

# RecurDyn/EHD Tutorial

Piston Lubrication

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FunctionBay, Inc.

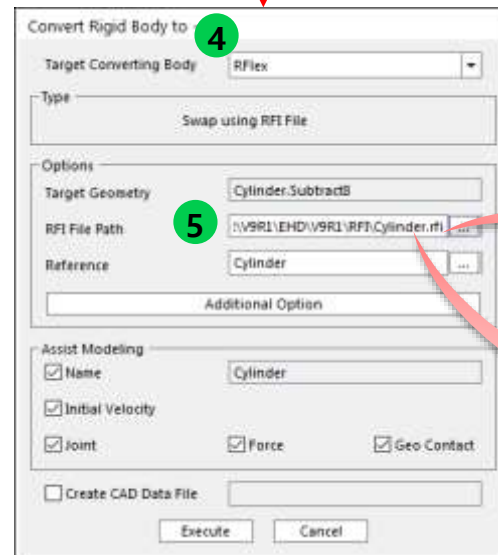
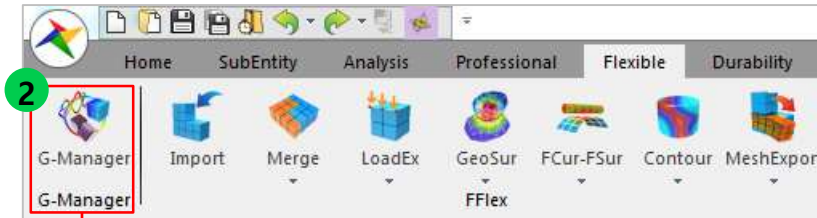
# Step 01 – Import RFlex Bodies

## Steps

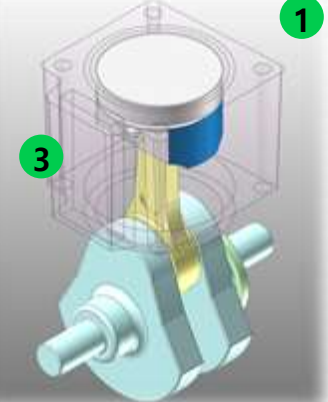
- 1 Open the  
"PistonLubricationEHD\_  
Tutorial\_Start.rdyn" model in  
RecurDyn V9R1
- 2 Select **G-Manager** icon in G-  
Manager group of Flexible tab
- 3 Select the **Cylinder** rigid body.
- 4 In G-Manger dialog, change the  
"Target converting body" to  
"RFlex"
- 5 Specify the RFI file in the "RFI  
File Path" input field using the  
already provided "Cylinder.rfi"  
and click **Execute**.
- 6 **Swap** the **Piston** body as same  
as above STEP 2~5, using the  
provided "Piston.rfi" file.
- 7 **Save** the model as  
"PistonLubricationEHD\_Tutorial\_R  
flex.rdyn"

※ You can simulate and review the result of  
EHD applied to the rigid bodies.

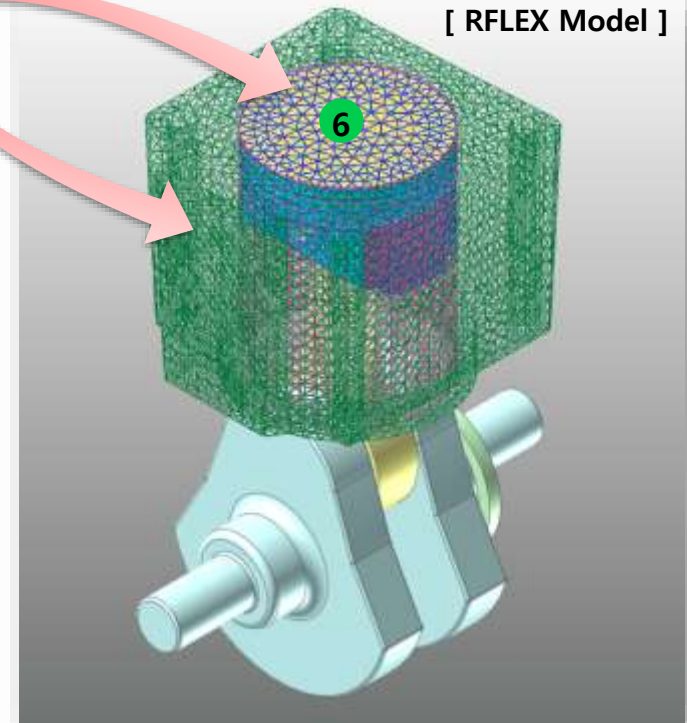
*PistonLubricationEHD\_Tutorial\_Rigid.rdyn*



[ Rigid Model ]



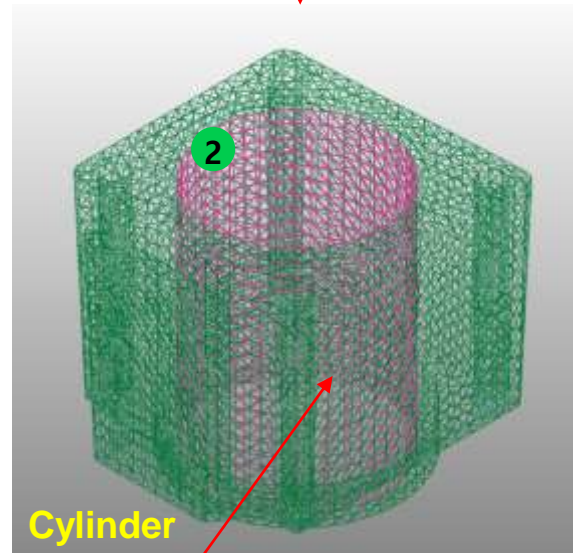
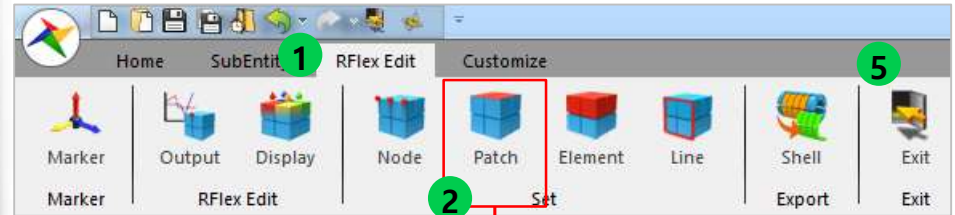
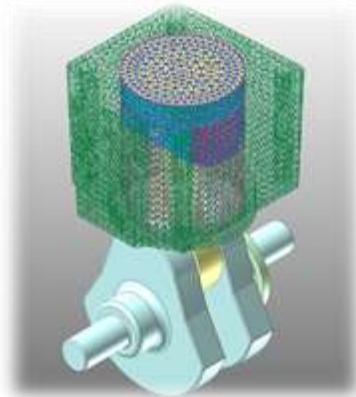
[ RFLEX Model ]



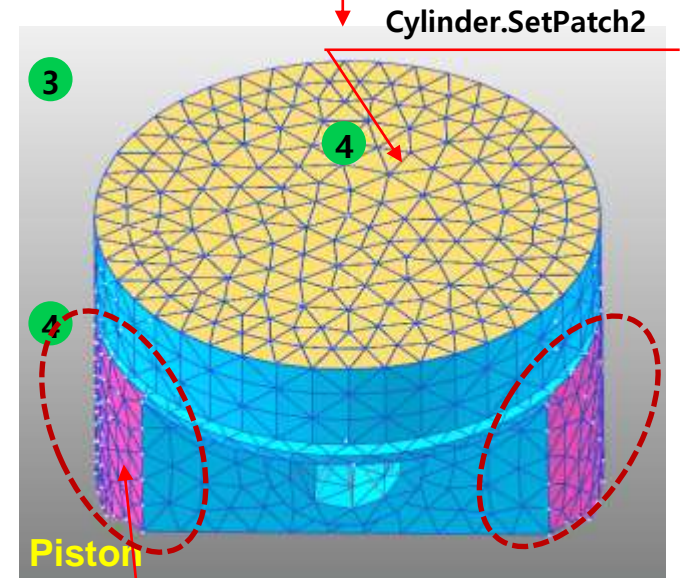
# Step 02 – Make a PatchSet

## Steps

- ① Enter the **edit mode** of the Cylinder Body to create the PatchSet.
- ② Create **PatchSet** as an EHD **Cylinder Wall** as shown figure. (Use Add/Remove (Continuous))
- ③ **Exit** the **edit-mode**, and **enter** the **Piston** body.
- ④ Create **2 PatchSets** as for Piston. (**SetPatch1** using both side surfaces to apply EHD and **SetPatch2** using the upper surface to apply Gas-force Pressure) as shown in the figure.
- ⑤ **Exit** the **edit-mode**.



Cylinder.SetPatch1



Cylinder.SetPatch1

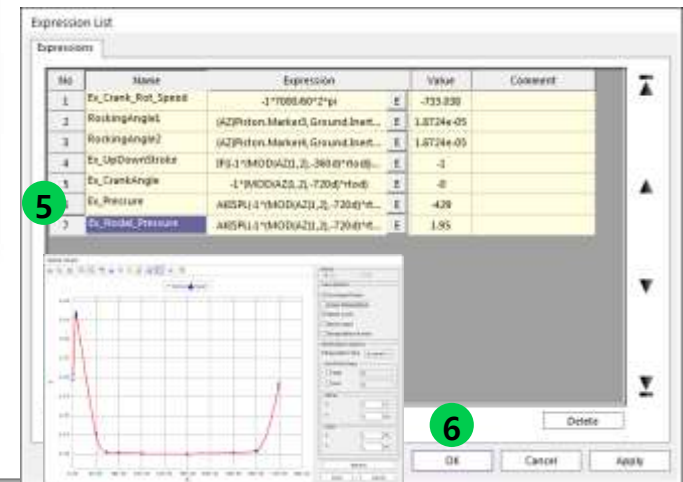
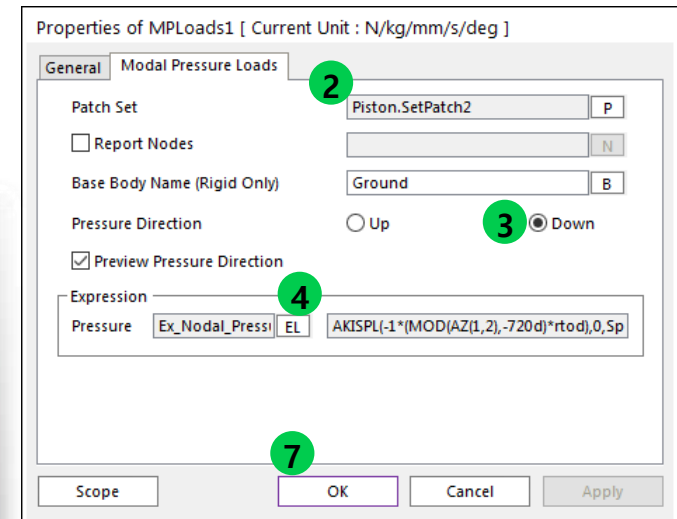
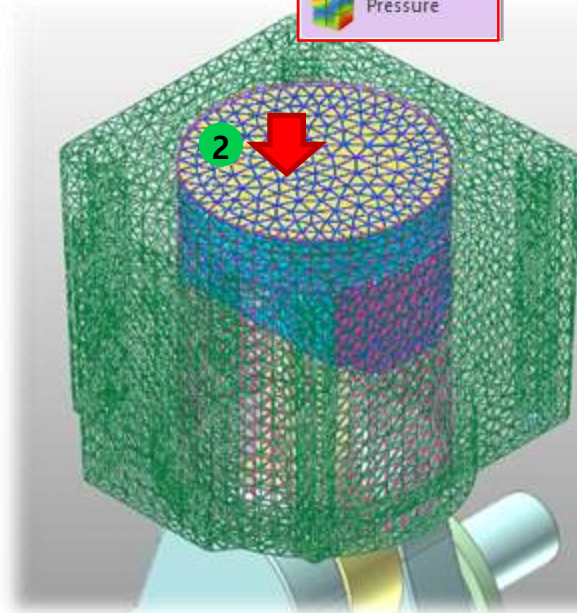


# Step 03 – Create the Modal Pressure to the Piston

## Steps

- ① Select **"Pressure"** icon (**Modal Pressure Load**) in **RFlex Group** of **Flexible** tab.
- ② In a Modal Pressure Load dialog, set **Piston.SetPatch2** as the **Patch Set**
- ③ Change the **Pressure Direction** from "Up" to **"Down"** direction
- ④ Click the **EL** button of **[Expression]-[Pressure]**.
- ⑤ In the Expression List dialog, **select** the **"Ex\_Nodal\_Pressure"** expression.
- ⑥ Close Expression List dialog
- ⑦ Click the "OK" to close the dialog.

※ The firing gas force is defined by Function Expression. In that expression, the gas force will be generated using a spline curve w.r.t the Crank Angle vs. Gas Force

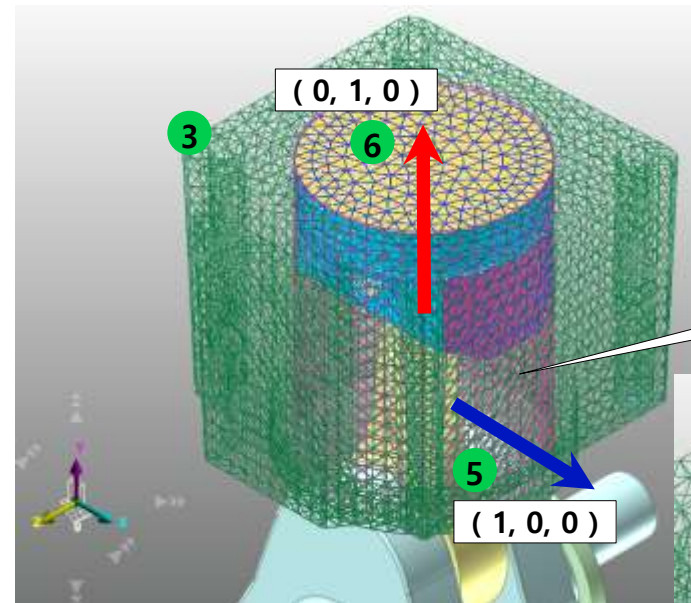
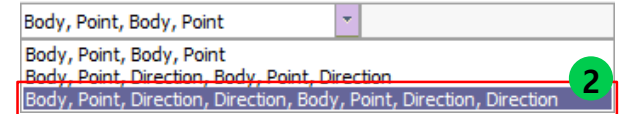




# Step 04 – Create Piston Lubrication EHD Entity

## Steps

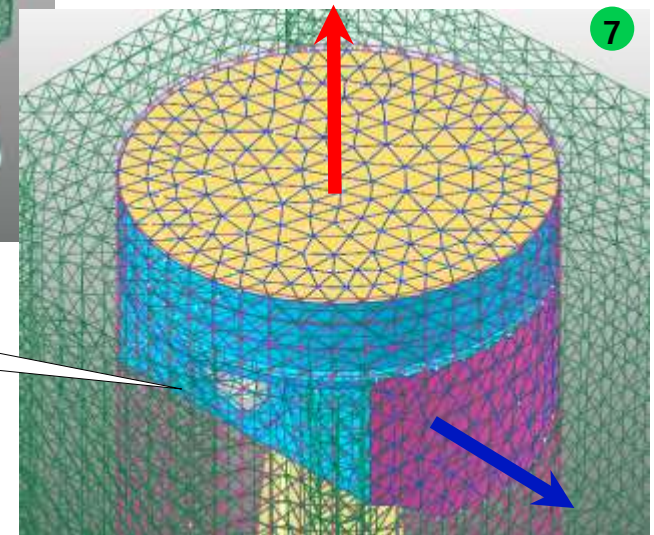
- ① Select **PistonLub** icon in the Toolkit group of the Toolkit tab.
- ② Set the **Creation option** to “**Body,Point,Direction,Direction,Body,Point,Direction,Direction**” (You can define the EHD axis more clearly)
- ③ Choose the **Cylinder** RFlex Body as Base-body of EHD
- ④ Pick the **Center Point of Base Body (Cylinder)**. In this tutorial, it is “0,-46.5,0”
- ⑤ Set the **direction #1 of Base-Body** to Global Y Axis (0, 1, 0)  
→ Y-axis direction of Base Marker
- ⑥ Set the **direction #2 of Base-Body** to Global X Axis (1, 0, 0)  
→ X-axis direction of Base Marker
- ⑦ Define the **Action Body** as same as above steps 3 ~ 6
  - Action Body: Piston
  - Center Point: 0,-29.5,0
  - Direction #3: Global Y Axis
  - Direction #4: Global X Axis
- ⑧ Lubrication1 is created.



④ Cylinder EHD Position:  
( 0, -46.5, 0 )

Piston EHD Position:  
( 0, -29.5, 0 )

**X, Y Axis Directions of both bodies MUST BE SAME!**



# Step 05 – Define the EHD Geometry Properties

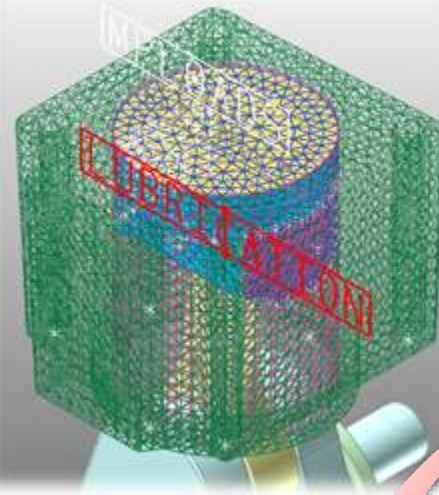
## Steps

### [EHD Geometry Setting]

- ① Open the Properties Dialog of **Lubrication1** (PistonLub EHD)
- ② Input the EHD Geometry **Properties** as below:
  - Piston Diameter: 70
  - Piston Height: 29
  - Cylinder Diameter: 70.045
  - Cylinder Height: 95
- ③ Input "**Piston.SetPatch1**" in the **Piston PatchSet** field.
- ④ Input "**Cylinder.SetPatch1**" in the **Cylinder PatchSet** field.

### [Mesh Grid Setting]

- ⑤ Click the "**Mesh Grid Setting**" button.
- ⑥ In the Mesh Grid Setting dialog,
  - **Circumference Node No.:** 42
  - **Axial Node No.:** 21
- ⑦ Open the "**Oil Hole\_Groove Effect Setting**" dialog, and check on the "**View Nodes**", then you can see the Mesh Grid Display.
- ⑧ Close the dialog.



1 Properties of Lubrication1 [ Current Unit : N/kg/mm/s/deg ]

General Connector Lubrication

Piston Diameter 70. Pv

Piston Height 29. Pv

Cylinder Diameter 70.045 Pv

Cylinder Height 95. Pv

Dynamic Viscosity[Pa.s] 6.e-03 Pv

2

5 Mesh Grid Setting Adjust Node Position

Additional Options Solver Setting

Piston Patch Set (RFlx) Piston.SetPatch1 P 3

Profile Output Point for Clearance

Cylinder Patch Set (RFlx) Cylinder.SetPatch1 P 4

Profile Film Thickness

Mesh Grid Setting

Circumference Node No. 44 6

Axial Node No. 19

7 Oil Hole\_Groove Effects Setting

Close

### Tips: How to decide the No. of Mesh Grid

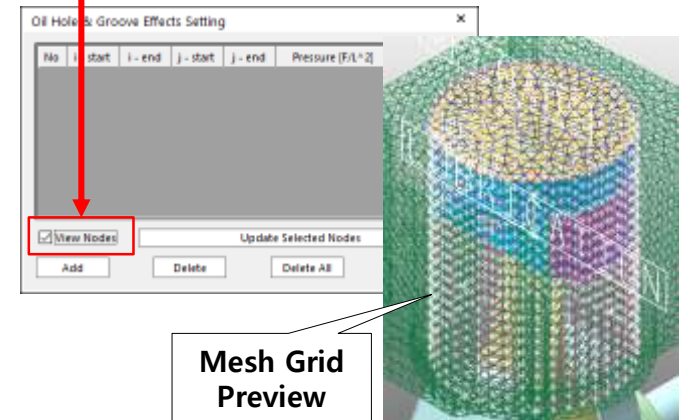
To improve the efficiency of the simulation of RecurDyn/EHD Model, make the length of the mesh grid similar to the maximum gap between piston and cylinder.

In the Tutorial, In this tutorial, the maximum gap is about 5 mm.

The circumference length is  $\pi \times 70.045 = 220.05$  and height is "95"

Therefore, the recommended values are:

- Circumference Node No. is 44 ( $5 \times 44 = 220$ )
- Axial Node No. is 19 ( $5 \times 19 = 95$ )



# Step 06 – Define the EHD Material Properties

## Steps

- ① In the property dialog of **Lubrication1**, Input the **Dynamic Viscosity** as "**6e-3**".
- ② Click the "**Additional Options**" button.
- ③ Use "**Direct Input**" in Asperity Contact Information.
- ④ Input the values as shown below:
  - **Roughness: 0.001**
  - **Composite Elastic Modulus: 68000**
  - **Elastic Factor: 0.003**
  - **Friction Coefficient: 0.5**
- ⑤ Close the dialog

Properties of Lubrication1 [ Current Unit : N/kg/mm/s/deg ]

General Connector Lubrication

Piston Diameter 70. Pv

Piston Height 29. Pv

Cylinder Diameter 70.045 Pv

Cylinder Height 95. Pv

Dynamic Viscosity[Pa.s] 6.e-03 Pv

Mesh Grid Setting Adjust Node Position

Additional Options Solver Setting

Piston Patch Set (RFlex) Piston.SetPatch1 P

Profile Output Point for Clearance

Cylinder

Additional Options

Viscosity Information

Pressure-Viscosity Coefficient[1/Pa] 0. Pv

Asperity Contact Information

Direct Input Each Parameter

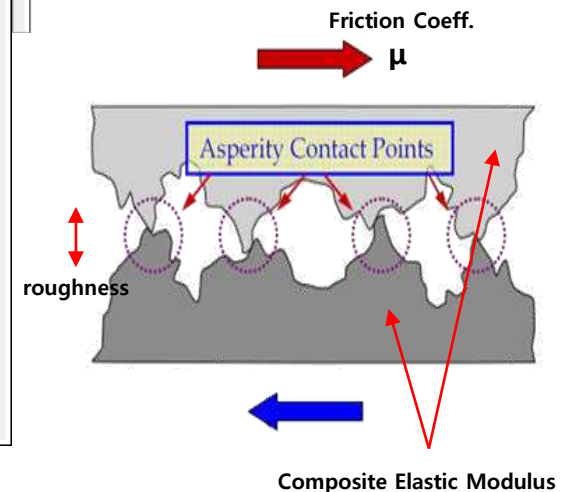
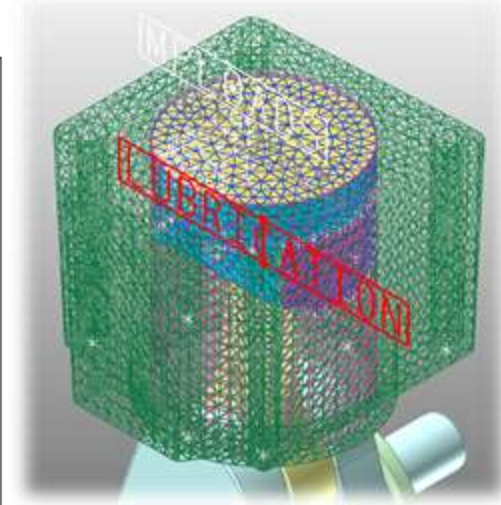
Roughness[L] 1.e-03 Pv

Composite Elastic Modulus[F/L] 68000. Pv

Elastic Factor 3.e-03 Pv

Friction Coefficient 0.5 Pv Friction

Close

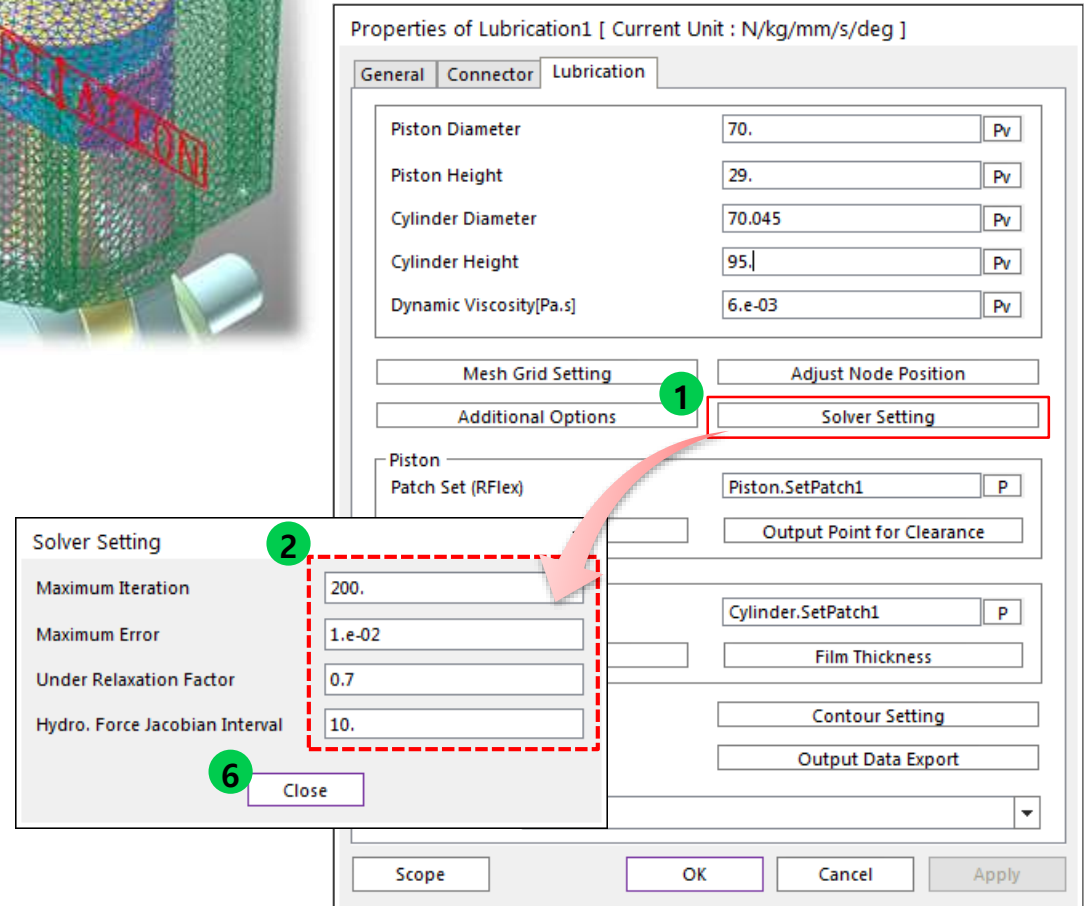
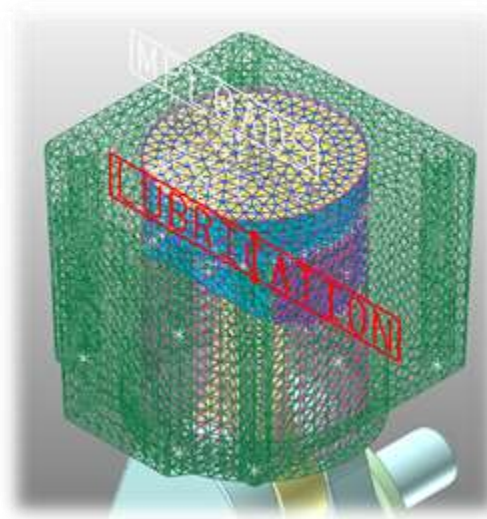




# Step 07 – Set the EHD Solver Settings

## Steps

- ① In the property dialog of **Lubrication1**, click the “**Solver Setting**” button
- ② Set the number of “**Maximum Iteration**” to “**200**”
- ③ Set the “**Maximum Error**” to “**1e-2**”
- ④ Set the “**Under Relaxation Factor**” to “**0.7**”
- ⑤ Set the “**Hydro. Force Jacobian Interval**” to “**10**”  
(The bigger the value that you use, the faster the solving speed can be. However, increasing this value can reduce the accuracy)
- ⑥ **Close** the dialog





# Step 08 – Run EHD Dynamic Analysis

## Steps

- ① Open the property dialog of **Cylinder** RFlex Body, and select only **5 mode shapes** (seq 7 ~ seq 11) and close the dialog
- ② Open the property dialog of **Piston** RFlex Body, and select only **5 mode shapes** (seq 7 ~ seq 11) and close the dialog.

※ The more mode shapes are selected, the longer the solving speed would be.

- ③ Select **Dyn/Kin** icon in Simulation Type group of Analysis tab.
- ④ Set the **End Time** to "**3.e-2**"
- ⑤ Set the **Step** to "**1000**"
- ⑥ Click the "**Simulate**" button

**Dynamic/Kinematic Analysis**

General Parameter Initial Condition

End Time: 3.e-2 [Py]

Step: 1000 [Py]

Plot Multiplier Step Factor: 1 [Py]

☐ Output File Name

Include

☐ Static Analysis

☐ Eigenvalue Analysis

☐ State Matrix

☐ Frequency Response Analysis

☐ Hide RecurDyn during Simulation

☐ Display Animation

Gravity

X: 0 Y: -9806.65 Z: 0 [Gravity]

Unit: Newton - Kilogram - Millimeter - Second

[Simulate] [OK] [Cancel]

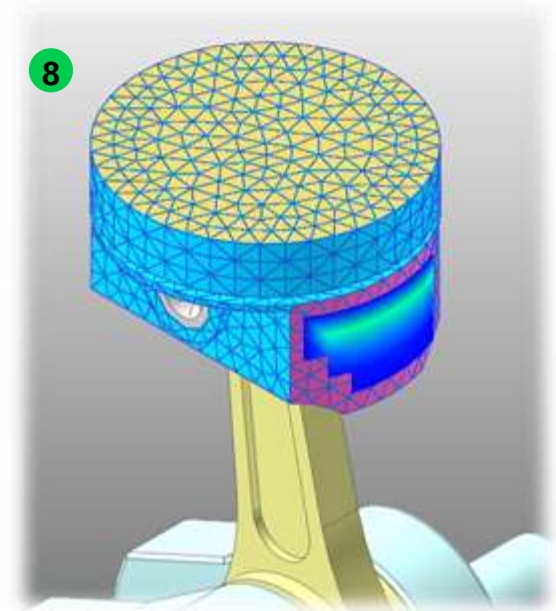
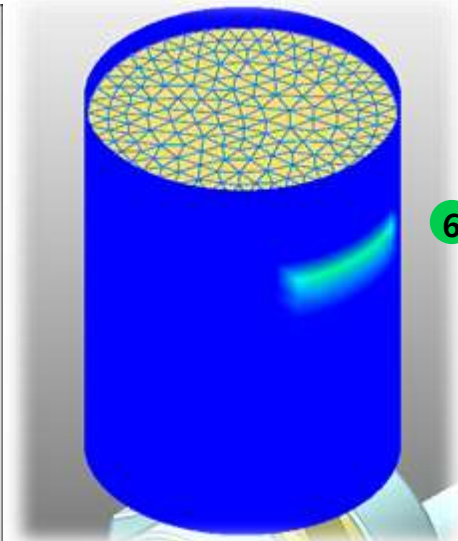
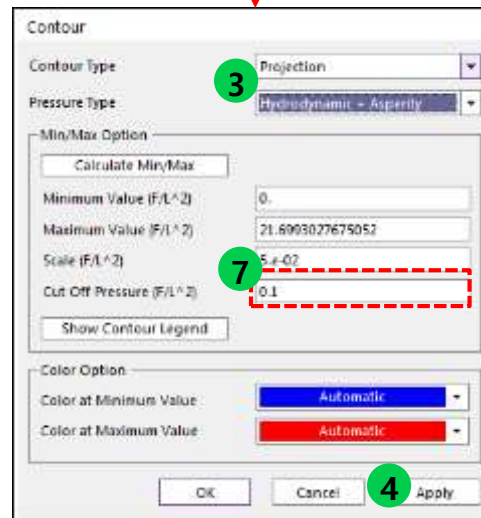
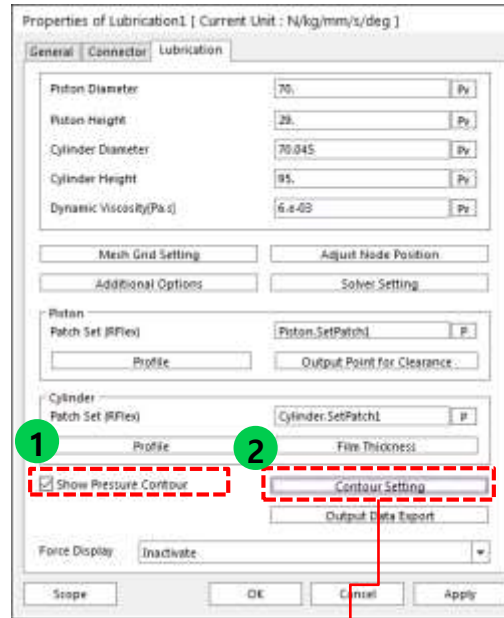
CPU: 4.0 GHz  
RAM: 32.0 GB  
CPU Time: 34 min

# Step 09 – Review the EHD Analysis Results (1)

## Steps

### [EHD Contour Result]

- ① Open property dialog of **Lubrication1** & check on the **"Show Pressure Contour"**
- ② Click the **"Contour Setting"** button
- ③ Set **Pressure Type** to **"Hydrodynamic + Asperity"**
- ④ Click the **Apply** Button
- ⑤ Play the **Animation**
- ⑥ You can see the contour plot of the **EHD force result** in the working plane
- ⑦ Set the **Cut Off Pressure** to **"0.1"**, then click the **Apply** button.
- ⑧ Play the **Animation**, you can see the contour plot and the values less than the Cut Off value will not be displayed.



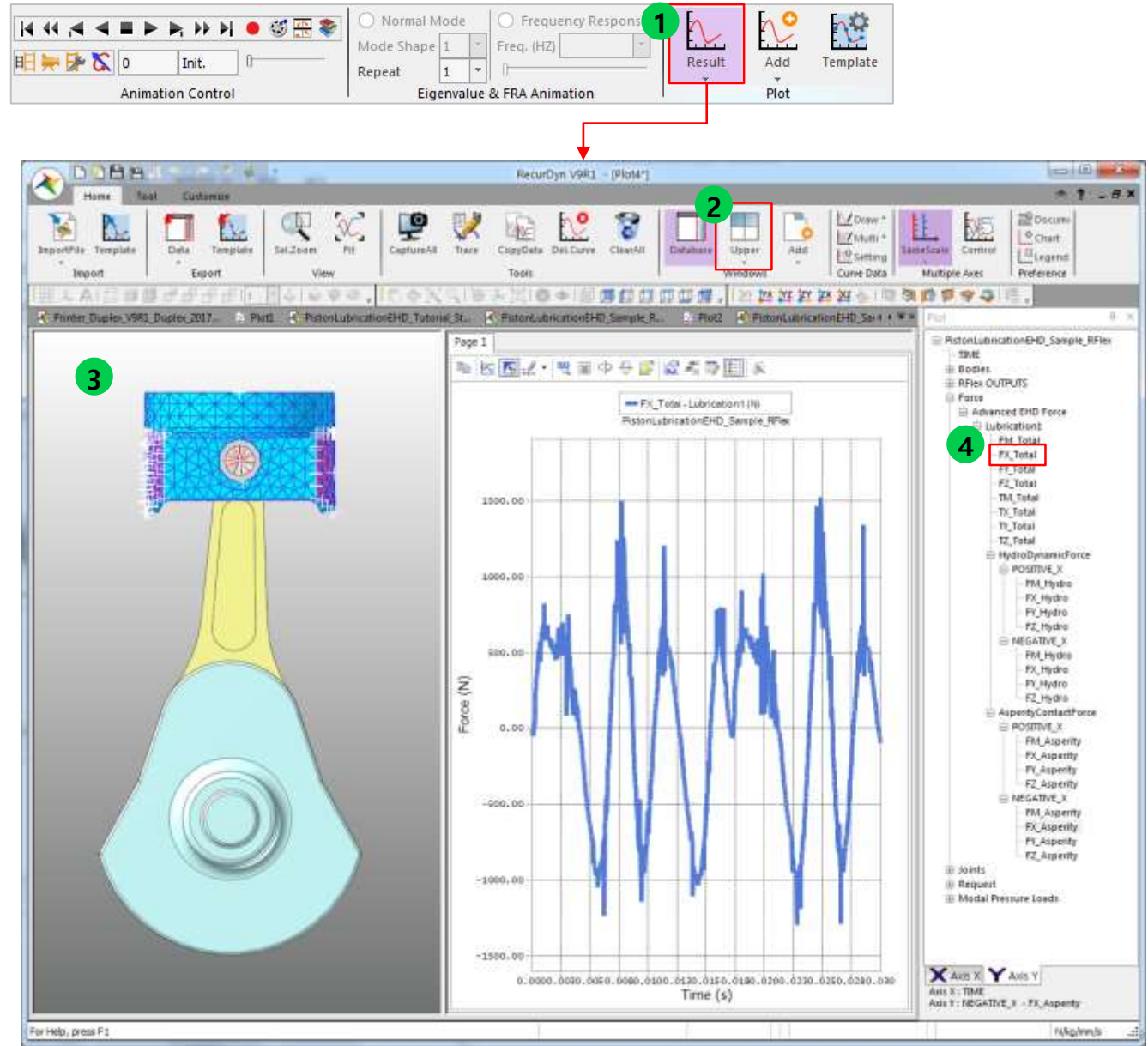
# Step 10 – Review the EHD Analysis Results (2)

## Steps

### [EHD Plot Results]

- ① Select the **"Result"** icon in the Plot group of Analysis Tab.
- ② Select **Upper** icon in Windows group of Home tab to Split the Plot Window
- ③ Load animation to the left-side window. ([Tool]-[Animation]-[LoadAni])
- ④ Click the Right-side Plot window, and **draw the curve** from Plot Database ("**Force/Advanced EHD Force/Lubrication1/FX\_Total**")

※ User can see the Hydro+Asperity Total Lubrication Force between Piston and Cylinder. Also, user can see the contact area in the left-side animation result.





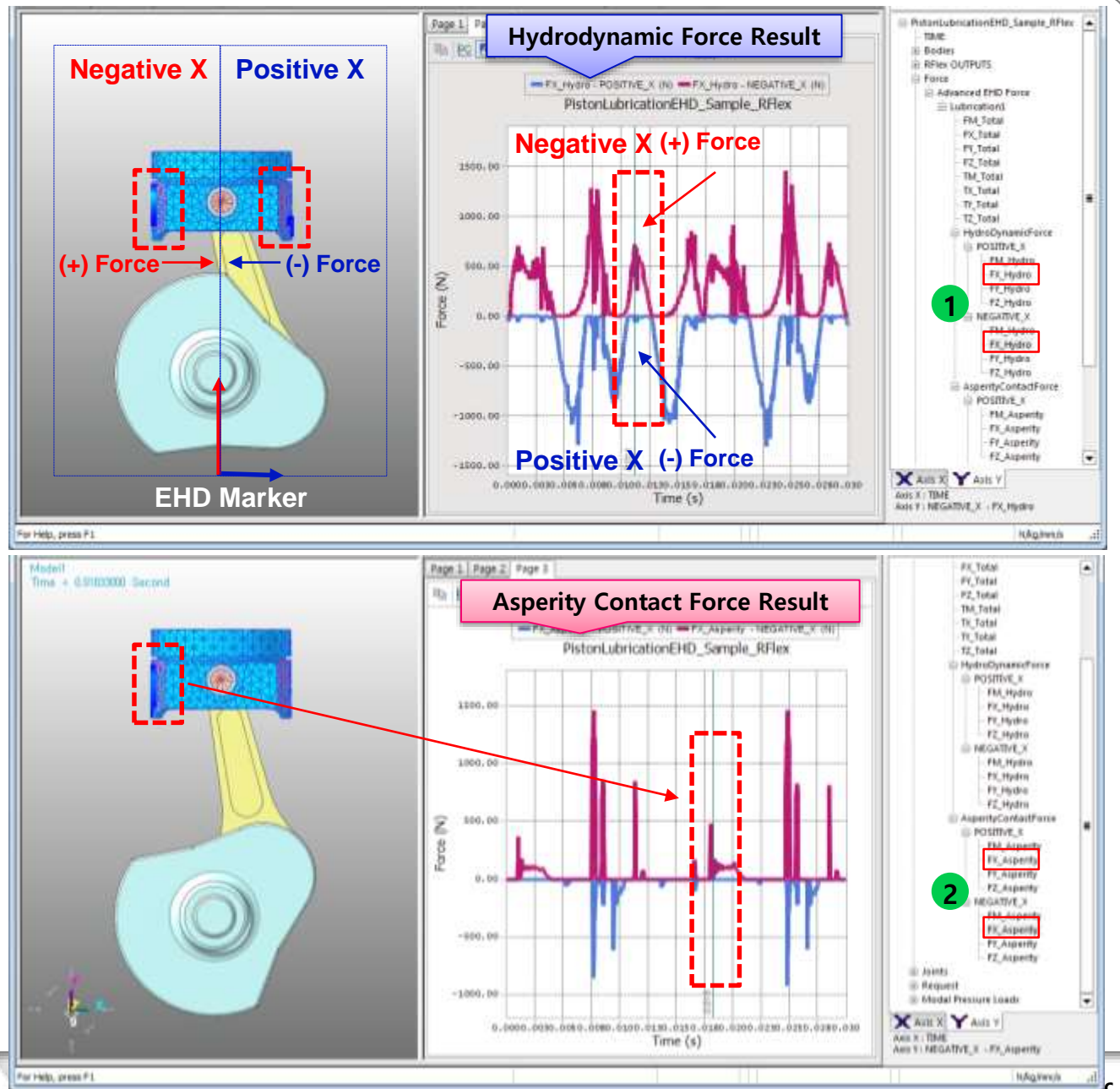
# Step 11 – Review the EHD Analysis Results (3)

## Steps

### [EHD Plot Results]

- ① Draw the curves from Plot Database  
 ".../Lubrication1/HydroDynamicForce/Positive\_X/FX\_Hydro" and  
 ".../Lubrication1/HydroDynamicForce/Negative\_X/FX\_Hydro".
- ② Add a New Page ([Home]-[Windows]-[Add])
- ③ Then draw the curves in the new page.  
 ".../Lubrication1/AsperityContactForce/Positive\_X/FX\_Asperty" and  
 ".../Lubrication1/AsperityContactForce/Negative\_X/FX\_Asperty".

※ You can see where the contact area is and the magnitude of the contact force.





# Step 12 – Create Output Points for Clearance

## Steps

- ① Return to the Working window of RecurDyn, open the property dialog of **Lubrication1** (EHD property)
- ② Click the **"Output Point for Clearance"** button
- ③ Set the **reference marker** to **"Piston.Marker1"** (Action Marker of Lubrication1)
- ④ Add 4 **Output Gap points**
- ⑤ Set the **Height / Angle** as below:
  - 1) 14, 0
  - 2) -14, 0
  - 3) 14, 180
  - 4) -14, 180
- ⑥ **Close** the dialog

**1** Properties of Lubrication1 [ Current Unit : N/kg/mm/s/deg ]

General Connector Lubrication

Piston Diameter: 70.  
 Piston Height: 29.  
 Cylinder Diameter: 70.045  
 Cylinder Height: 95.  
 Dynamic Viscosity[Pa.s]: 6.e-03

Mesh Grid Setting Adjust Node Pos  
 Additional Options Solver Setting

Piston  
 Patch Set (RFlx) **2** **Piston.SetPatch1**  
 Profile **Output Point for Clearance**

**3** **Output Gap Point**

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

Reference Marker **3** **Piston.Marker1** **6** **Close**

**4** Add Delete

**7**

Point 3 Point 1  
 Point 4 Ref. Marker Point 2

Model  
 Time = 0.01833000 Second

Page 1

Point1\_Gap - MeasurePoint1 (mm) Point2\_Gap - MeasurePoint2 (mm)  
 Point3\_Gap - MeasurePoint3 (mm) Point4\_Gap - MeasurePoint4 (mm)  
 PistonLubricationEHD\_Sample\_RPlot

Length (mm)

Time (s)

Control  
 Crank  
 PistonPin  
 Dynamic\_Crank  
 Piston  
 Cylinder  
 RFlx OUTPUTS  
 Force  
 Advanced EHD Force  
 Lubrication1  
 FM\_Total  
 Fx\_Total  
 Fy\_Total  
 Fz\_Total  
 TM\_Total  
 Tx\_Total  
 Ty\_Total  
 Tz\_Total  
 HydrodynamicForce  
 MeasurePoints  
 MeasurePoint1  
 Point1\_Gap  
 MeasurePoint2  
 Point2\_Gap  
 MeasurePoint3  
 Point3\_Gap  
 MeasurePoint4  
 Point4\_Gap

Axis X: TIME  
 Axis Y: MeasurePoint4 - Point4\_Gap

# Step 13 – Modify the Piston Profile

## Steps

### [Piston Profile Modification]

- ① Click the **"Profile"** button.
- ② Check on **"Use Profile"** option, in the **Piston Profile** dialog
- ③ Set the values as below:
  - 1) **Profile Length:** 29
  - 2) **Number of Angle:** 44
  - 3) **Ref. Marker:** Piston.Marker1
  - 4) **No. of Height:** 19
- ④ Click the **"Create Data Field Uniformly"** button
- ⑤ The input filed of **Profile** is filled automatically  
(You cannot modify the values directly in this dialog)
- ⑥ **Export** the data as \*.csv
- ⑦ **Open** the \*.csv file by **Excel**, and **modify** the profile data.
- ⑧ **Import** the modified \*.csv in **Piston Profile** dialog.  
(In this tutorial, you can use pre-created **"ProfileData.csv"**)
- ⑨ **Close** the Profile dialog
- ⑩ You can run **simulation** again using the new setting.

The image illustrates the process of modifying the piston profile in a simulation software. It consists of several parts:

- Properties of Lubrication1 Dialog:** The 'Piston Profile' sub-dialog is shown with the 'Use Profile' option checked. The 'Profile Length' is set to 29, 'Number of Angle' to 44, 'Reference Marker' to 'Piston.Marker1', and 'Number of Height' to 19. The 'Create Data Field Uniformly' button is highlighted.
- Profile Data Table:** A table showing the profile data. The first row contains values: 0, 0.1818..., 16.363..., 24.545..., 32.727..., 40.909..., 49.090..., 57.272..., 65.454..., 73.636..., 81.818..., 90, 98.181... The second row contains values: 14.5, 12.300000..., 11.27777..., 9.800000..., 8.055555..., 6.444444..., 4.833333..., 3.222222..., 1.611111..., 0, 1.611111..., 3.222222..., 4.833333..., 6.444444..., 8.055555..., 9.800000..., 11.27777..., 12.300000..., 14.5.
- Excel Spreadsheet:** A screenshot of an Excel spreadsheet showing the profile data, with the 'Import' and 'Export' buttons highlighted.
- Graph:** A graph showing the contact force (N) versus time (s). The graph compares the 'Profile' (blue line) and 'Non-Profile' (red line) models. The 'Profile' model shows a significantly higher peak force compared to the 'Non-Profile' model.

User can compare the Asperity Contact force between Non-profile and Profile model



# Thank you.

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