Workshop 3.1: 2D Magnetic Transient analysis

Release 2020R2

Overview

- Large Rotational Motion
  - Maxwell Transient solver can consider interactions between transient electromagnetic fields and mechanical motion of objects.
  - Maxwell Transient (with motion) includes dB /dt arising from mechanically moving magnetic fields in space, i.e. moving objects. Thus, effects coming from so-called motion induced currents can be considered.
  - Rotational motion can occur around one single motion axis.
  - This workshop represents a quick start to using rotational motion. It will exercise rotational motion in Maxwell 2D using a rotational actuator (experimental motor) example. Workshop consists of three parts
    - Example1: Large Rotation Standstill
    - Example2: Large Rotation at Constant Speed
    - Example3: Large Rotational Transient Motion

Example 1: Large Rotation Standstill

- **The Maxwell Approach**
  - **Maxwell separates moving from non-moving objects. All moving objects must be enclosed by one so-called Band object.**
  - **For rotational motion, the band object must be cylindrical (3D) or circular (2D). Shell-shaped geometries must be avoided**
  - **Maxwell considers all moving objects to form one single moving object group. In 3D an additional "Inner Band" Object must be inserted**
  - **Constant Speed mode:**
  - **If the model is set to operate in constant speed mode, no mechanical transient is considered**
  - **However motional effects are included in the field solution.**
  - **Mechanical Transient mode:**
  - **In case inertia, Damping and mechanical load are specified, Maxwell will compute the mechanical equation in each time step.**

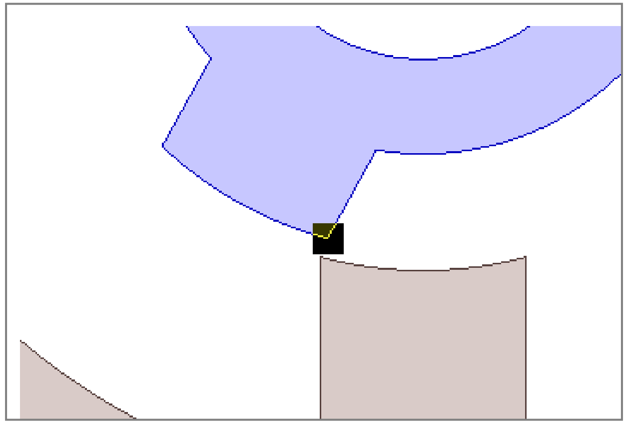
$$J_{mech}\frac{d^2\varphi_m(t)}{dt^2} + K_D(t)\frac{d\varphi_m(t)}{dt} = T_{elec}(t) - T_{mech}(t)$$

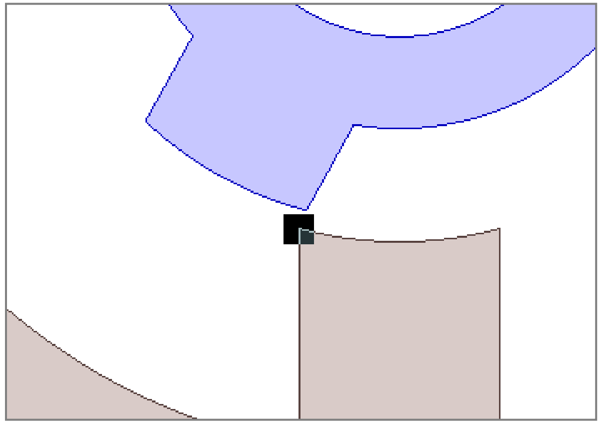
Open input file

- Open the file
  - Browse to the file WS3_1.aedt and open it
  - Prior to employing large motion, the electromagnetic part of the model should work correctly. Users are advised not to setup a complex model completely at once rather work in steps. Perform few simulation tests before trying run complex setup with motion
- Examine Geometry
  - We use stranded windings with constant current (to generate a fixed stator flux vector around which Rotor1 will oscillate later). Eddy effects are not activated
  - Verify that Symmetry Mutiplier is set to 1
  - Verify that Model Depth is set to 25.4mm

Create Band

- **Determine Size of Band Object**
  - Select the menu item *View → Visibility → Active View Visibility*
  - Uncheck the Visibility for all parts except Stator1 and Rotor1
  - Select the menu item *Modeler → Measure → Position*
  - Move the cursor to the end vertex of Rotor1 and just place on it (Do not click)
  - Read the Distance value from the Measure Data window (51.05 mm)
  - Move the cursor to the inner vertex of Stator1 and just place on it
  - Read the Distance value (53.75 mm)
  - Press Esc to exit measure
  - Thus, band should have a radius of 52.4 mm. Here, 52.5 mm will be used.





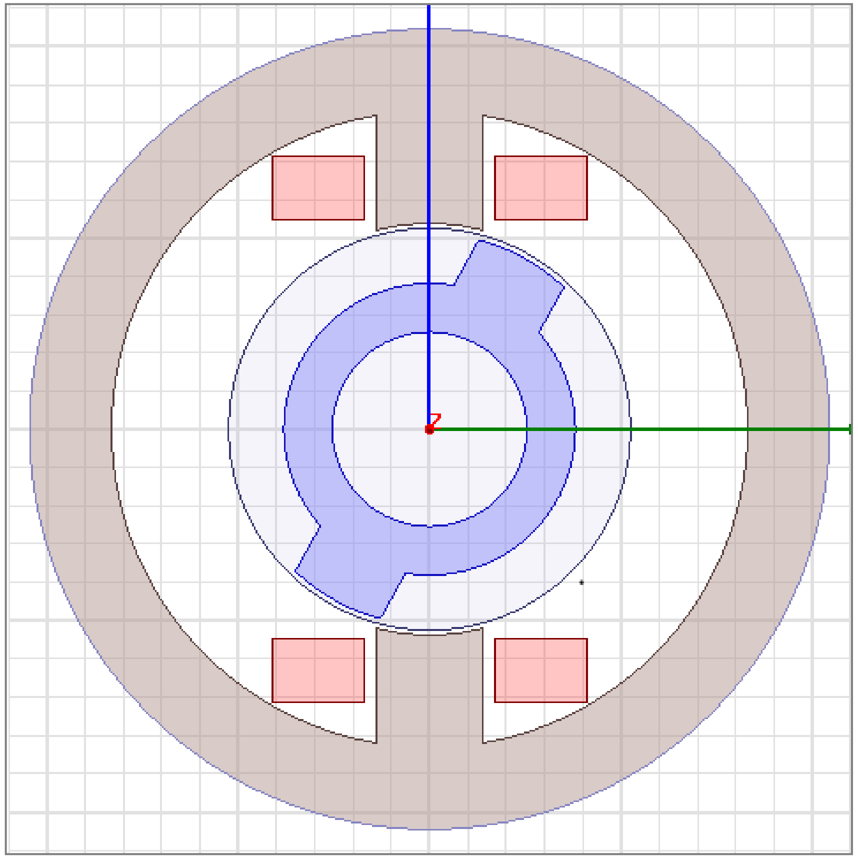
Create Band

- **Draw Band Object**
  - **Select the menu item *Draw → Circle***
  - **Using the coordinate entry fields, enter the center of circle**

    X: 0, Y: 0, Z: 0, Press the *Enter* key
  - **Using the coordinate entry fields, enter the radius**

    dX: 52.5, dY: 0, dZ: 0, Press the *Enter* key

- **Change Attributes**
  - **Change the name of resulting sheet to Band1**
  - **Change the transparency of the sheet to 0.9**
  - **Select the menu item *View → Visibility → Show All → Active View***



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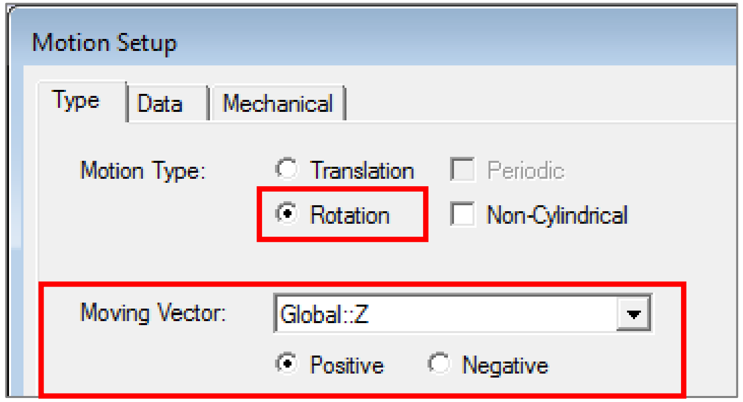
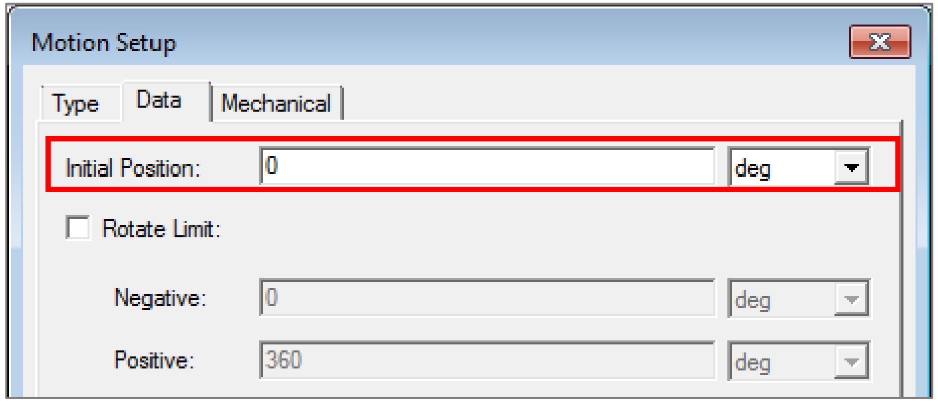
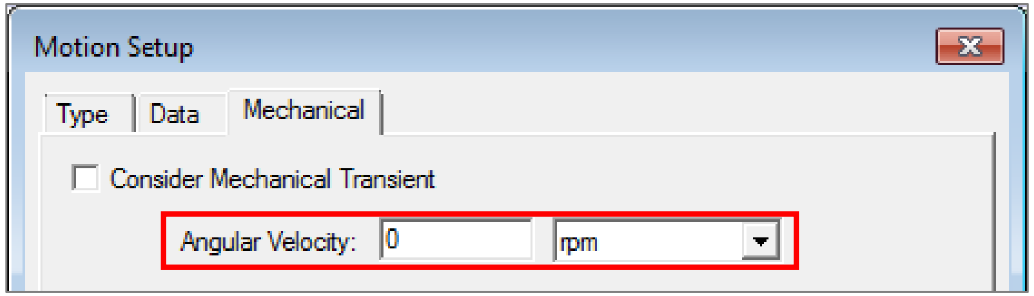
Assign Motion

- **Specify motion**
  - **Select the object Band1 from history tree *RMB → Assign Band***
  - **In Motion Setup window,**
    - ***Type tab***
    - **Motion Type: Rotation**
    - **Rotation Axis: Global:Z**
    - **Positive: ☑ Checked**
    - ***Data tab***
    - **Initial Position: 0 deg**
    - ***Mechanical tab***
    - **Angular Velocity: 0 rpm**
    - **Press OK**







Note: Initial position of 0 deg indicates that motion will start at t = 0 with the rotor position being as in the geometry. A non-zero initial position would start with Rotor rotated by jm0 from the current position. Angular velocity of 0 rpm indicates that rotor will be under standstill condition

Mesh Operations

Note: Meshing is a very critical issue with respect to simulation speed and accuracy. Here a coarse mesh is applied which will just yield satisfactory results.

For torque computation, the most critical areas are the airgap and its immediate proximity. Thus, the band mesh is crucial for accurate results.

A Cylindrical Gap Treatment mesh Operation is automatically created after motion setup. It ensures mesh refinement in the airgap. We also apply a length based mesh on the surface and inside Band

- Assign Mesh Operations on Band
  - Select the object Band1 from the history tree
  - *RMB → Assign Mesh Operations → Inside Selection → Length Based*
  - In Element Length Based Refinement window,
    - Name: Band_Length
    - Restrict Length of Elements: ☐ Unchecked
    - Restrict the Number of Elements: ☑ Checked
    - Maximum Number of Elements: 5000
    - Press OK

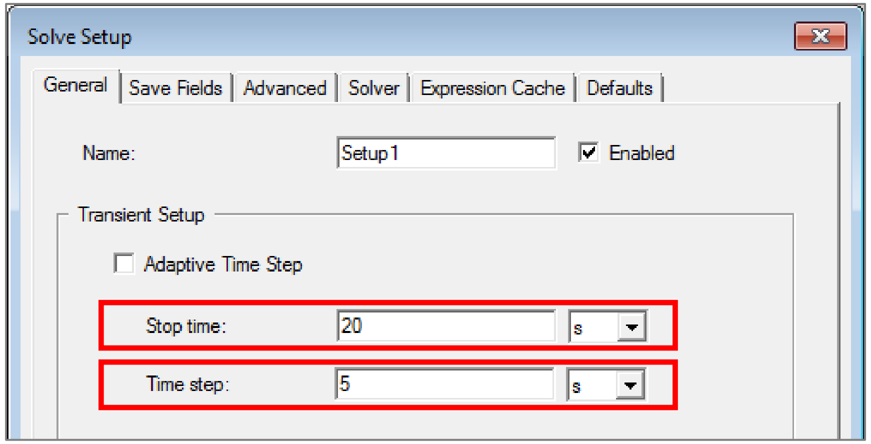
Mesh Operations

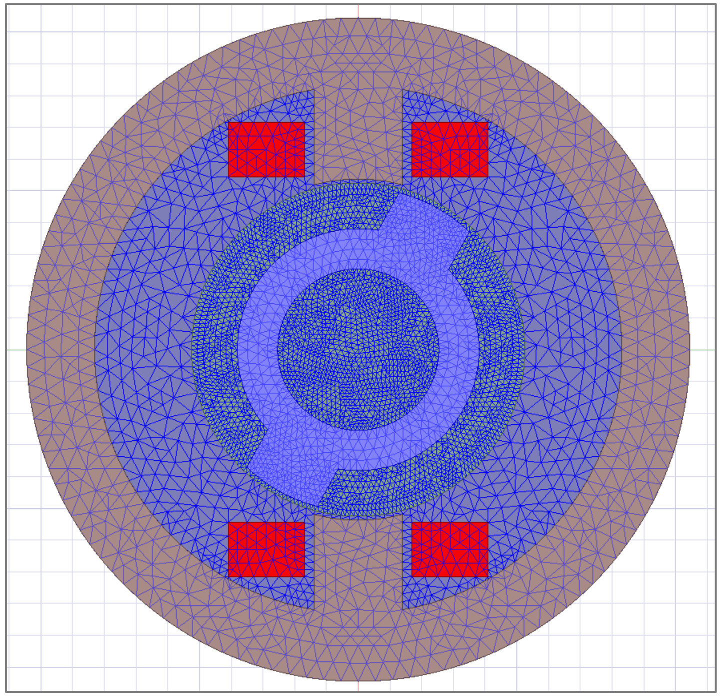
- Assign Mesh Operations on other Objects
  - In Similar way specify Mesh operations on other objects as specified below
  - All Coils
    - Name: Coils_Length
    - Maximum Number of Elements: 100
  - Rotor1
    - Name: Rotor_Length
    - Maximum Number of Elements: 1000
  - Stator1
    - Name: Stator_Length
    - Maximum Number of Elements: 1000
  - Background1
    - Name: Background_Length
    - Maximum Number of Elements: 1000

Note: Simultaneously selecting all coils will try to assign 100 tetrahedrals to all coil objects, i. e. about 25 to each

Analyze

- Create Analysis Setup
  - *RMB on Analysis → Add Solution Setup*
  - In Solve Setup window,
    - Stop Time: *20 s*
    - Time Step: 5 s
    - Press OK
- Run the Solution
  - *RMB on Setup1 → Analyze*
- Plot Mesh
  - Select the menu item *View → Set Solution Context*
  - In Set view Context window,
    - Change Time to 20 s
    - Press OK
  - Select the menu item *Edit → Select All (Ctrl+A)*
  - *RMB on the plot area → Plot Mesh*



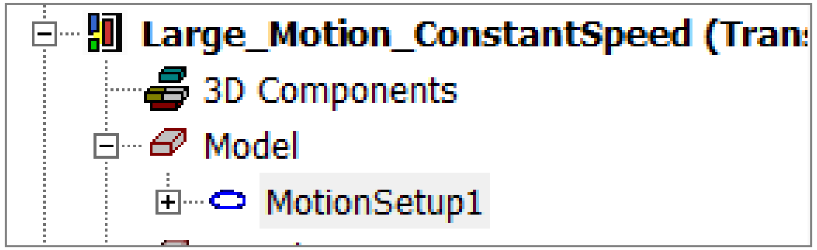


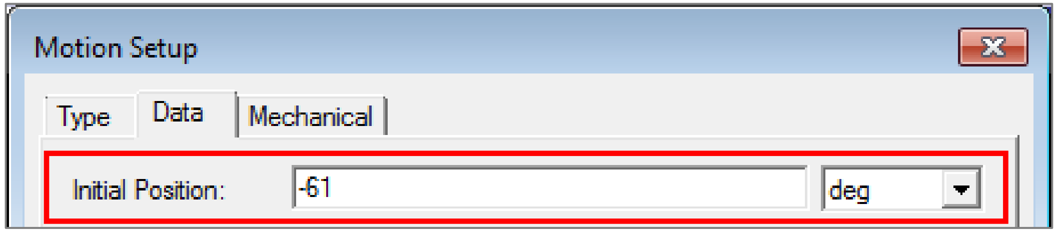
Example 2: Large Rotation at Constant Speed

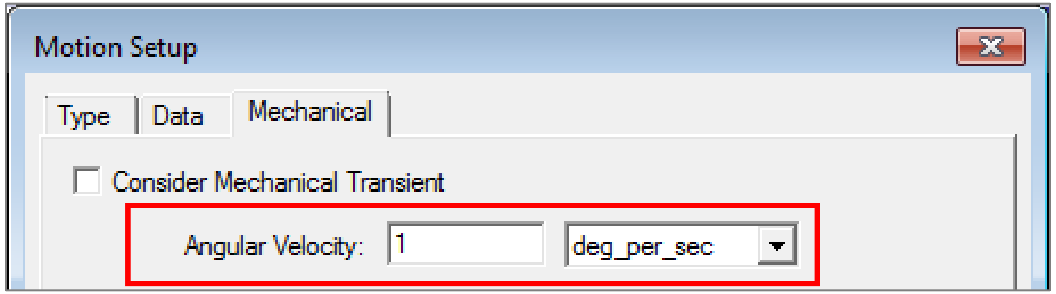
- About Example
  - We will now operate the rotational actuator at a very slow constant speed
  - Remember, there is only one magnetic excitation present in the model – namely constant coil current with stranded windings. Alternatively, Rotor1 could have been assigned permanent magnet properties. Eddy effects have been switched off for all objects
  - We can now use Transient with Large Motion to monitor cogging torque effects

Modify Existing Design

- Create a Copy of Design
  - Select the design *Large_Motion_Standstill*, right click and select Copy
  - Right click on the Project Name and select Paste
  - Change the name of the design to *Large_Motion_ConstantSpeed*
- Modify Rotation
  - Expand the tree of the new design
  - Double click on MotionSetup1 to open Motion Setup window
  - Data tab
    - Change Initial Position to -61 deg
  - Mechanical tab
    - Change Angular Velocity to 1 deg_per_sec
    - Press OK



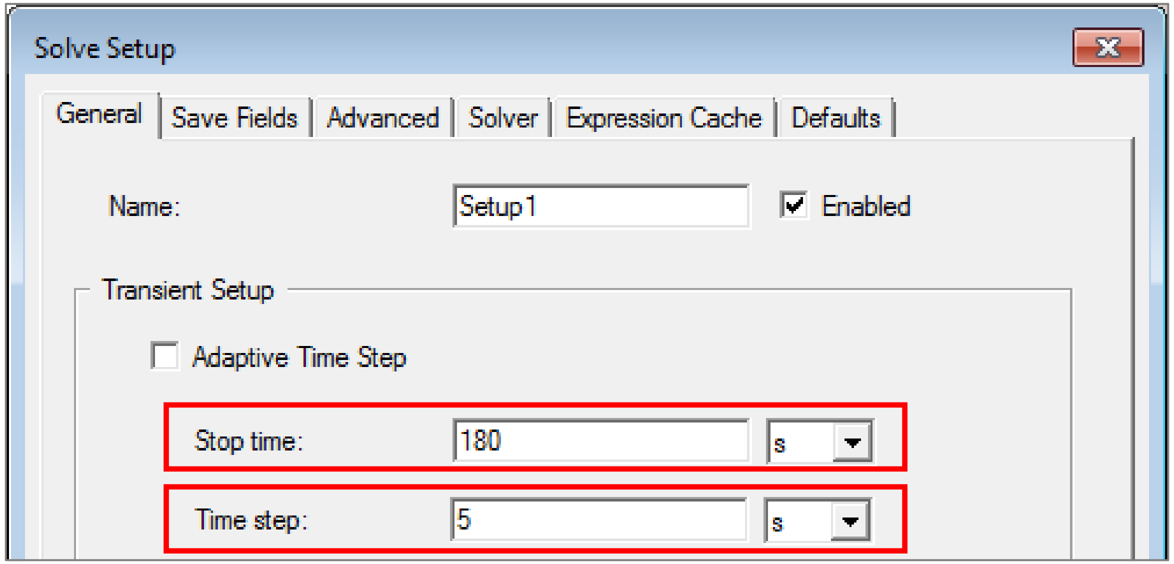




Note: Rotor as drawn has a -29° offset. This is taken to be the zero position for the transient solver. By giving an extra -61°, positive rotation of 1°/s starts at -90°

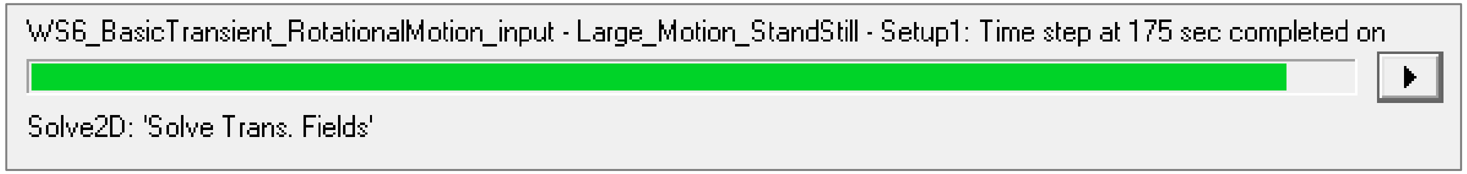
Analyze

- **Modify Solution Setup**
  - Expand the tree for Analysis from Project manager window
  - Double click on Setup1 to open Solve Setup window
  - In Solve Setup window,
    - Change Stop Time to 180 s
    - Change Time Step to 5 s
    - Press OK



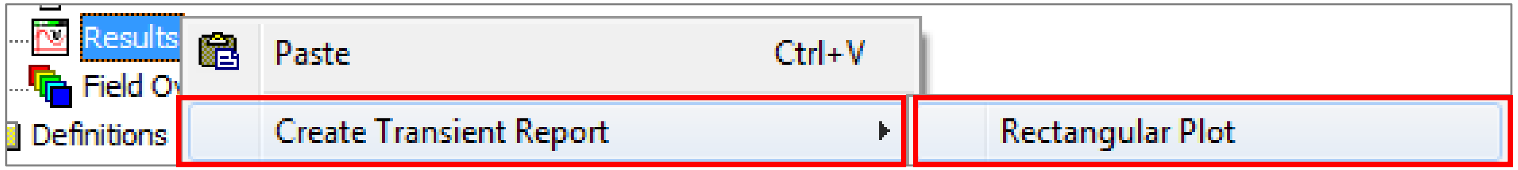
Note: By rotating at a speed of 1°/s, Rotor will move 180°, i. e. from -90° to +90°, at 5°/step

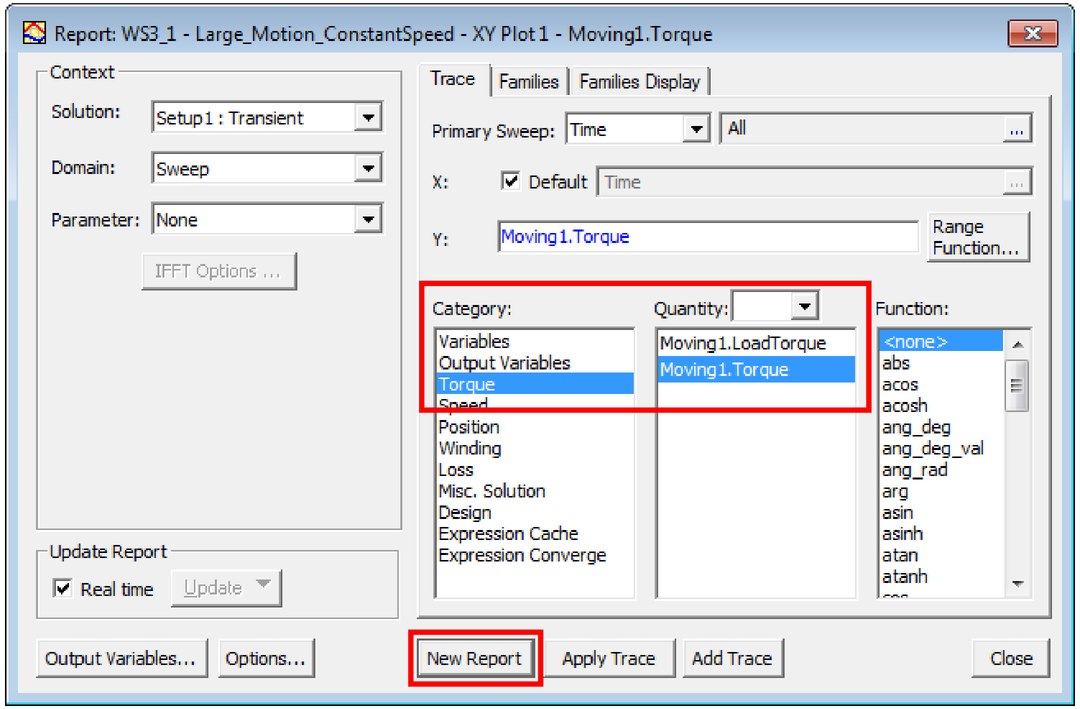
- **Run the Solution**
  - *RMB on Setup1 → Analyze*

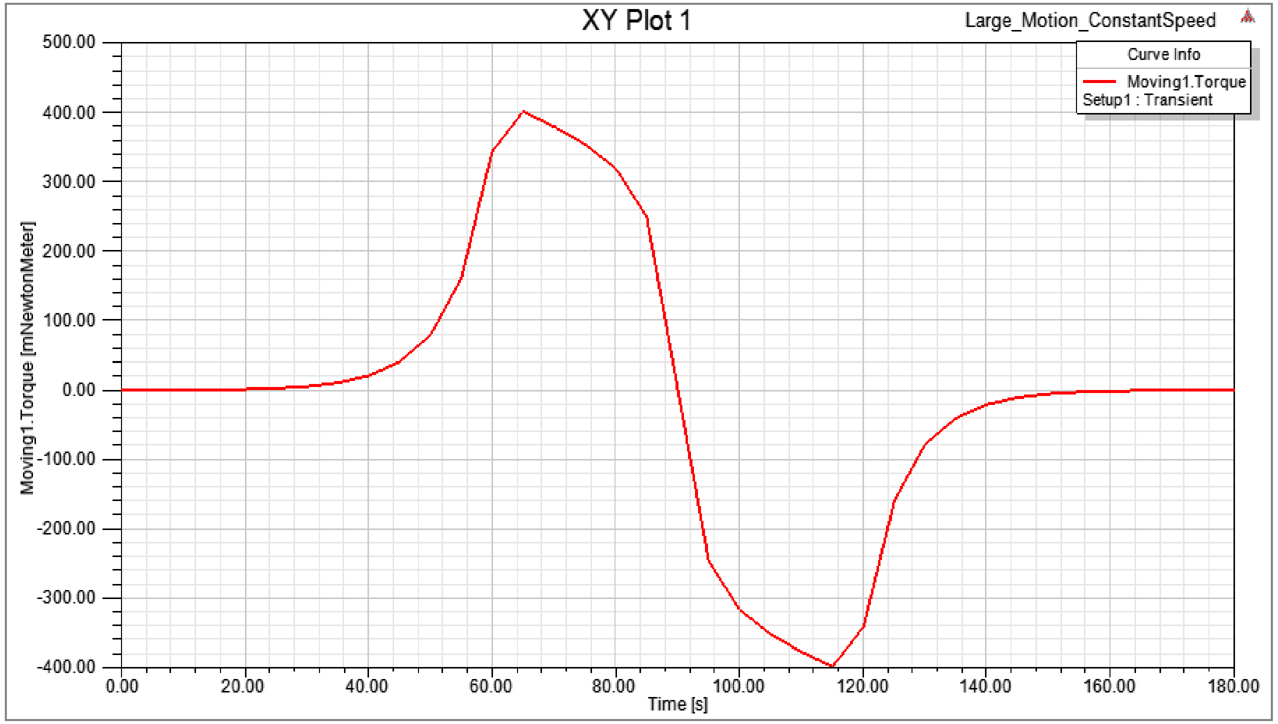


Plot Torque vs. Time

- **Create a Plot**
  - *RMB on Results → Create Transient Reports → Rectangular Plot*
  - **In Reports window,**
    - **Category: Torque**
    - **Quantity: Moving1.Torque**
    - **Select New Report**







Example 3: Large Rotation with Mechanical Transient

- **About Example**
  - We will now operate the actuator as a one-body oscillator. Inertia will be specified as well as some damping. We can expect Rotor to oscillate around the stator flux axis (y-axis) at some natural frequency f0, which can be approximated as:

$$f_0 = \frac{1}{2\pi}\sqrt{\frac{c_\psi}{J_{mech}}}$$

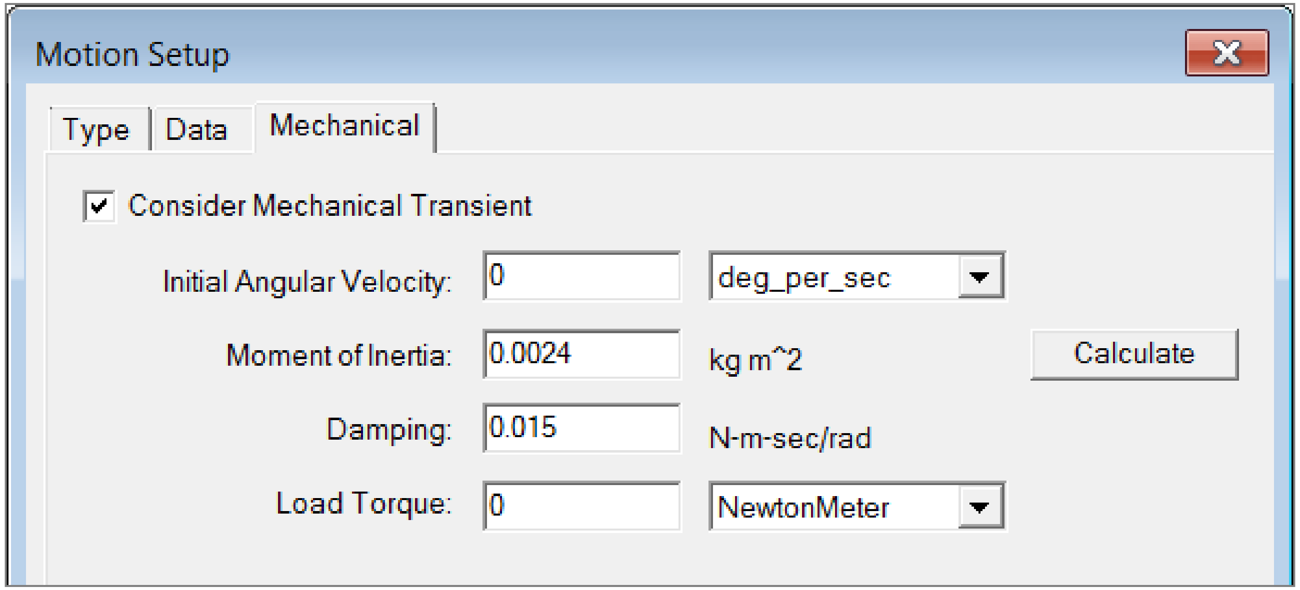
  - J_{mech} in kgm2 is the total moment of inertia acting on Rotor; cy in Nm/rad is the magnetic rigidity. As an analogy it can be understood as a mechanical spring spanned between Rotor and Stator, whose force coming from magnetic field
  - We can roughly calculate rigidity c from cogging torque function (stable limb):

$$c_\psi = \frac{\Delta T_\psi}{\Delta \varphi_{mech}} \approx \frac{400\ \mathrm{mNm}}{\mathrm{rad}(10°)} = 2.3\ \mathrm{N\,m/r\,ad}$$

  - Assuming inertia J_{mech} = 0.0024 kgm2, an approximated f0 = 5 Hz results

Modify existing Design

- Create a Copy of Design
  - Copy the design Large_Motion_ConstantSpeed and rename it as Large_Motion_MechTransient
- Modify Rotation
  - Data tab
    - Change Initial Position to 0 deg
  - Mechanical tab
    - Consider Mechanical Transient: ☑ Checked
    - Initial Angular Velocity: 0 deg_per_sec
    - Moment of Inertia: 0.0024 Kgm^2
    - Damping: 0.015 N-m-sec/rad
    - Load Torque: 0 NewtonMeter
  - Press OK



Note: This causes 15 mNm resistive torque at 1 rad/s. We expect oscillation between -29° to +29° (w. r. t. stator flux axis) at f_0 < 5 Hz with damped amplitude.

Analyze

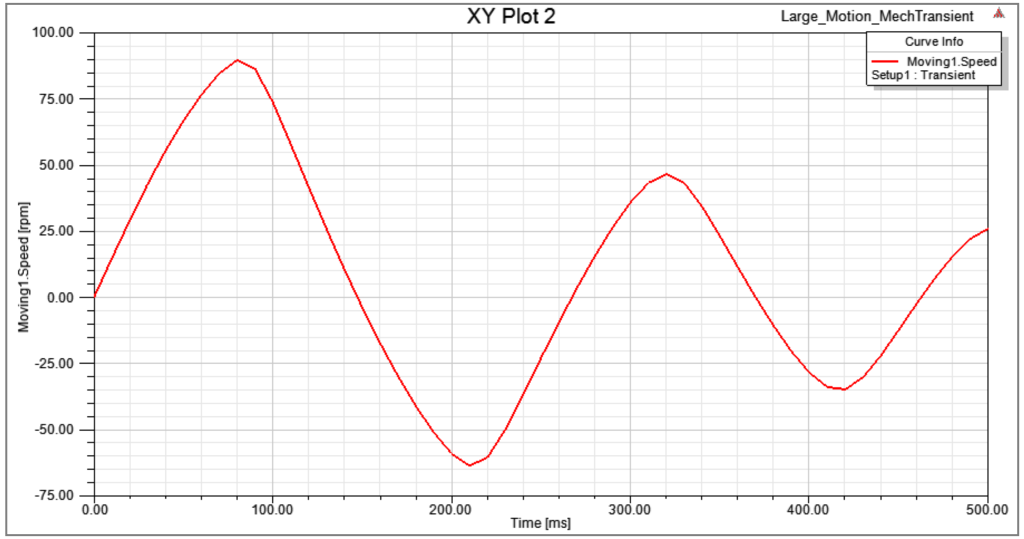
- **Modify Solution Setup**
  - **Expand the tree for Analysis from Project manager window**
  - **Double click on Setup1 to open Solve Setup window**
  - **In Solve Setup window,**
  - **Change Stop Time to 0.5 s**
  - **Change Time Step to 0.01 s**
  - **Press OK**

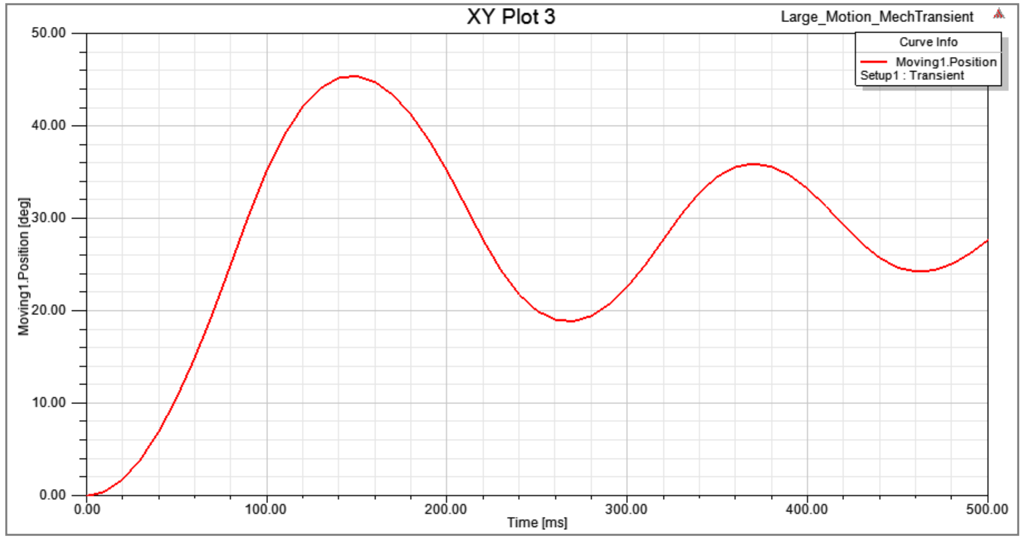
Note: From f_0, we can expect a >200 ms cycle. At 10 ms timestep we sample one cycle >20 times

- **Run the Solution**
  - ***RMB on Setup1 → Analyze***

Results

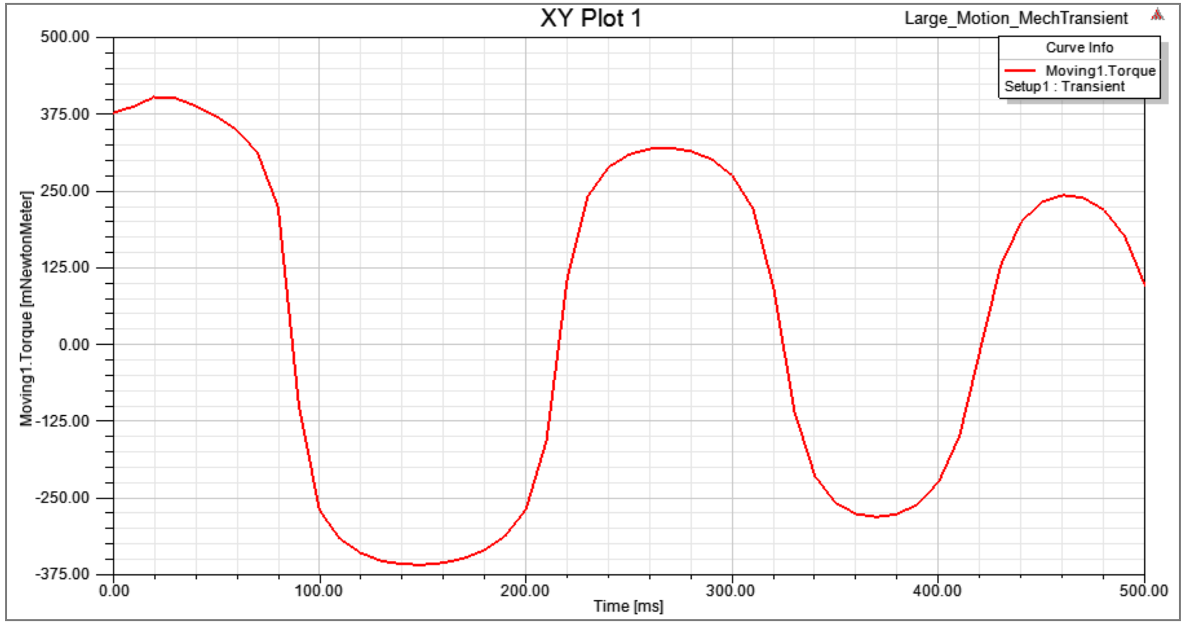
- Create Plots for Speed and Position
  - *RMB on Results → Create Transient Report → Rectangular Plot*
  - In Reports window,
    - Solution: Setup1: Transient
    - Parameter: Moving1
    - X: Default
    - Category: Speed
    - Quantity: Speed
    - Press New Report
    - Change Category to Position
    - Quantity: Position
    - Press New Report





Results

- View existing Plots
  - Expand the tree for Results from Project Manager window
  - Double click on Torque plot that was created previously
  - From Results, it can be seen that
    - T_{elec} looks as expected from previous simulations.
    - ω_{mech} corresponds to Telec's first derivative and is correct.
    - φ_{mech} oscillates around +29°, which is the stator flux axis (y) with respect to the initial position.



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Appendix: Variables and Expressions explanation

$\varphi_{mech}(t)$	Mechanical angular position in rad (angles can also be given in degrees).
φ_{mech0}	Initial φ_m in rad. Note that the *drawn rotor position* is considered as φ_{m0} = 0.
$d\varphi_{mech}(t)$ / dt, $\omega_{mech}(t)$	Mechanical angular speed in rad/s.
ω_{mech0}	Initial ω_m in rad/s.
$d^2\varphi_{mech}(t) / dt^2$	Mechanical angular acceleration in rad/s^2.
J_{mech}	Moment of inertia in kg·m^2. This is the total inertia acting on the moving object group. If extra inertia needs to be included (i. e. inertia not geometrically modeled), just add this to J_m.
$k_D(t)$	Damping koefficient in Nm·s/rad. For k_D = 1 Nm·s/rad, resistive torque of 1 Nm would be generated if the moving parts turn at 1 rad/s. k_D can be a function of t, ω_m, or φ_m.
T_{elec}	Magnetically generated torque in Nm.
T_{mech}	Mechanical extra torque in Nm, this can be a constant or a function of t, ω_m, or φ_m. Note, that a positive T_m value will accelerate rather than brake.
t	The current simulation time in s.

Saving the Project

- **This completes the workshop**
- **Save the file with the name Workshop_3_1 in the working folder**

End of Presentation