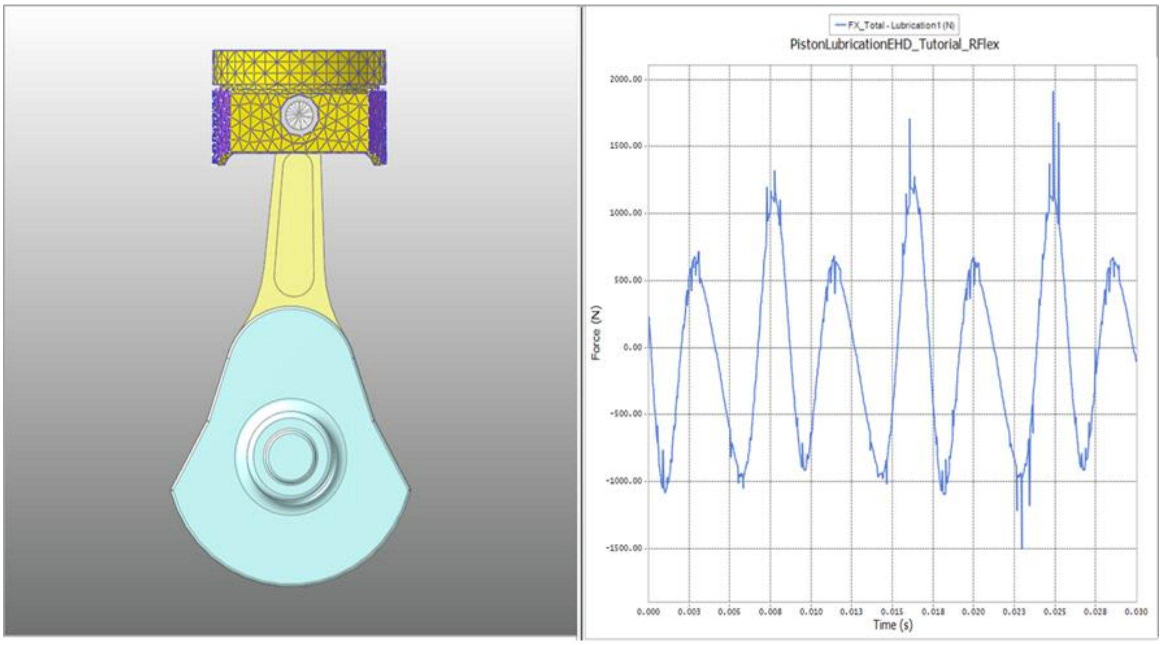


5. To view only the skirt section of the piston, enter **0.1** in the **Cut Off Pressure** field in the **Contour** dialog window and click the **Apply** button to check the **Contour**.



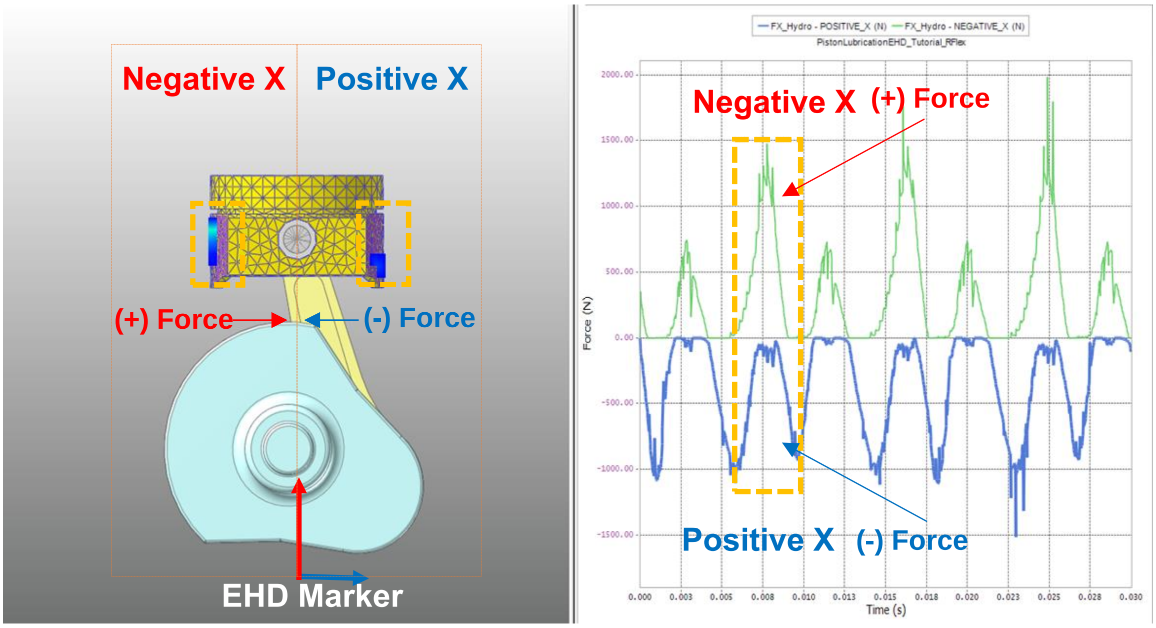
Viewing Plot Result

1. Click the **Plot Result** icon in the **Plot** group under the **Analysis** tab.
2. From the **Plot Window**, click the **Show Upper Windows** icon in the **Windows** group under the **Home** tab.
3. In the widow at the left, click the **Load Animation** icon in the **Animation** group under the **Tool** tab. In the widow at the right, select the **Force/ PistonLubrication EHD Force/Lubrication1/Total/FX_Total** option in **Plot Database** to draw a plot.



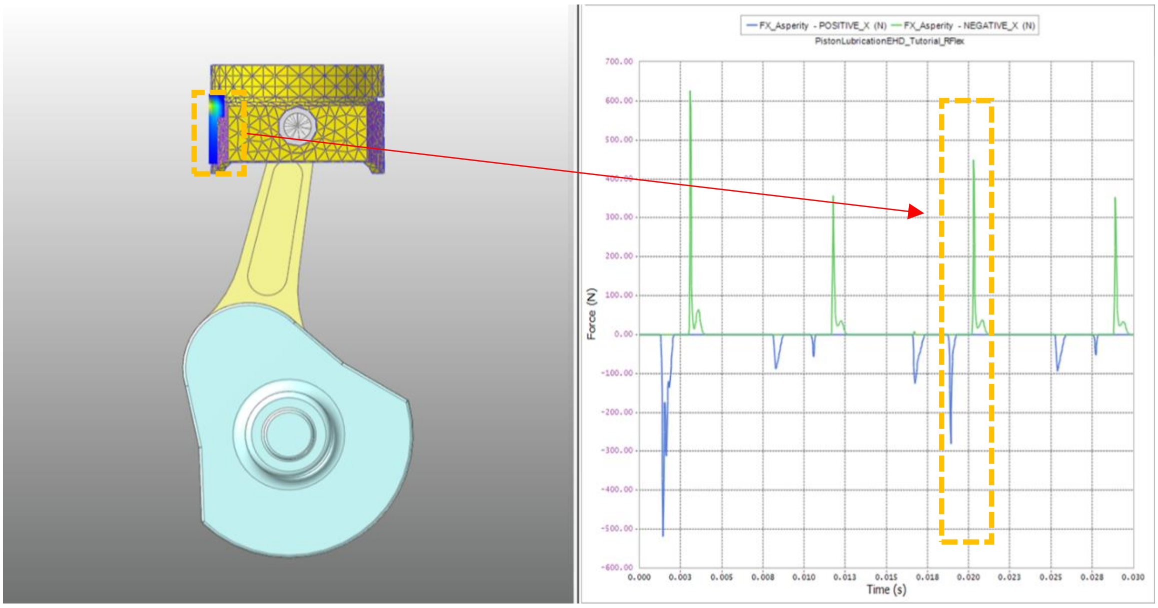
4. Clear the plot drawn just before. From **Plot Database**, select the following two data items to draw them:

   - **Force/PistonLubrication EHD Force/Lubrication1/HydroDynamicForce/POSITIVE_X/FX_Hydro**
   - **Force/PistonLubrication EHD Force/Lubrication1/HydroDynamicForce/NEGATIVE_X/FX_Hydro**



5. Click the **Add Page** icon in the **Windows** group under the **Home** tab to add a page to the **Plot Window**. From **Plot Database**, select the following two data items to draw them:

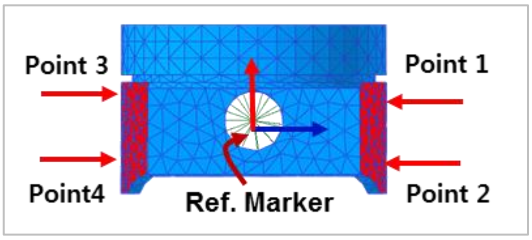
   - **Force/PistonLubrication EHD Force/Lubrication1/AsperityContactForce/POSITIVE_X/FX_Asperity**
   - **Force/PistonLubrication EHD Force/Lubrication1/AsperityContactForce /NEGATIVE_X/FX_Asperity**

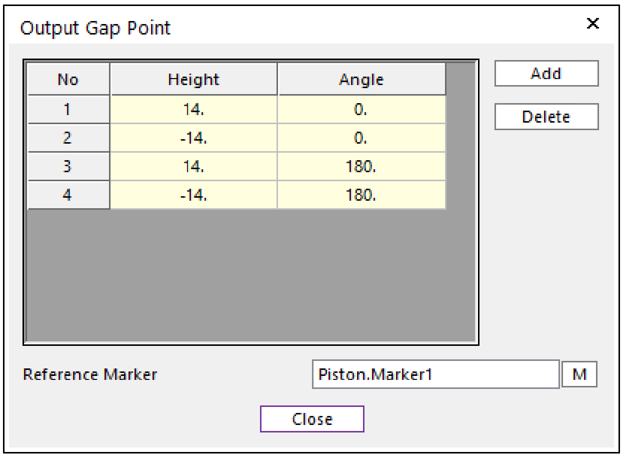


- From the plot and contour results, you can check the contact point and the magnitude of the force over time.

Checking Oil Film Thickness at Desired Points

1. Go back to the **Modeling Window**, right-click **Lubrication1** and select **Property** from the context menu.
2. Click the Output Point for Clearance button in the Properties dialog window for Lubrication1.
3. To check lubrication depths at the points shown in the figure to the right, set the **Output Gap Point** dialog window as follows:
   a. Enter **Pistion.Marker1** in the **Reference Marker** field.
   b. Click the **Add** button several times to enter information as follows:
      1) Height: 14, Angle: 0
      2) Height: -14, Angle: 0
      3) Height: 14, Angle: 180
      4) Height: -14, Angle: 180
   c. Click the **Close** button to close the dialog window.





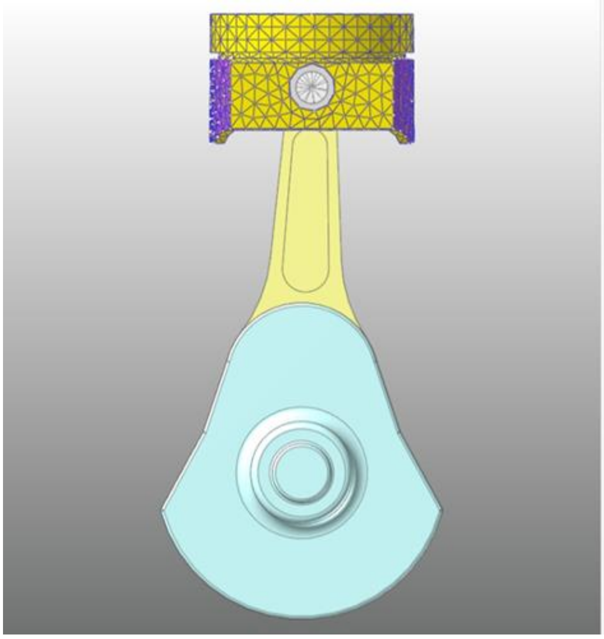
Output Gap Point

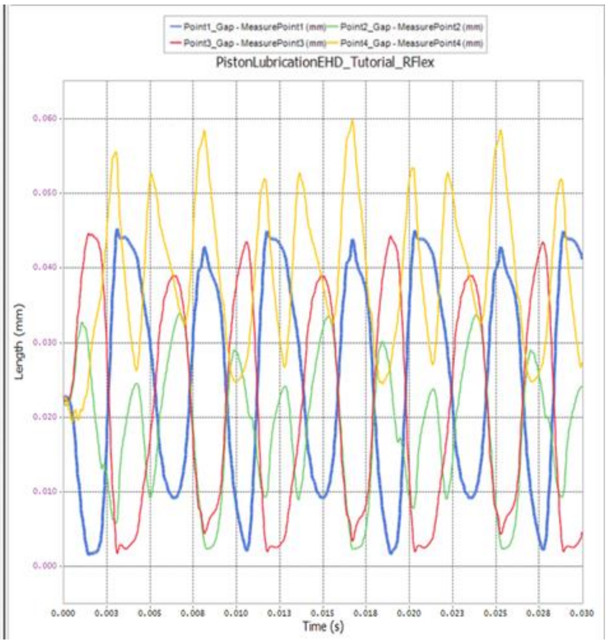
No	Height	Angle
1	14.	0.
2	-14.	0.
3	14.	180.
4	-14.	180.

Add
Delete
Reference Marker: Piston.Marker1 M
Close

4. To check the values, perform the analysis again.
5. Click the **Plot Result** icon in the **Plot** group under the **Analysis** tab.
6. From the **Plot Window**, click the **Show Upper Windows** icon in the **Windows** group under the **Home** tab.

7. In the window at the left, click the **Load Animation** icon in the **Animation** group under the **Tool** tab. In the window at the right, select the 4 data items under the **Force/ PistonLubrication EHD Force/Lubrication1/MeasurePoints** option in **Plot Database** to draw all of them.





Chapter

6

Modifying Piston Profile and Analyzing Piston Lubrication

Task Objectives

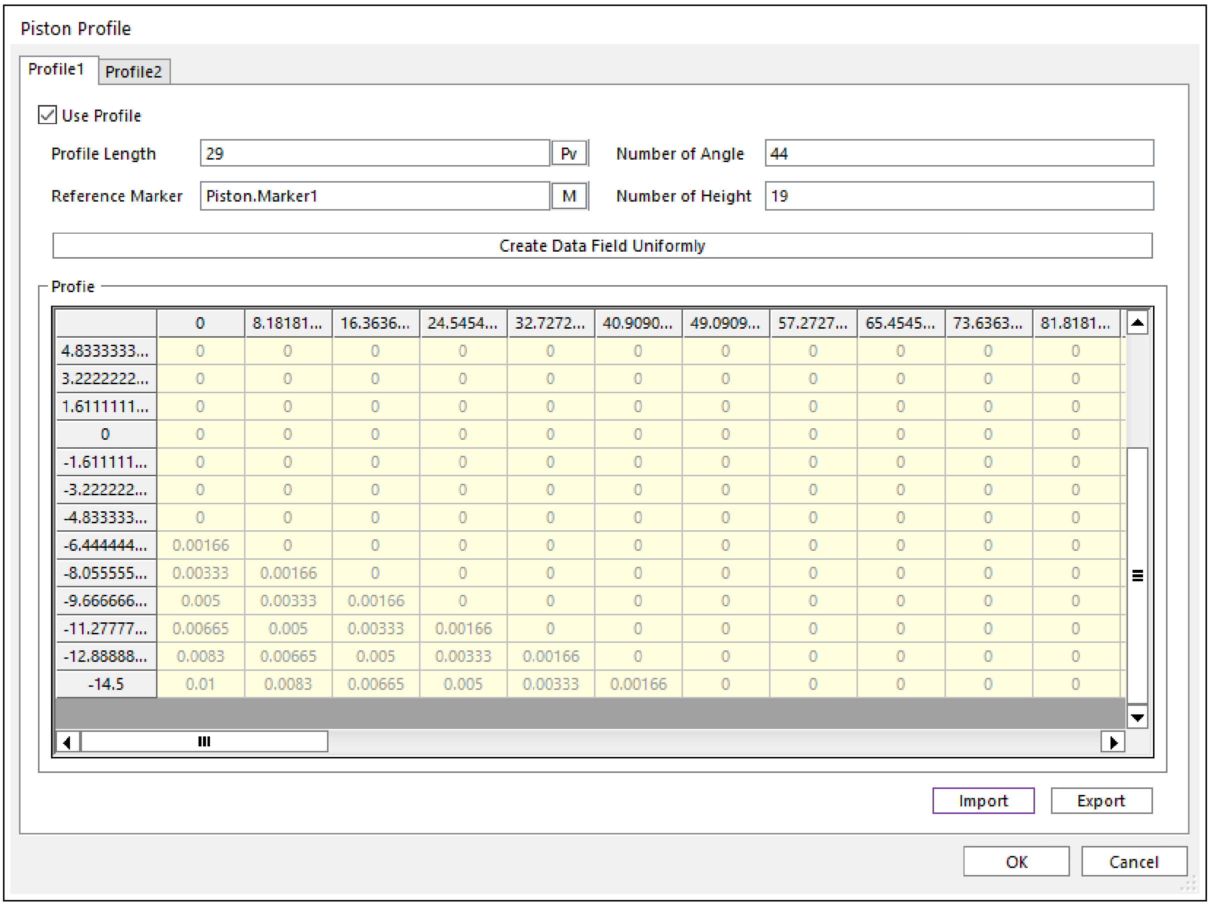
In this chapter, you will learn how to analyze piston lubrication by changing the piston profile without modifying the previously defined RFlex model.

Estimated Time to Complete This Task

10 minutes

Modifying Piston Profile

1. Right-click **Lubrication1** and select **Property** in the context menu.
2. Click the **Profile** button in the **Piston** group under the **Properties** dialog window for **Lubrication1**.
3. When the **Piston Profile** dialog window appears, check the **Use Profile** option and enter values for the parameters to set the profile as follows:
   - **Profile Length: 29**
   - **Number of Angle: 44**
   - **Reference Marker: Piston.Marker1**
   - **Number of Height: 19**
4. From the **Piston Profile** dialog window, click the **Create Data Field Uniformly** button and the data will be generated automatically for each angle and height.
5. Click the **Export** button to export the generated data.
   - You cannot modify the data in the **Piston Profile** dialog window. Export the data to a file and use Excel or a text editor to modify the data in the file.
6. Click the **Import** button to import the **ProfileData.csv** file provided in this tutorial. (File path: <Install Dir>\Help\Tutorial\Toolkit\EHD\PistonLubrication)



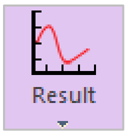
	0	8.18181...	16.3636...	24.5454...	32.7272...	40.9090...	49.0909...	57.2727...	65.4545...	73.6363...	81.8181...
4.8333333...	0	0	0	0	0	0	0	0	0	0	0
3.2222222...	0	0	0	0	0	0	0	0	0	0	0
1.6111111...	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
-1.611111...	0	0	0	0	0	0	0	0	0	0	0
-3.222222...	0	0	0	0	0	0	0	0	0	0	0
-4.833333...	0	0	0	0	0	0	0	0	0	0	0
-6.444444...	0.00166	0	0	0	0	0	0	0	0	0	0
-8.055555...	0.00333	0.00166	0	0	0	0	0	0	0	0	0
-9.666666...	0.005	0.00333	0.00166	0	0	0	0	0	0	0	0
-11.27777...	0.00665	0.005	0.00333	0.00166	0	0	0	0	0	0	0
-12.88888...	0.0083	0.00665	0.005	0.00333	0.00166	0	0	0	0	0	0
-14.5	0.01	0.0083	0.00665	0.005	0.00333	0.00166	0	0	0	0	0

7. Click the **OK** button in the **Piston Profile** dialog window to close it as well as to apply the data to the model. Click the **OK** button in the **Properties** dialog window for **Lubrication1**.

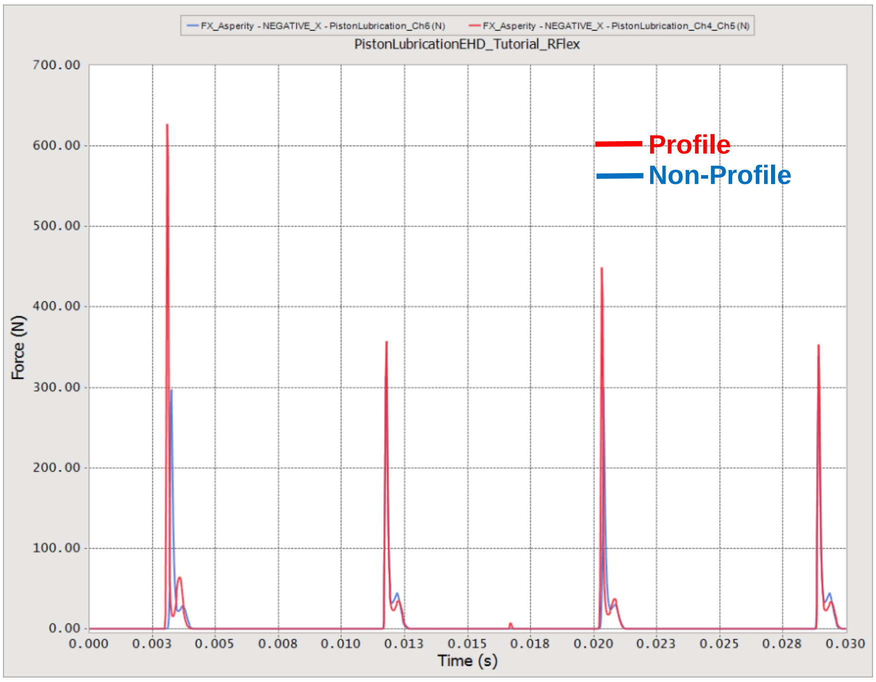
Analysis and Comparison

1. Save the model as **PistonLubricationEHD _RFlex2.rdyn**.

2. On the **Analysis** tab, in the **Simulation Type** group, click the **Dyn/Kin** icon.
3. The **Dynamic/Kinematic Analysis** dialog window appears.
4. After verifying the simulation conditions, click **Simulation**.



5. Click the **Plot Result** icon in the **Plot** group under the **Analysis** tab.
6. From the **Plow Window**, import the rplt file, which is the result of previous analysis.
7. Right-click the **Force/PistonLubrication EHD Force/Lubriation1/AsperityContactForce/NEGATIVE_X/FX_Asperity** data from **Plot Database** and click **Multi Draw** from the context menu.



- You will see that the result changes according to the piston profile.

Thanks for participating in this tutorial!