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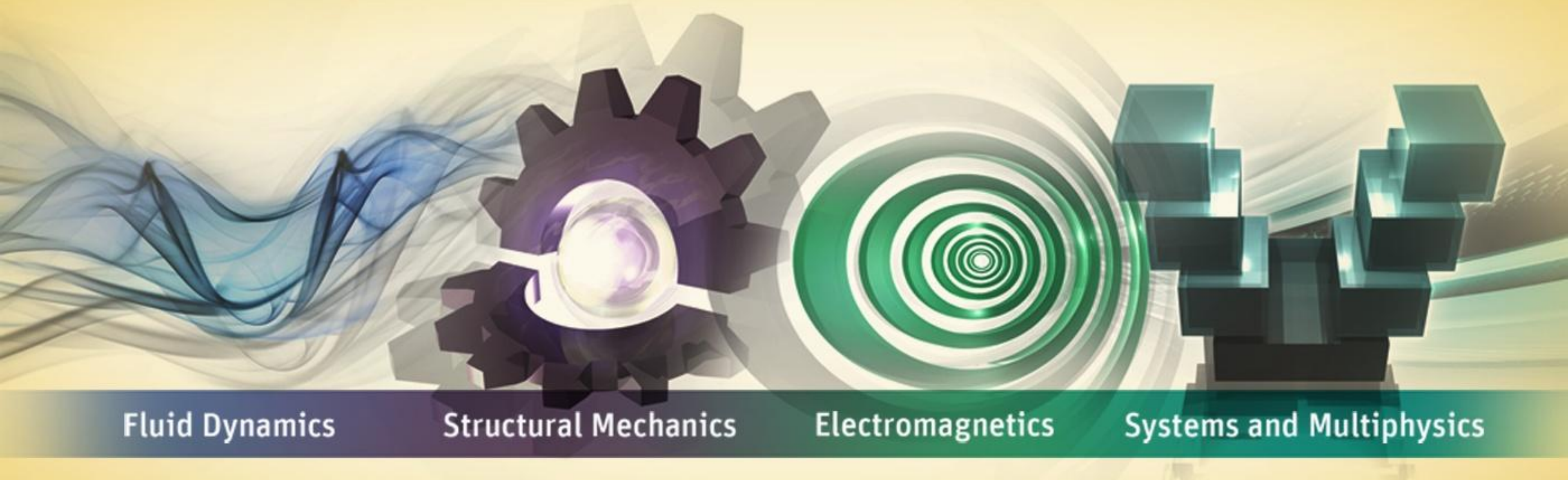
Workshop 6:
Basic Transient Rotational Motion



ANSYS Maxwell 3D V16

About Workshop

- **Large Rotational Motion**
  - Maxwell Transient solver can consider interactions between transient electromagnetic fields and mechanical motion of objects.
  - Maxwell Transient (with motion) includes $\mathrm{d}B/\mathrm{d}t$ 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 3D using a rotational actuator (experimental motor) example. Workshop consists of three parts

    Example1: Large Rotational Standstill

    Example2: Large Rotational Constant Speed

    Example3: Large Rotational Transient Motion

Rotational Large Motion

- **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
  - Maxwell considers all moving objects (inside the *band*) to form one single moving object group.
  - *Constant Speed* mode:
    - If the model is setup to operate in constant speed mode, Maxwell will not compute mechanical transients.
    - However, changing magnetic fields owing to speed ω_m, i. e. dB/dt effects are included in the field solution.
  - *Mechanical Transient* mode:
    - In case inertia was specified, Maxwell will compute the motion equation in each time step.

$$\boxed{J_m \cdot \mathrm{d}^2\varphi_m(t) / \mathrm{d}t^2 + k_D(t) \cdot \mathrm{d}\varphi_m(t) / \mathrm{d}t = T_\nu(t) + T_m(t)}$$

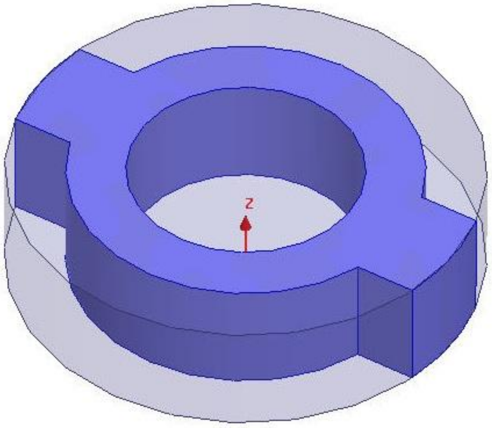
Open Input File

- **Open the file**
  - Select the menu item ***File → Open***
  - Browse to the file **WS6_BasicTransient_RotationalMotion.mxwl** and **open** it
  - Prior to employing large motion, the electromagnetic part of the model should work correctly. Users are well advised not to setup a complex model completely at once ratherwork in steps. Perform few test simulation on the electromagnetic part alone before trying run complex setup with motion.
- **Examine Geometry**
  - All moving objects can be separated from the stationary objects and can be combined to one single rotating group. All moving objects be considered to perform the same cylindrical motion.
  - However, the *band* object has a hole that we have to fill first.
  - Because there is only one moving object, there is no immediate need to enclose it. But filling the hole can also be achieved by fully enclosing Rotor1 by an extra object. We will first do this.

Create Enclosure

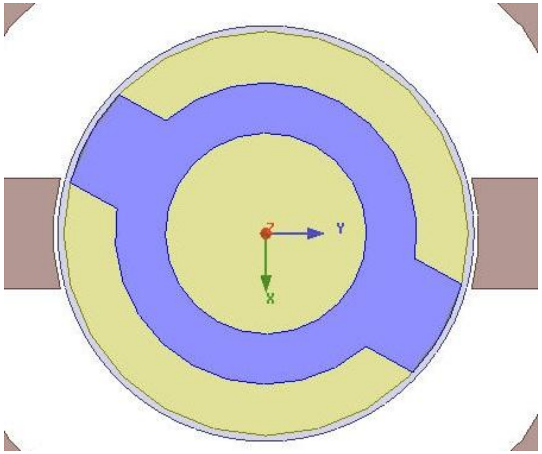
- **Create Enclosure for Rotor**
  - Outer radius of Rotor is around **51.05 mm** and height is **25.4 mm**
  - Select the menu item ***Draw →Cylinder***
    1. Using the coordinate entry fields, enter the center of the base
       - **X: 0, Y: 0, Z: 0**, Press the **Enter** key
    2. Using the coordinate entry fields, enter the radius
       - **dX: 51.05, dY: 0, dZ: 25.4**, Press **the** Enter key
  - Change the name of the resulting object to **Region_Inner** and material to **Vacuum**

Note: Instead of using coordinate entry field, users can directly pick vertices of Rotor to specify radius and height directly.



Crate Band

- **Create Band**
  - Outer surface segmentation should be between 1° and 5°, i. e. we will have between 360 and 72 outer surface segments.The *band* object should preferably cut through the middle of the airgap, leaving about the same space to Rotor1 and Stator1. However, this is not a must.
  - Inner radius of the Stator is around 53.75 mm while outer radius of Rotor is around 51.05 mm. Thus middle position comes out to be 52.4 mm. So we will use 52.5 mm as radius of Band object
  - Select the menu item ***Draw → Regular Polyhedron***
    1. Using the coordinate entry fields, enter the center of the base
       - **X: 0, Y: 0, Z: -12.5**, Press the **Enter** key
    2. Using the coordinate entry fields, enter the radius
       - **dX: 52.5, dY: 0, dZ: 50**, Press the **Enter** key
    3. Number of Segments: **72**
  - Change the name of the object to **Band**
  - Set material to **Vacuum**



Example 1: Large Rotational Standstill

Assign Motion

- **Specify Motion**
  - Select the object **Band** from the history tree
  - Select the menu item ***Maxwell 3D → Model → Motion Setup → Assign Band***
  - In Motion Setup window,
    - **Type** tab
      1. Motion Type: **Rotation**
      2. Rotation Axis: **Global:Z**
      3. Positive: ☑ **Checked**
    - **Data** tab
      1. Initial Position: **0 deg**
    - **Mechanical** tab
      1. Angular Velocity**: 0 rpm**
    - Press **OK**

Note: Initial position of 0deg 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 Rotor1 rotated by φ_{m0} from the current position. Angular velocity of 0rpm 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 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 mesh Operation is automatically created after motion setup which will ensure refinement of mesh in the gap region between Band and Stator/Rotor. We will also apply a length based mesh on the surface and inside of Band1

- **Assign Mesh Operations on Band**
  - **S**elect the object **Band1** from the history tree
  - Select the menu item ***Maxwell 3D → Mesh Operations → Assign → Inside Selection → Length Based***
  - In Element Length Based Refinement window,
    1. Name: **Band_Length**
    2. Restrict Length of Elements: ☑ **Checked**
    3. Maximum Length of Elements: **20 mm**
    4. Restrict the Number of Elements: ☐ **Unchecked**
    5. Press OK

Mesh Operations (*Contd…*)

- **Assign Mesh Operations on Coils**
  - Press Ctrl and select the objects **CoilA** and **CoilB**
  - Select the menu item ***Maxwell 3D → Mesh Operations → Assign → Inside Selection → Length Based***
  - In Element Length Based Refinement window,
    1. Name: **Coils_Length**
    2. Restrict Length of Elements: ☐ **Unchecked**
    3. Restrict the Number of Elements: ☑ **Checked**
    4. Maximum Number of Elements: **1000**
    5. Press **OK**

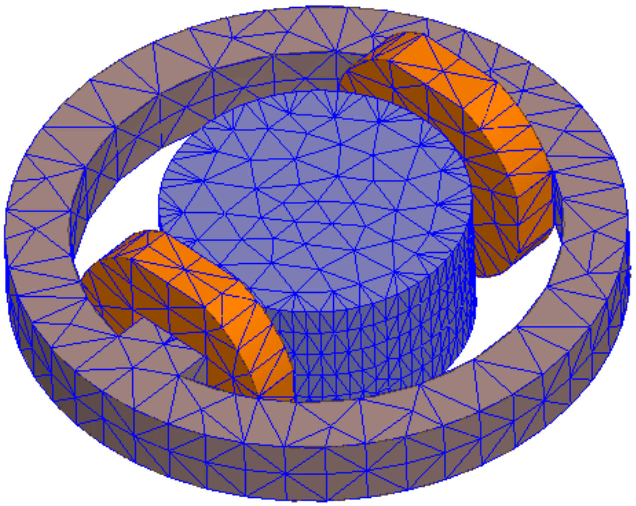
Note: Simultaneously selecting CoilA and CoilB will try to assign 1000 tetrahedrals to both objects, i. e. about 500 to each

Mesh Operations (*Contd…*)

- **Assign Mesh Operations on other Objects**
  - In Similar way specify Mesh operations of other objects as specified below
  - **Region_Inner**
    1. Name: **Region_Inner_Length**
    2. Maximum Number of Elements: **2000**
  - **Rotor**
    1. Name: **Rotor_Length**
    2. Maximum Number of Elements: **2000**
  - **Stator**
    1. Name: **Stator_Length**
    2. Maximum Number of Elements: **2000**
  - **Region**
    1. Name: **Region_Length**
    2. Maximum Number of Elements: **2500**

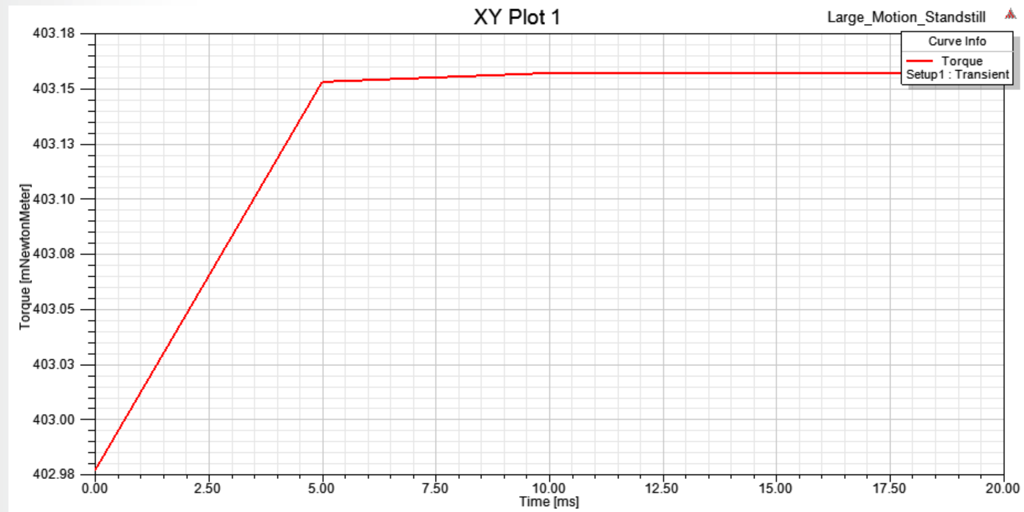
Analyze

- **Create Analysis Setup**
  - Select the menu item ***Maxwell 3D →Analysis Setup→Add Solution Setup***
  - In Solve Setup window,
    1. Stop Time: **20 ms**
    2. Time Step: **5 ms**
    3. Press **OK**
- **Run the Solution**
  - Select the menu item ***Maxwell 3D →Analyze All***
- **Plot Mesh**
  - Select all the objects except **Region**
  - Select the menu item ***Maxwell 3D →Fields →Plot Mesh***



Results

- **Create Plot for Torque**
  – Select the menu item ***Maxwell 3D → Results → Create Transient Report → Rectangular Plot***
  – In Reports window,
    1. Solution: **Setup1: Transient**
    2. Parameter: **Moving1**
    3. X: **Default**
    4. Category: **Torque**
    5. Quantity: **Torque**
    6. Press **New Report**



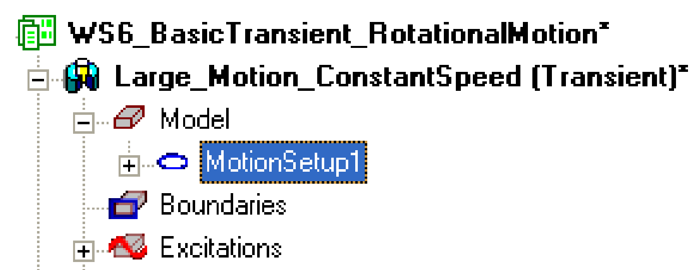
  – Report should show a constant torque value of **0.4Nm**

Example 2: Large Rotational 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 Design

- **Create a Copy of Design**
  - Select the tab **Large_Motion_Standstill** from the Project manager window, right click and select **Copy**
  - Right click on the Project Name in Project Manager window and select **Paste**
  - Change the name of the design to **Large_Motion_ConstantSpeed**
- **Modify Rotation**
  - Expand the tree for **Model** from Project Manager window
  - Double click on **MotionSetup1** to open Motion Setup window
  - In Motion Setup window,
    - **Data** tab
      1. Change Initial Position to **-61 deg**
    - **Mechanical** tab
      1. 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

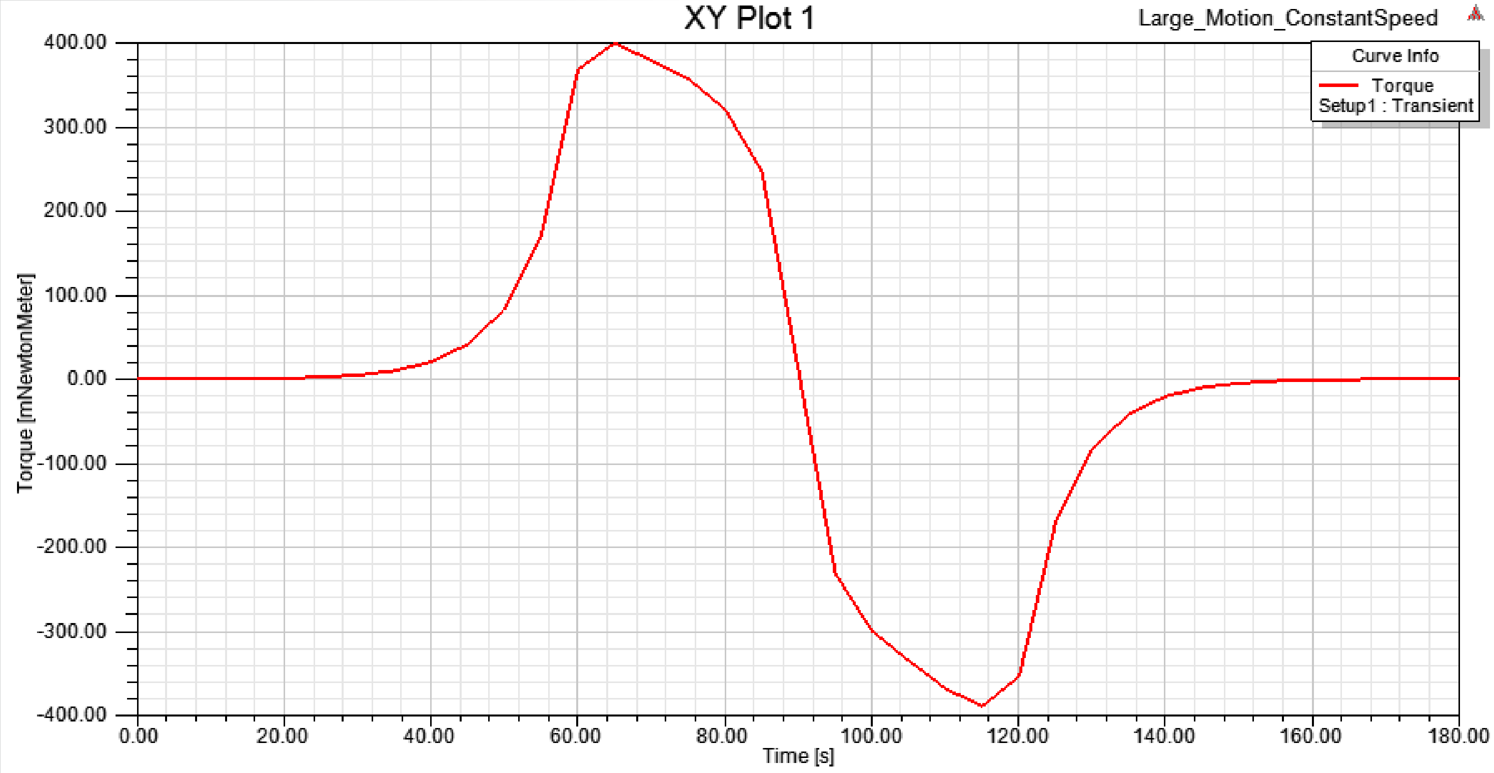
- **Modify Solution Setup**
  - Expand the tree for **Analysis** from Project manager window
  - Double click on **Setup1** to open Solve Setup window
  - In Solve Setup window,
    1. Change Stop Time to **180 s**
    2. Chnage Time Step to **5 s**
    3. Press **OK**

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

- **Run the Solution**
  - Select the menu item ***Maxwell 3D → Analyze All***

Results

- **View Plot**
  - Expand the tree for **Results** from Project Manager window
  - Double click on **Torque** plot that was created previously



Example 3: Large Rotational Transient Motion

- **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 f_0, which can be approximated as:

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

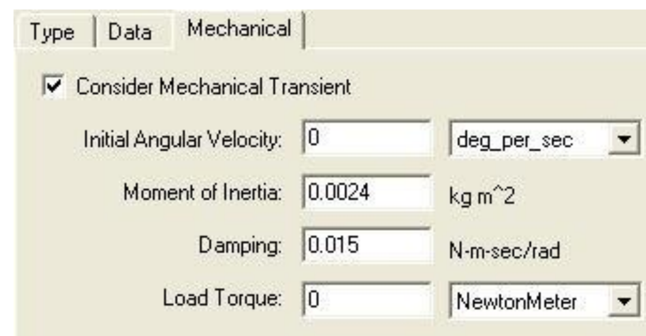
  - J in kgm^2 is the total moment of inertia acting on Rotor. c_ψ in Nm/rad is the magnetic rigidity. As an analogy it can be understood as a mechanical spring spanned between Rotor and Stator, whose force coming from magnetic field.
  - We can roughly calculate rigidity c from cogging torque function (stable limb):

$$c_\psi = \frac{\Delta T_\psi}{\Delta \varphi_m} \approx \frac{400\ \mathrm{mNm}}{\mathrm{rad}(10°)} = 2.3\ \mathrm{Nm/rad}$$

  - Assuming inertia J = 0.0024 kgm^2, an approximated f_0 = 5 Hz results.

Modify Design

- **Create a Copy of Design**
  - Copy the design **Large_Motion_ConstantSpeed** and rename it as **Large_Motion_MechTransient**
- **Modify Rotation**
  - In Motion Setup window,
    - **Data** tab
      1. Change Initial Position to **0 deg**
    - **Mechanical** tab
      1. Consider Mechanical Transient: ☑ **Checked**
      2. Initial Angular Velocity: **0 deg_per_sec**
      3. Moment of Inertia: **0.0024 Kgm^2**
      4. Damping: **0.015 N-m-sec/rad**
      5. 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

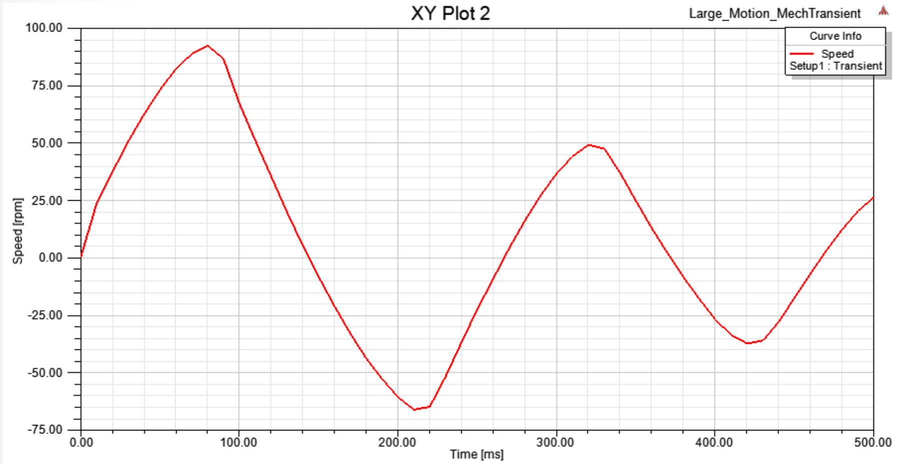
- **Modify Solution Setup**
  - Expand the tree for **Analysis** from Project manager window
  - Double click on **Setup1** to open Solve Setup window
  - In Solve Setup window,
    1. Change Stop Time to **0.5 s**
    2. Chnage Time Step to **0.01 s**
    3. Press **OK**

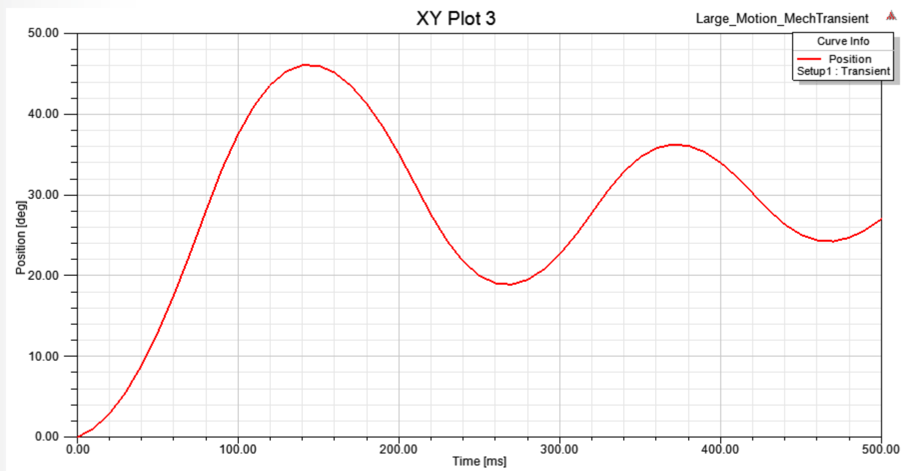
Note: From f_0, we can expect a >200 ms cycle. At 10 ms timestep we will sample one cycle >20 times.

- **Run the Solution**
  - Select the menu item ***Maxwell 3D → Analyze All***

Results

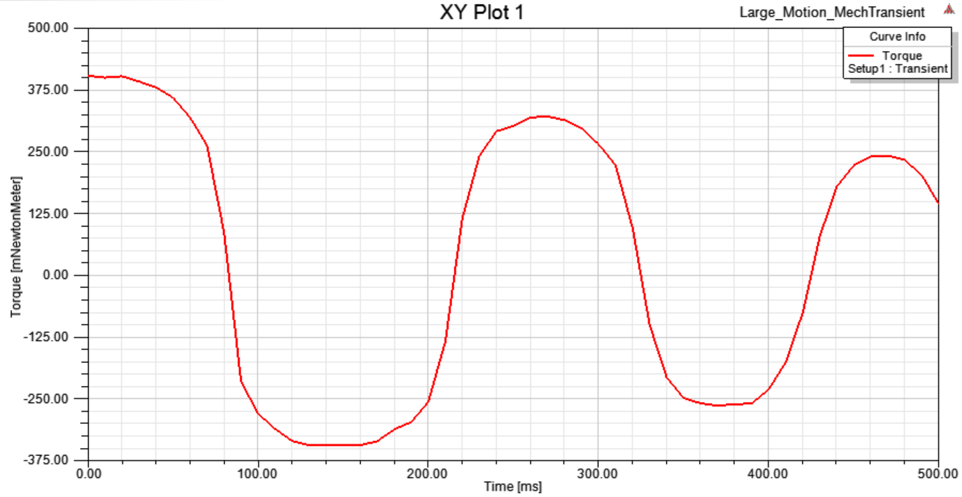
- **Create Plots for Speed and Position**
  - Select the menu item ***Maxwell 3D → Results → Create Transient Report → Rectangular Plot***
  - In Reports window,
    1. Solution: **Setup1: Transient**
    2. Parameter: **Moving1**
    3. X: **Default**
    4. Category: **Speed**
    5. Quantity: **Speed**
    6. Press **New Report**
    7. Change Category to **Position**
    8. Quantity: **Position**
    9. Press **New Report**





Results (*Contd…*)

- **To View Plot**
  - 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_ψ looks as expected from previous simulations.
  - ω_m corresponds to T_ψ's first derivative and is correct.
  - φ_m oscillates around +29°, which is the stator flux axis (y) with respect to the initial position.

Appendix : Variable Explanation:

$\varphi_m(t)$	Mechanical angular position in rad (angles can also be given in degrees).
φ_{m0}	Initial φ_m in rad. Note that the *drawn rotor position* is considered as $\varphi_{m0} = 0$.
$d\varphi_m(t) / dt$, $\omega_m(t)$	Mechanical angular speed in rad/s.
ω_{m0}	Initial ω_m in rad/s.
$d^2\varphi_m(t) / dt^2$	Mechanical angular acceleration in rad/s^2.
J_m	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_ψ	Magnetically generated torque in Nm.
T_m	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.