Today’s Topics:
- 2nd law with rotation
- Rolling without slipping
- Rolling resistance

Review - Moments

What is the moment of the 10N force about A?

Newton’s Second Law with Rotation:

\[ \sum \tau = (\tau_{net}) = I \alpha \]

Combined Translation and Rotation:

\[ \sum \vec{F} = m\vec{a}_{cm} \quad \sum \tau = I_{cm} \alpha \]

- The axis through the center of mass must be an axis of symmetry
- The axis must not change direction

Example: Spinning Disk, part I

The 30 kg uniform disk is supported by a frictionless pin. Find the angular acceleration caused by the given force.

What equation for \( I_{disk} \)?

Example: Spinning Disk, part II

The 30 kg uniform disk is supported by a frictionless pin. Find the angular acceleration caused by the hanging weight.

Will the new \( \alpha \) be:
A. greater than 3.33 rad/s²
B. equal to 3.33 rad/s²
C. less than 3.33 rad/s
Rolling Without Slipping:

The angular velocity at the instantaneous axis, $\omega_o$, is \underline{________} to the angular velocity at the center of mass, $\omega_{CM}$.

Example: Acceleration of Tennis Ball

Find the acceleration of the tennis ball as it rolls down the incline.

What would happen if incline was frictionless?

Example: Coefficient of friction

Determine the minimum coefficient of static friction so the tennis ball does not slip.

Rolling Resistance

also called rolling friction or rolling drag

\[ F_{rr} = C_{rr}N \]

Approximation.

$F_{rr}$ - Force from rolling resistance
$C_{rr}$ - Coefficient of rolling resistance
$N$ - Normal force

<table>
<thead>
<tr>
<th>$C_{rr}$</th>
<th>Surface</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.001 - 0.0025</td>
<td>steel wheels on steel rails</td>
</tr>
<tr>
<td>0.0015 - 0.0025</td>
<td>bicycle tires</td>
</tr>
<tr>
<td>0.006 - 0.01</td>
<td>truck tire on asphalt</td>
</tr>
<tr>
<td>0.01 - 0.015</td>
<td>ordinary car tires on concrete</td>
</tr>
<tr>
<td>0.03</td>
<td>car tires on tar or asphalt</td>
</tr>
<tr>
<td>0.2 - 0.4</td>
<td>car tire on loose sand</td>
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</tbody>
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