Contents

9 Simulation of Kinematic Chains with *Working Model*

This section serves as a tutorial to simulate the planar mechanism R-RTR shown in Fig. 9.1 by using *Working Model*. The mechanism has three links, the driver link (link 1), the slider (link 2), and the rocker (link 3).

Step 1: Opening *Working Model*

1. Click on the *Working Model* program icon to start the program.

2. Create a new *Working Model* document by selecting "New" from the "File" menu.

Toolbars create links, joints, and mechanism actuators.

3. Specify the units for the simulation.

4. Set up the workspace.

In the "View" menu: select "Workspace", check Coordinates and X,Y Axes from the Navigation box, and check all the objects from the Toolbars box except Simple; turn off Grid Snap and turn on Object Snap; select "Numbers and Units" and change the Unit System to SI (degrees); select "View Size" and chose the objects on screen to be 1.0 times actual size.

Step 2: Creating the links

This step creates the three moving links of the mechanism. The background serves as the fixed frame link (ground).

1. Create the driver link.

Click on the rectangle tool in the toolbar to sketch out a rectangular body. Position the mouse at the first corner, click once, then move the mouse to the location of the opposite corner and click again. Four black boxes appear around the link indicating that it has been selected. Modify its dimensions at the bottom of the screen accordingly to the height $h = 0.1$ m, and the width $w = 0.01$ m (see Fig. 9.2).

2. Create the slider and the rocker.

Click on the "Rectangle" tool in the toolbar. The tool is now selected and it can be used multiple times. Sketch out two rectangular bodies, those are, the rocker and the slider. Choose the widths $w = 0.15$ m for the rocker and $w = 0.040$ m for the slider. The height of the rocker is $h = 0.010$ m and the height of the slider is $h = 0.020$ m.

The depth of all objects in *Working Model* is $d = 0.001$ m by default.

3. Change the properties of the links.

Press the Shift key and click on the driver link, rocker, and slider, respectively. Select “Properties” in the “Window” menu and change the material to Steel, the coefficients of static and kinetic friction to 0.0 (no friction), the coefficient of restitution to 1.0 (perfect elastic), and the charge to 0.0 (no charge), as shown in Fig. 9.3.

Remark. The commands Zoom in and Zoom out can be used by clicking on the icons at the top of the screen in order to make the objects clearly visible.

Step 3: Connecting the slider and the rocker

1. Move the slider over the rocker.

2. Select the horizontal “Keyed Slot joint” icon at the left of the screen. The icon appears as a rectangle riding over a horizontal slot.

3. Move the cursor over the snap point at the center of the slider and click the mouse button. The screen should look like Fig. 9.4.

Step 4: Adding a motor to the driver link

Similar to a pin joint, a motor has two attachment points. A motor automatically connects the top two bodies. If only one body were to lay beneath the motor, the motor would join the body to the background. The motor then applies a torque between the two bodies to which it is pinned.

1. Click on the “Motor” tool in the toolbox. This tool appears as a circle, sitting on a base with a point in its center. The cursor should now look like a small motor.

2. Place the cursor over the “snap point” on the center of axis and click the mouse button.

3. Click on the “Split” button in the toolbar. Click on the pin joint and drag it to the snap point at the bottom of the driver link.

4. Click on the “Join” button in the toolbar. Since the motor is fixed to the ground, the driver link moves in place.

5. Click on the driver link and change the value of the angle ϕ at the bottom of the screen to -45° (Fig. 9.5).

Step 5: Connecting the driver link and the slider

1. Select the anchor tool.

2. Click on the driver link to anchor the link down. The anchor fixes the body to the ground during construction.

3. Click on the “Pin joint” tool.

4. Place the cursor over the upper end of the driver link. When an “X” appears around the pointer, click the mouse button.

5. Click on the “Split” button in the toolbar. *Working Model* creates two connected overlapping pin joints.

6. With the pointer tool selected, click on the pin joint and drag it to the snap point at the center of the slider (Fig. 9.6).

7. Click on the “Join” button in the toolbar. *Working Model* merges the two pin joints into a single one, moving the unanchored link into place.

8. Click on the driver link. Select the “Move to front” option in the “Object” menu. This places the link in front of the rocker, making it visible, as in Fig. 9.7.

Step 6: Connecting the rocker to the ground

1. Click on the “Point element” in the toolbox. Place the cursor wherever on the ground and click the mouse button.

2. Modify the coordinates of the point accordingly to $x = 0.05$ m and $y = 0$.

3. Click on the “Pin joint” in the toolbox. Place the cursor on top of the point and click the mouse button. The pin joint is now fixed to the ground.

4. Using “Split” and “Join”, connect the rocker to the pin joint.

5. Select the anchor, used to keep the driver link in position during building, and press the Delete key to remove it.

The screen should look like in Fig. 9.8.

Step 8: Adding an external torque

1. Click on the “Torque” tool from the toolbox and then click on the rocker. This will apply an external torque to the rocker.

2. Select the torque and modify its value to $M_{ext} = 100$ N·m in the “Properties” menu.

Step 7: Measuring positions, velocities, accelerations, torques and forces

1. Select the driver link, then go to “Measure” menu and “Position” submenu. Apply the command “Rotation graph” to measure the rotation angle of the driver.

2. Click on the “Point element” from the toolbox and then click on the end point of the rocker. The point is now attached to the rocker. Go to “Measure”

menu and apply the commands "Position", "Velocity", and "Acceleration" to measure the position, velocity and acceleration of the point. Click on the arrow in the right upper corner of the measurement window to change it from graphic to numerical.

3. Select the motor, then go to "Measure" menu and apply the command "Torque Transmitted" to measure the torque of the motor.

4. Select the pin joint that connects the driver link to the ground. Go to "Measure" and apply the command "Force" to measure the reaction force between the ground and the driver.

5. Select the rigid keyed slot joint that connects the slider to the rocker. Go to "Measure" and apply the command "Force" to measure the reaction force between the slider and the rocker.

6. Select the pin joint that connects the rocker to the ground. Go to "Measure" and apply the command "Force" to measure the reaction force between the ground and the rocker.

7. Select the pin joint that connects the driver link to the slider. Go to "Measure" and apply the command "Force" to measure the reaction force between the slider and the driver.

Remark. When you select a joint to create a meter to measure the reaction force, the meter measures the forces exerted on the body located at the top when the joint was created. The components of the forces are given in terms of the local coordinate system. In order to measure the components of the pin joint forces in terms of the global coordinate systems, the angles of the two points that compose the pin joint are set to the value 0. The two points that compose a pin joint are seen by selecting the joint and opening the "Properties" window.

An example is shown in Fig. 9.9. The pin joint between the driver link and the slider (Fig. 9.6), denoted by `Constraint[17]`, is composed of the two points `Point[15]` and `Point[16]`. Select `Point[15]` from the window "Properties" and change its angle to the value 0. Then select `Point[16]` and change its angle to 0. Now the components of the pin joint forces are measured in terms of the global coordinate system.

Step 7: Running the simulation

1. With the pointer tool selected, select all the bodies. Select the "Do Not Collide" option in the "Object" menu.

2. Select "Numbers and Units" in the "View" menu. Select More Options and change the Rotational Velocity to Revs/min.

3. Double-click on the motor to open the "Properties" box. Modify the velocity of the motor to -50 rpm, as shown in Fig. 9.9.

7. Click on each graph and modify its label from "Window" menu and "Appearance" submenu.

8. Click on "Run" in the toolbar.

Tape controls, which are used to run and view simulations, are located at the bottom of the screen.

9. Click on "Reset" in the toolbar. The simulation resets to the initial frame 0.

Remark. To increase the Simulation Accuracy, select "Accuracy" from the "World" menu and change the Animation Step to a larger value and the Integration Error to a smaller value.

The screen should look like in Fig. 9.10.

Results

For the mechanism simulated above, the following results are obtained: the motor torque is $M_{mot} = -147.651$ N·m; the position of the point D is $\mathbf{r}_D = 0.139\mathbf{\imath} + 0.121\mathbf{\jmath}$ m, the velocity of the point D is $\mathbf{v}_D = 0.936\mathbf{\imath} - 0.685\mathbf{\jmath}$ m/s; the acceleration of the point D is $\mathbf{a}_D = -1.077\mathbf{\imath} - 10.324\mathbf{\jmath}$ m/s^2; the reaction force of the ground on the driver link is $\mathbf{F}_{01} = 1302\mathbf{\imath} - 953\mathbf{\jmath}$ N; the reaction force of the slider on the driver link is $\mathbf{F}_{21} = -1302.128\mathbf{\imath} + 953.180\mathbf{\jmath}$ N; the reaction force between the rocker and the slider is $F_{23} = 1613.764$ N; the reaction force of the ground on the rocker is $\mathbf{F}_{03} = -1302.15\mathbf{\imath} + 953.291\mathbf{\jmath}$ N;

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