User's Guide

Magnetic Sensing Enhanced Proximity Tool

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ABSTRACT

When designing any end product, it is not uncommon for engineers of multiple disciplines to work together to create the final design. Often a mechanical engineer might set aside an area where electronic components can reside and provide area constraints that must fit the PCB within. Simulation tools exist to assist electrical engineers with layout and circuit design to optimize performance for most devices. However, this is not typically the case for magnetic position sensors. The challenge for these devices is that SPICE modelers cannot determine the input magnetic field provided the shape, material, and position of the magnet. However, this information is critical to understand when defining sensor placement and when selecting the magnet to use in the final product. Without these details, the total design cycle time can be lengthened by repeated prototype and verification test builds.

The purpose and function of the Magnetic Sensing Enhanced Proximity Tool is to provide an easy access simulation platform which is able to quickly provide simulated magnetic field and device output data. Guess work in prototype builds can be greatly reduced by modeling the complete electro-mechanical response. This is accomplished using the open-source python library MagPyLib.

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1 Introduction

The Magnetic Sense Enhanced Proximity Tool is built in Python using a simple graphical user interface, which prompts the user for design information regarding the magnetic material, magnet shape, type of motion, sensor location and sensor type. Successful simulations will produce a 3D animation showing the motion of the magnet relative to a sensor marker. The orientation of the magnet and sensor may be adjusted to model many basic motion types. These include axial, joystick and hinge rotations as well as linear travel. It is also possible to capture the magnetic field vector components at a single sample location.

1.1 Simulating Magnetic Fields

This tool is intended for use as an electro-mechanical design aid to help understand the magnetic field produced by a single moving magnet and to predict device behavior by plotting simplified sensor outputs.

Temperature inputs for this tool only evaluate changes in the magnet strength on the assumption of a constant linear response. However, real magnets have temperature operating ranges that vary based on shape and material selection. It is the sole responsibility of the user to be aware regarding the operating range of their selected magnet and to ensure that both the magnet and sensor always remain within their specified operating range. The modeled temperature compensation for device output behavior only considers intentional compensation of the device sensitivity, but this will not impact any other device parameters.

It is always recommended to prototype and evaluate mechanical systems using real components to verify typical operating tolerances and system behaviors. For instance, ferromagnetic materials which may be present in system construction can interact with magnetic fields and will change the observable inputs to the magnetic sensor.

Functions matching several common types of motion are provided, and resulting typical device performance are modeled to demonstrate the relationship between mechanical position of the magnet and the electrical response of the sensor.

When defining magnet and sensor position and alignment, this tool allows for independent rotation of both the magnet and the sensor. Each user defined rotation is applied by rotating the object around the specified axis. This may also be understood to be rotation within the plane orthogonal to the rotation axis. For example, rotation about the Z-axis is rotation in the XY plane. Figure 1-1 shows the default sensor orientation aligned to the positive X,Y, and Z axes. Figure 1-2 through Figure 1-4 show the result of a single +90° rotation about the X,Y,&Z axes from the default alignment. In each case the global orientation remains unchanged, but the relative sensitivity of the sensor is changed to reflect the rotation.

In each image, the red arrow represents the sensor X-axis, the green arrow represents the sensor Y-axis, and the blue arrow represents the sensor Z-axis.

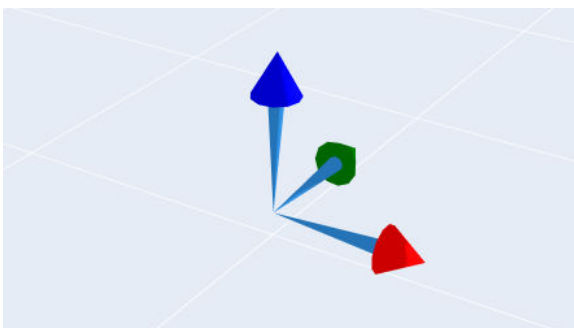

Figure 1-1. Sensor With No Rotation

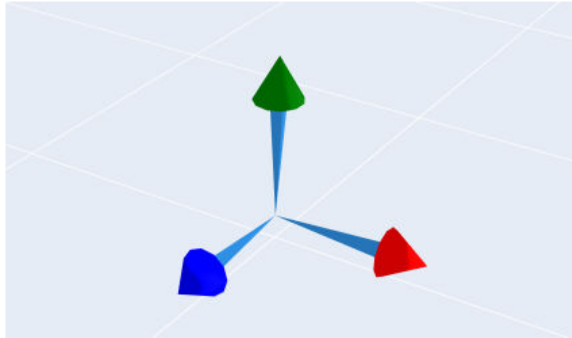

Figure 1-2. Sensor Rotated 90° About X-Axis

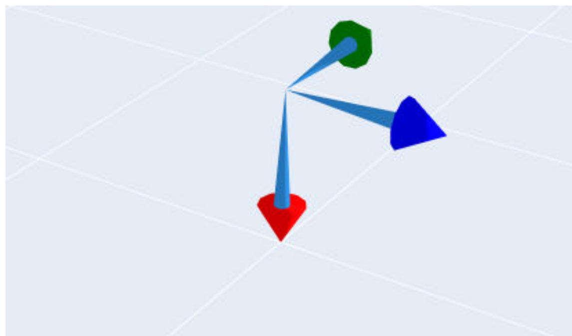

Figure 1-3. Sensor Rotated 90° About Y-Axis

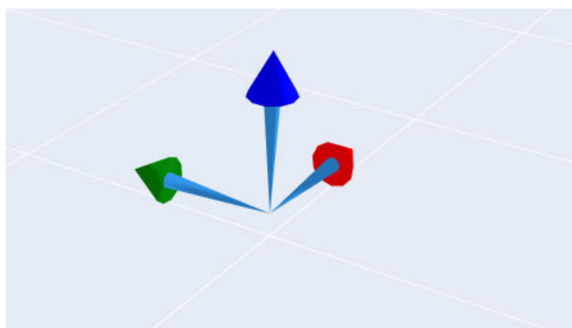

Figure 1-4. Sensor Rotated 90° About Z-Axis

The default orientations for each magnet shape are shown in Magnet Shapes.

2 Supported Functions

The Magnetic Sensing Enhanced Proximity Tool allows the user to select several types of motion for each of the magnet options. Hinge motion, rotation, linear displacement, and joystick functions are all available with customizable user inputs. Additionally, for a quick approximation, the field produced by each magnet type may be checked at individual static positions.

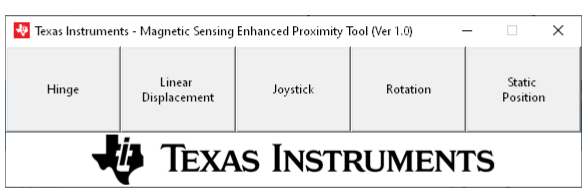

Figure 2-1. Menu Top-Level

The general flow when defining a simulation follows this process:

1. Define the Magnet:
    a. Select the shape from the Magnet Shape drop-down and set the desired number of poles if required. Fields should auto-populate in the Magnet Geometry section labeled with the required magnet dimensions.
    b. Select the material type from the Magnet Material drop-down. This populates a list of common material grades that can be selected from the Material Grade drop-down. If the desired grade is not shown, select Custom.
    c. Most magnetic materials have a specified range for acceptable values of Br (Remanence). Select High, Typical, or Low from the radio buttons, and the tool will auto-populate the Remanence value expected at 20°C. If this does not match exactly the value needed your magnet, you may manually enter a value and over-ride the preset.
    d. Set the operating temperature. Magnetic materials have a typical temperature coefficient that describes the changes in magnetic strength of the material as temperature varies through most normal operating conditions. This tool assumes a constant coefficient across all temperatures and does not consider changes in behavior at extreme temperature.
    e. Enter the dimensions of the magnet as required in each field of Magnet Geometry.
2. Define the Magnet Alignment:
    a. The starting position of the magnet may be set using the X Position, Y Position, and Z Position fields in magnet alignment. Each value is relative to the center of the magnet. Linear displacement occurs smoothly from the start position to the end position while maintaining magnet orientation.
    b. The orientation of the magnet may also be adjusted using X Angle, Y Angle, and Z Angle. These rotations will occur about the magnet center and can be used to align the magnet in the correct direction. The rotation operations occur in XYZ order.
3. Define Magnet Travel:
    a. The Magnet Travel section of the user input window updates based on the type of motion for each function. More detailed descriptions for this step may be found in these sections:
        i. Hinge
        ii. Linear Displacement
        iii. Joystick
        iv. Rotation
        v. Static Position
4. Define Sensor Alignment - The magnetic field observed at any point may be selected by defining a sensor position and alignment.
    a. Set the absolute X Position, Y Position, and Z Position.
        i. **This revision of the tool does not inhibit placing the sensor within the magnet and only represents sensors as an infinitesimal point**. It is the user's responsibility to match this location to the target location of the sensing element within the package and to avoid mechanical conflict.
    b. Set the orientation of the sensor. The sensor can be rotated by any set of angles in XYZ order and the displayed simulation results will match this alignment. To help visualize the sensor alignment to the magnet, a coordinate cross-hair is shown reflecting the final sensor rotation.
5. Define simulation resolution:
    a. Enter the step size to simulate. Finer resolution simulations take longer to complete, but provide the best overall detail. If the total range of motion cannot be divided evenly, the tool adjusts the size of the final incremental step to the match the remainder.
6. Click "Start Simulation" to generate plots of Magnetic Fields observed at the sensor location.
    a. If desired, proceed to select a magnetic sensor following the steps in Device Emulation.
    b. To change functions, click "Return to Function Select".

2.1 Hinge

Hinge motion is commonly seen when monitoring door and lid positions, such as when detecting the screen position on a laptop. A simple hands-on tool to test the hinge function manually is available using the HALL-HINGE-EVM, which features a 3D printed assembly that includes magnet and sensor adjustment and a protractor with 1 degree intervals.

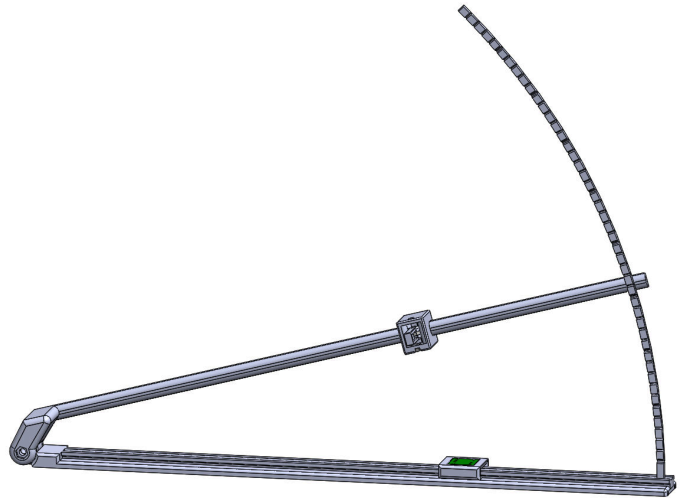

Figure 2-2. Hall-Hinge-EVM

To simulate hinge motion, select "Hinge" from the top-menu.

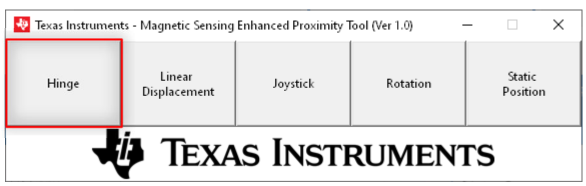

Figure 2-3. Hinge Function Selection

The resulting prompt appears as shown in Figure 2-4

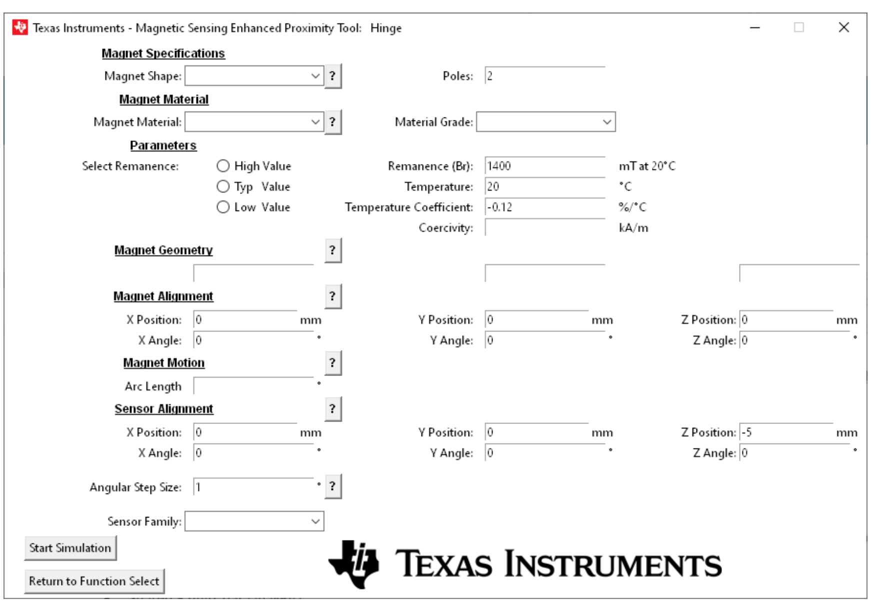

Figure 2-4. Hinge Function User Inputs

Magnet travel for this type of motion is described by the magnet rotating by some angular distance about the X-axis. This is normally setup by placing the sensor and magnet at some horizontal displacement from the hinge in the Y-direction. Vertical offset from the hinge may be set in the Z-direction.

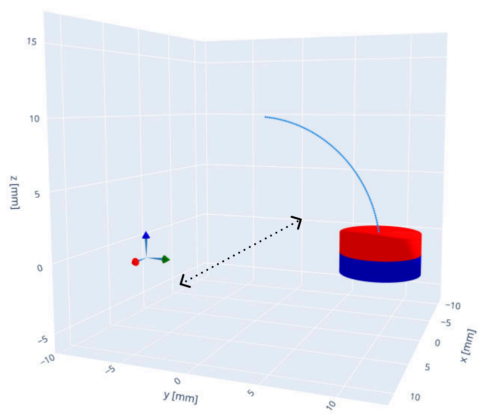

Figure 2-5. Hinge Motion Using an Axial Cylinder Magnet

The angular distance is entered by the user in the field marked "Arc Length" in the Magnet Motion section. An arc length of 360 produces a complete circular rotation about the X-axis.

2.2 Linear Displacement

Linear motion commonly occurs when detecting the position of an electronic switch, button-press, tracking objects that slide on tracks, and in liquid level detection. For long travel, this type of motion is commonly monitored using arrays of sensors such are described in *Linear Hall-Effect Sensor Array Design* and *Magnet Selection for Linear Position Applications*.

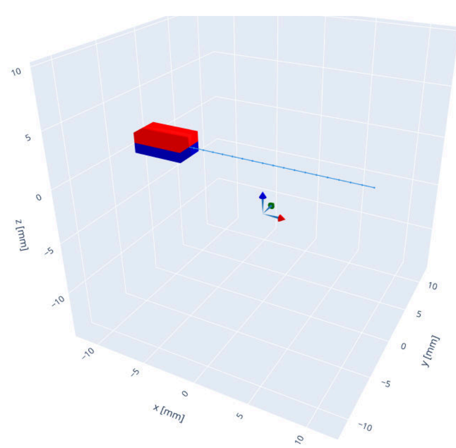

Figure 2-6. Linear Motion Using a Bar Magnet

To simulate linear magnet travel, select "Linear Displacement" from the top-menu.

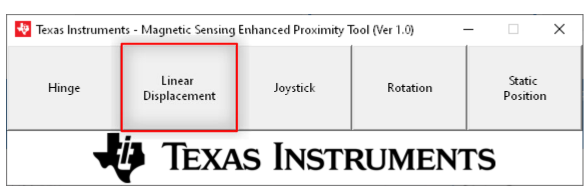

Figure 2-7. Linear Displacement Function Selection

The resulting prompt appears as shown in Figure 2-8

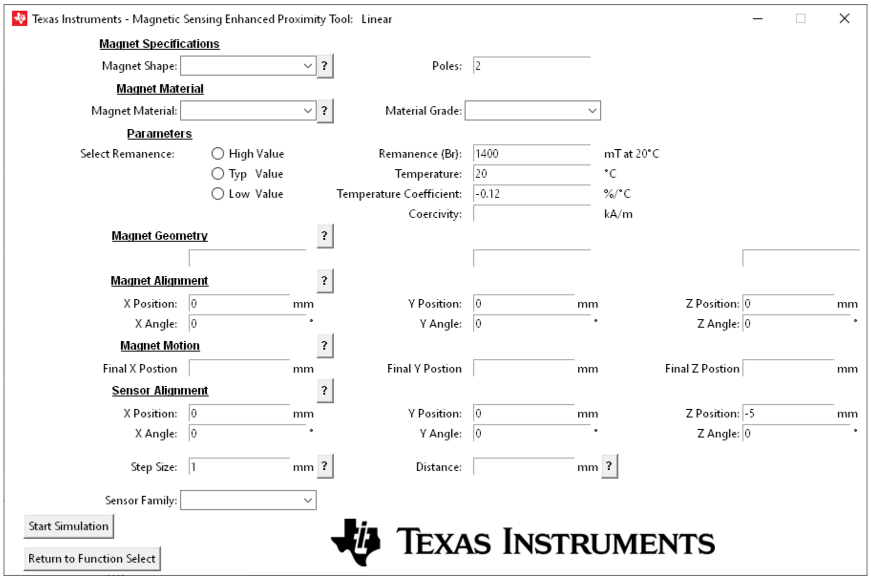

Figure 2-8. Linear Displacement Function User Inputs

Magnet travel occurs in a smooth fashion from the initial position entered in the Magnet Alignment section, and steps evenly to the final (X,Y,Z) position in the Magnet Motion section. This travel is commonly along a single axis, but the magnet may travel in all three dimensions simultaneously as needed.

2.3 Joystick

Joystick motion is another form of hinge motion which will occur about the origin as typically observed in human-machine interfaces such as video game controllers, automotive turn indicators, and other various industrial machine controls. This type of motion is described in Designing Joysticks with Hall-effect Sensors and *Measuring 3D Motion with Absolute Position Encoders*

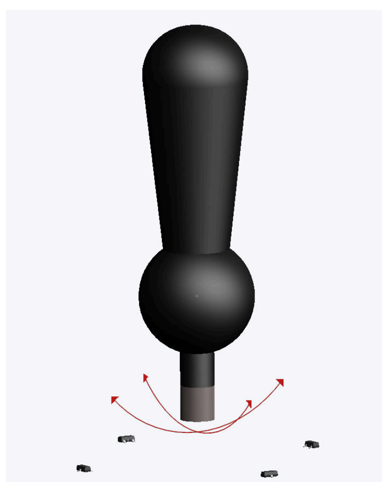

Figure 2-9. Joystick Motion

To Simulate joystick configurations select "Joystick" from the top menu as shown in Figure 2-10.

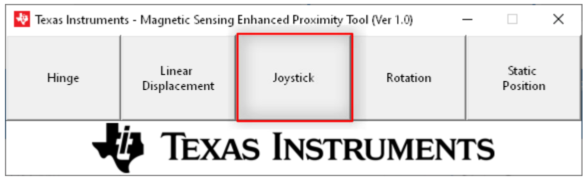

Figure 2-10. Joystick Function Selection

The resulting prompt will appear as shown in Figure 2-11

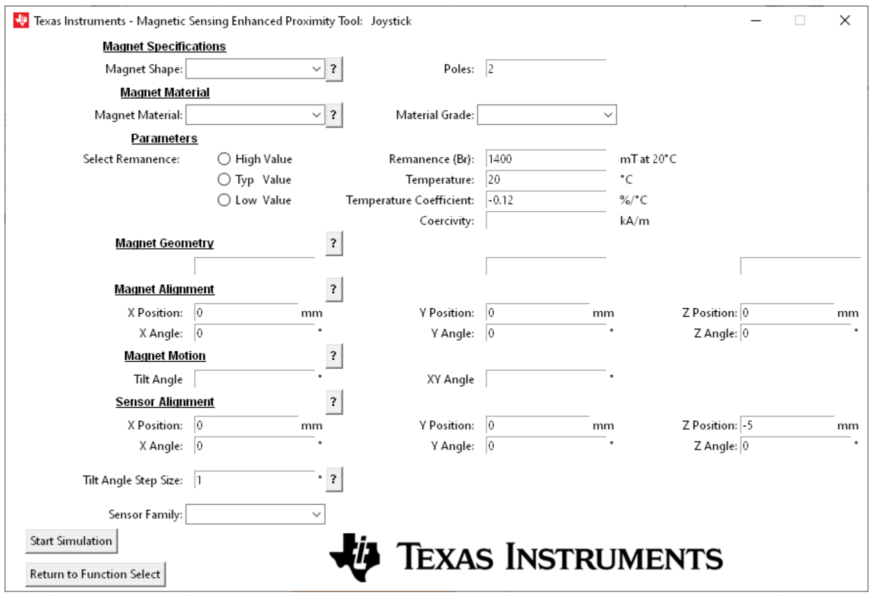

Figure 2-11. Joystick Function User Inputs

Magnet travel for this type of motion pivots about the origin by a distance described by "Tilt Angle" and in a direction "XY Angle". The normal expectation is that the magnet is placed at a location in the negative Z-direction. This distance is the fulcrum distance for the magnet. The sensor is also typically placed in the negative Z-direction below the magnet.

Figure 2-12 illustrates that as the magnet tilts, the range to the sensor increases accordingly in the required direction.

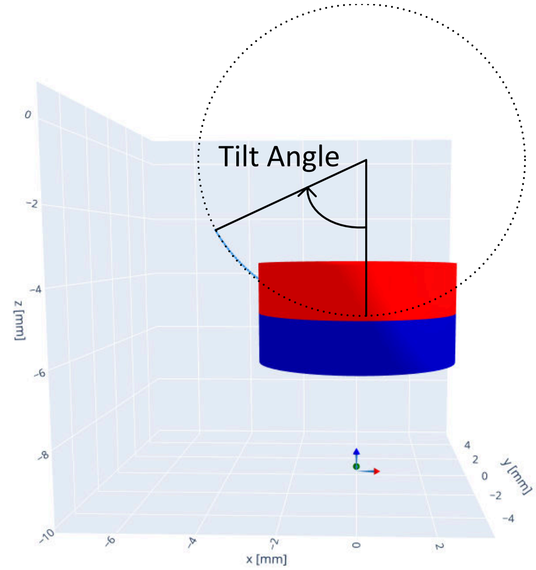

Figure 2-12. Joystick Tilt Angle Using an Axial Cylinder Magnet

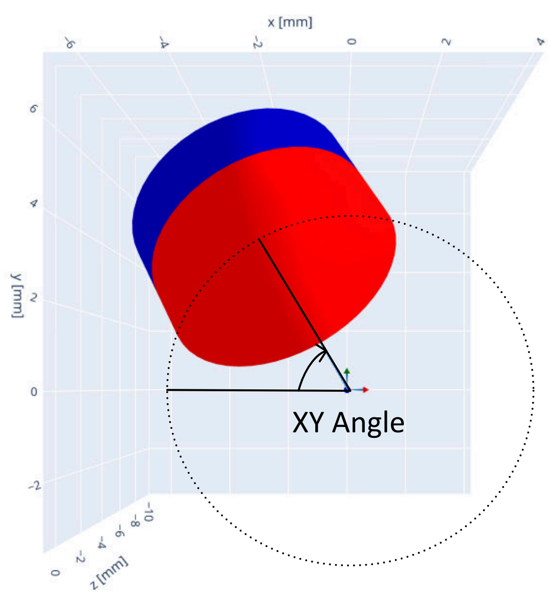

Figure 2-13. Joystick XY Direction Angle Using an Axial Cylinder Magnet

2.4 Rotation

Rotation is a useful function whenever motors are involved. Magnets mounted to a spinning motor shaft may be used to track absolute angle or track incremental step-wise rotation. Incremental rotation relies on counting state transitions to track the motor position, and therefore does not offer the same resolution from angle measurements. Incremental rotary position is appropriate when speed, direction, and revolutions are being measured. Angle measurements are important when precise position control is required.

More information about these functions can be found in *Reducing Quadrature Error for Incremental Rotaty Encoding Using 2D Hall-effect Sensors* and TIDA-060040

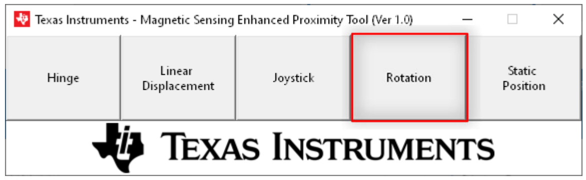

Figure 2-14. Rotation Function Selection

During a rotation simulation, the magnet will rotate about the Z-axis. The only required input is "Arc Length" in the Magnet Motion section. Typically this will be 360 for a full rotation, but may be set higher or lower to generate data for any region of interest.

"Z Angle" can be adjusted to define the rotation starting angle. Normally, "X Position" and "Y Position" should be set to 0. Any offset for either of these values produces run-out, which is when the axis of rotation is not aligned to the center of the object. Similarly, adding tilt to the magnet alignment in "X Angle" or "Y Angle" simulates wobble, which occurs when the magnet is not orthogonal to the rotating axis.

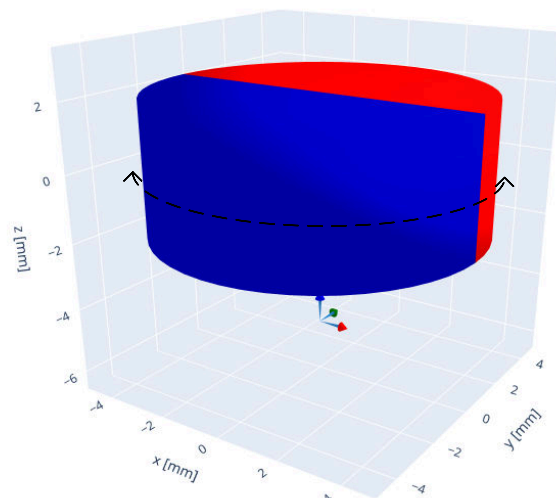

Figure 2-15. Rotation Motion Using a Diametric Cylinder Magnet

Depending on the mechanical constraints and how the magnet is to be observed, sensors can be placed on the axis of rotation (On-Axis), coplanar to the magnet center (In-Plane), or anywhere else a strong enough field may be measured in the axes of interest (Off-Axis).

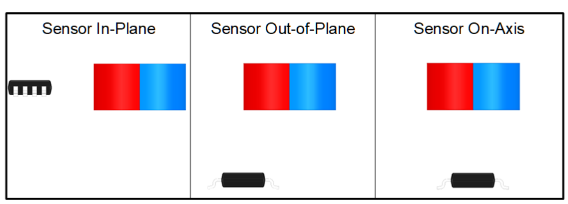

Figure 2-16. Sensor-Magnet Alignments

The user prompt for rotation simulation appears as in Figure 2-17.

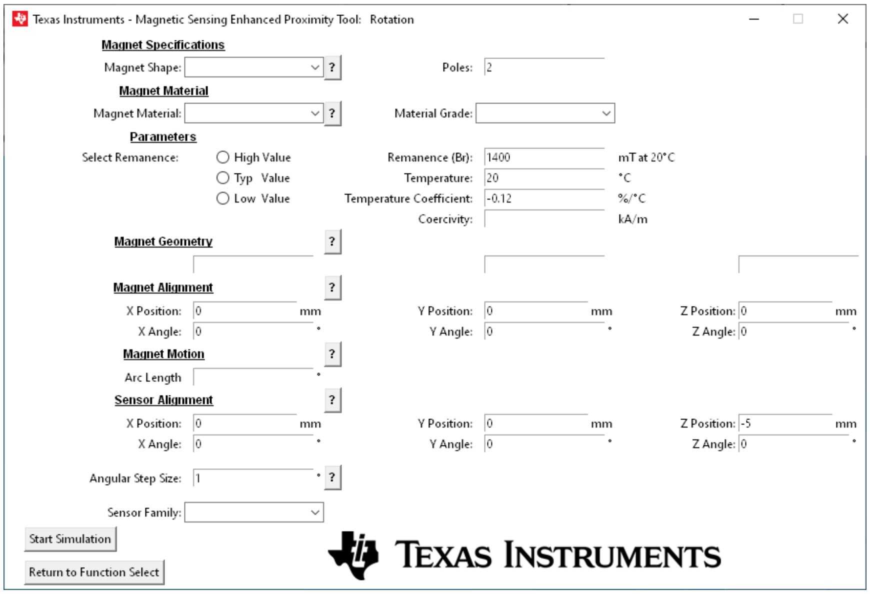

Figure 2-17. Rotation Function User Inputs

2.5 Static Position

The final function within the Magnetic Sensing Enhanced Proximity Tool requires no inputs to describe motion. Using this option only requires that the position of the magnet and sensor be defined.

Clicking "Start Simulation" will generate a pop-up window with the vector components for each axis at the sensor location.

Static position is helpful when quickly evaluating whether a magnet may be appropriate and what ranges specific field magnitudes will be observed.

3 Supported Magnets

The TI Magnetic Sense Enhanced Proximity Tool allows the user to specify a wide range of magnetic materials and shapes for single magnet simulations with no externally applied magnetic field.

Within the tool, tool-tips are available to the user when placing the cursor over the button shown in Figure 3-1. For all magnet cases, the North pole is represented in red, while the South pole is represented in blue.

Figure 3-1. Mouse-Over Tool-Tip

3.1 Built-In Library of Materials

A built in library of materials is included to assist with simulation setup. The library allows the user to select from a set of common magnet materials including:

- Sintered Neodymium-Iron-Boron (NdFeB)
- Samarium Cobalt (SmCo)
- Bonded Neodymium-Iron-Boron (NdFeB)
- Aluminum-Nickel-Cobalt (AlNiCo)
- Ceramic Ferrites
- Rubberized Ferrites

Each material type also has a set of selectable material grades with High/Typical/Low values, which may be selected as desired as shown in Figure 3-2.

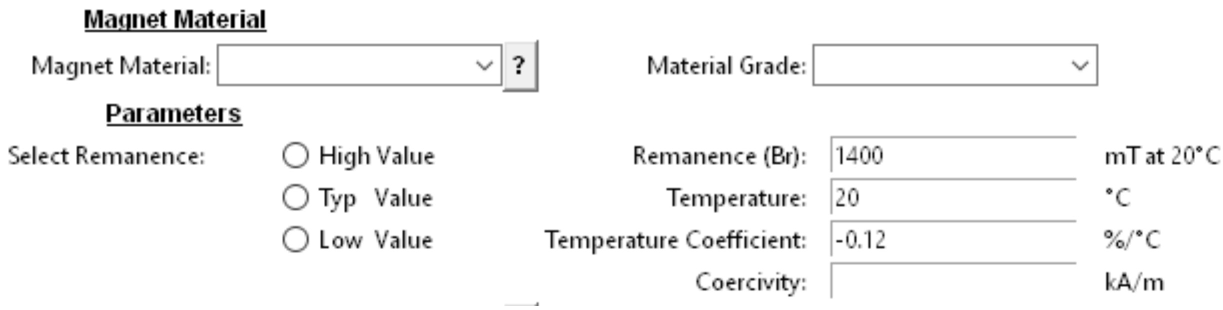

Figure 3-2. Magnet Selection

If none of the materials match the specific properties of the magnet to be simulated, it is possible to manually overwrite Remanence, Temperature Coefficient and Coercivity for a custom material.

3.2 Magnet Shapes

In addition to setting the strength of the magnetic material, the specific shape and orientation of the magnet influences the observed magnetic field. Each of the shapes and the respective default orientations is discussed in detail.

For each magnet, the placement within the simulation follows the magnet center. For example, coordinates of (0,0,0) place the centroid of the magnet on the origin. For a ring magnet, this point is not located within the body of the magnet since there is a bore hole through this part of the magnet. This is important to keep in mind when selecting the sensor location to avoid placing the sensor inside of the magnet body. In some cases, it is helpful to set the "Z Position" of the magnet at 1/2 the vertical height of the magnet. This places the global origin on the face of the magnet. With the magnet in this position, it becomes easier to place the sensor based on a known air gap distance.

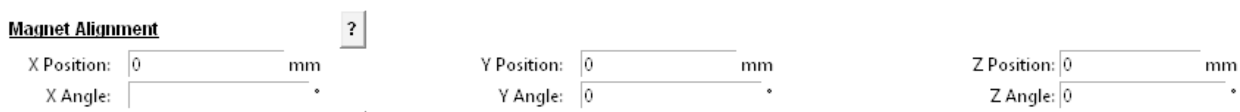

Figure 3-3. Magnet Alignment

All magnet shapes assume a starting orientation, and it may be necessary to perform rotations in order to obtain the desired alignment to the sensor. All multi-axis rotations will take place in X->Y->Z order.

3.2.1 Bar

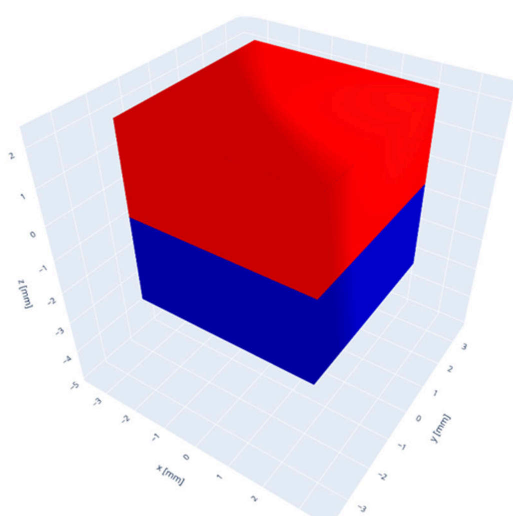

Figure 3-4. Bar Magnet

The standard dipole bar magnet is created by selecting "Bar" from the "Magnet Shape" dropdown menu and leaving the pole count at 2. This populates the "Magnet Geometry" fields and prompts the user to enter length, width, and height of the magnet. These parameters are drawn, respectively, in X, Y, Z order.

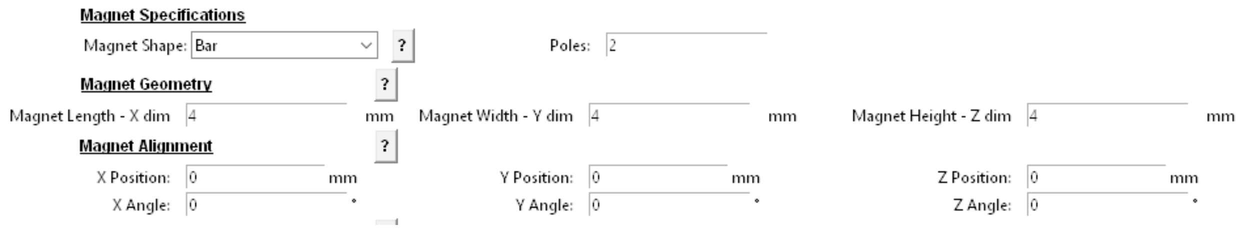

Figure 3-5. Bar Magnet Input Fields

Magnet orientation defaults with the North pole directed in the positive Z-direction. It may be necessary to perform a rotation to orient the magnet to match the target system. In this event, rotations may take place about each axis in X->Y->Z order.

For instance, to obtain a 2 mm thick bar magnet that is 3 mm wide and 5 mm long, but polarized in X, the settings shown in Figure 3-6 may be used.

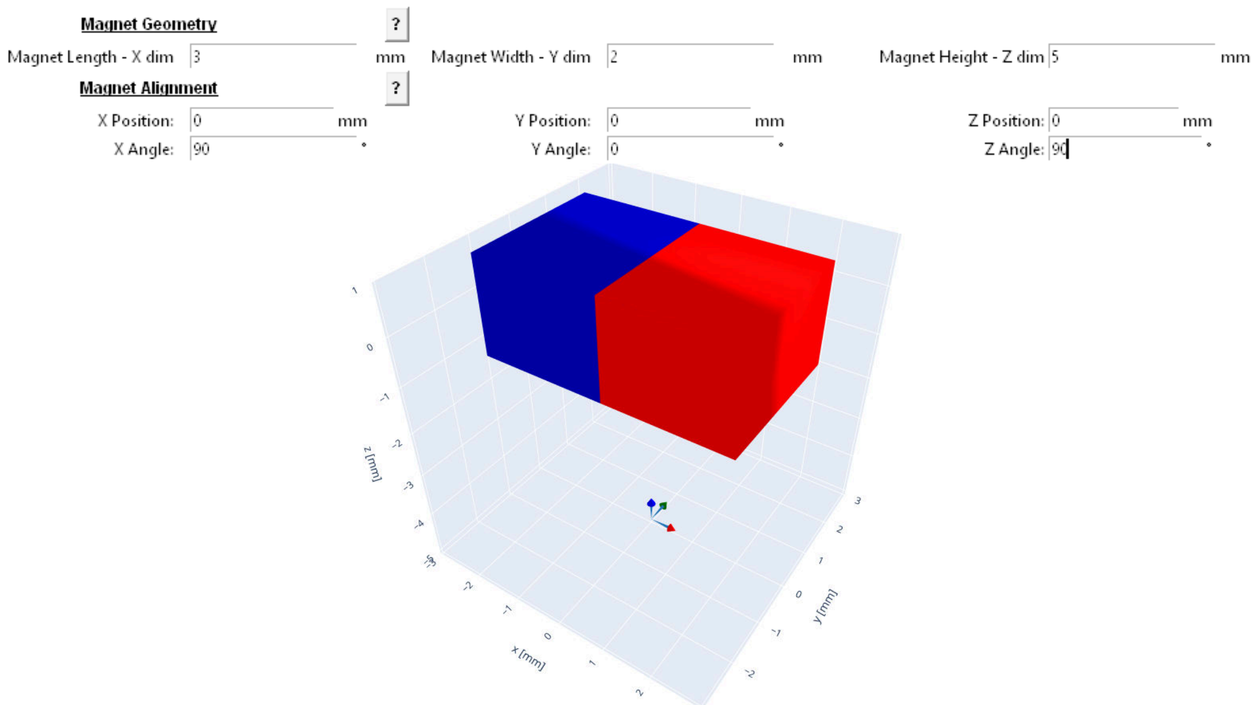

Figure 3-6. Rotated Bar Magnet

Bar magnets are ubiquitous and found commonly across many applications. Their simple shape and polarization result with a typically inexpensive option that is easy to orient during product assembly.

3.2.2 Strip

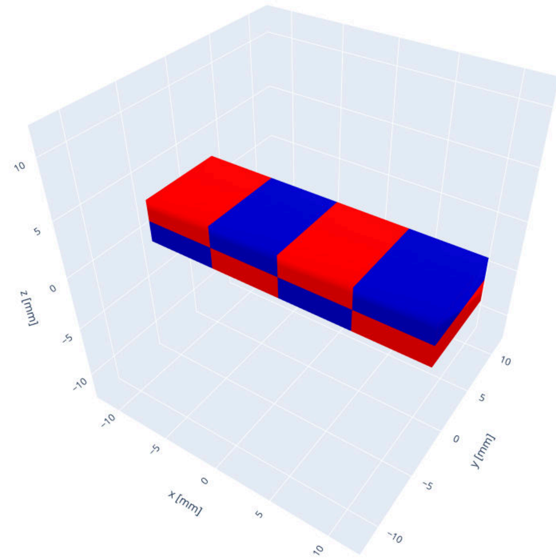

Figure 3-7. Strip Magnet

When the pole count of a bar magnet is increased above 2, it is possible to create a strip magnet. Often these magnets are created using a low cost flexible rubberized magnetic material. However, it is also possible to obtain custom bar magnets with multiple pole pair using stronger materials such as neodymium type magnets. The polarization alternates along the length of the magnet in the x-direction with each pole pair aligned in the Z-direction.

To create a magnet of this type, increase the default number of poles from 2 to any positive even integer value. For this magnet type, the total number of poles considering both the top and bottom of the magnet should be used. The magnet shown in Figure 3-7 has 8 poles.

These magnet types are commonly used for linear position encoding. When moving with respect to a latch type sensor, these can provide incremental position resolution.

3.2.3 Diametric Cylinder

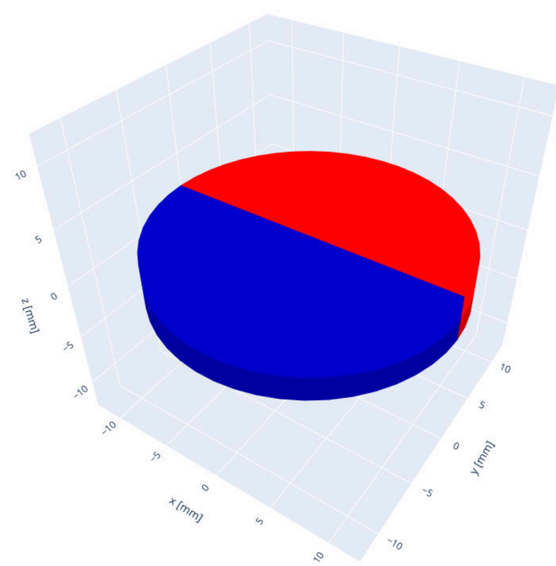

Figure 3-8. Diametric Cylinder Magnet

Cylindrical magnets are also commonly available with a variety of polarization options. When "Diametric Cylinder" is selected for the magnet shape, the resulting magnet will by definition be a dipole magnet. The result is that pole count is not a needed input. The default polarization direction for this magnet type is in the Y-direction.

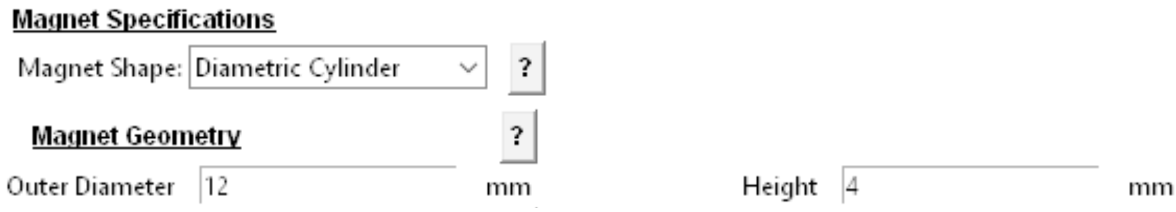

Figure 3-9. Diametric Cylinder Inputs

This magnet type is commonly used to track rotational angle. Used with either a single two-dimensional latch sensor or with two one-dimensional latch sensors, four distinct positions per revolution may be observed. However, if used with a linear device it is possible to capture absolute angle using electrical outputs that are 90° out of phase. This may be done with two one dimensional devices spaced about the magnet or using a single 3D sensor capable of capturing field components which are inherently 90° phase separated.

3.2.4 Axial Cylinder

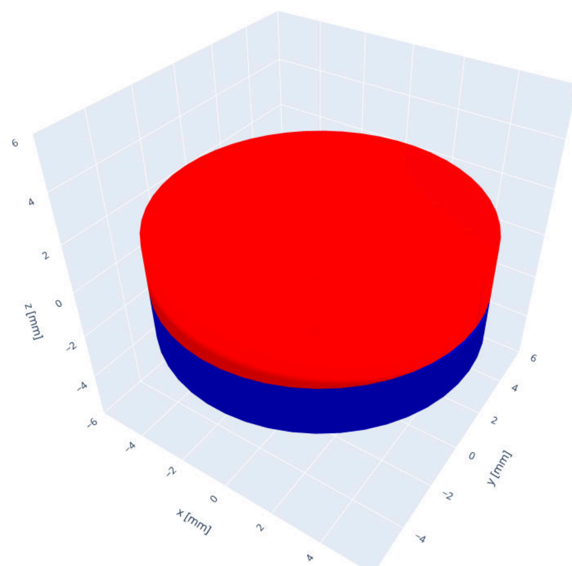

Figure 3-10. Axial Cylinder Magnet

Axial cylinder magnets are similar in nature to a diametric cylinder in that both magnets only have a single pole pair (2 poles). Magnet shape is defined using the same input parameters, but instead of showing polarization across the diameter of the cylinder, the polarization is along the axial length of the magnet. The default polarization for this magnet is in the Z-direction.

These magnets can be found in various lengths, and this length is a major factor in the overall field strength produced by the magnet. Often, coin shaped magnets are used to observe linear displacement and when the magnet approaches the sensor head-on.

3.2.5 Diametric Ring

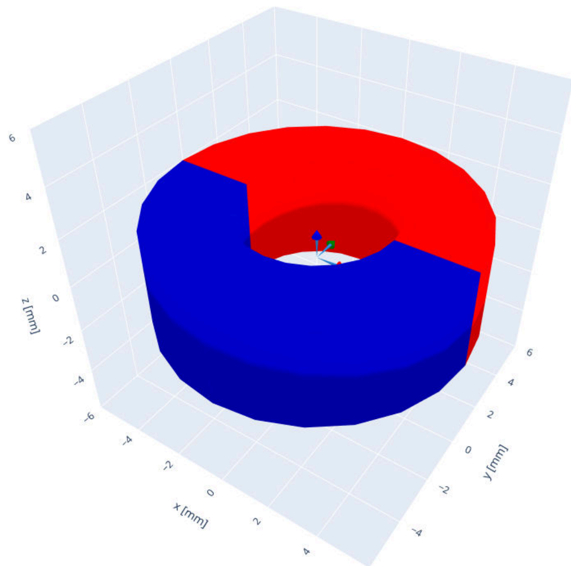

Figure 3-11. Diametric Ring Magnet

To create a diametric ring magnet, set the magnet shape to "Ring" and leave the number of poles at 2. The diametric ring magnet is similar to the diametric cylinder. The primary difference is that the center of the magnet is open, and the user is required to enter an inner diameter value as well. Polarization of this magnet type is in the Y-direction by default.

Figure 3-12. Diametric Ring Inputs

These magnets can be installed anywhere along the length of a rotating shaft for use in angle measurements. This is particularly helpful in cases where space is limited or access to the motor shaft is obstructed in such a way that a diametric cylinder cannot be easily installed on the end of the rotating shaft. Sensors may be placed to capture the rotating field to measure absolute angle with this magnet type as well.

3.2.6 Axial Ring

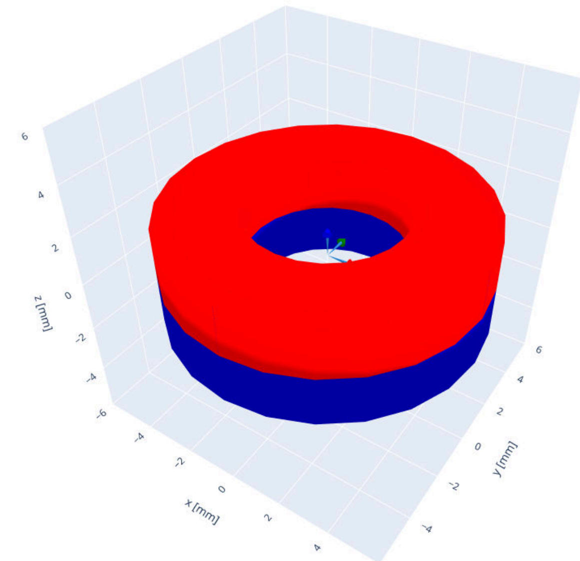

Figure 3-13. Axial Ring Magnet

Similar to the diametric ring magnet, an axial ring magnet features a center bore hole. Polarization for this magnet is directed axially in the Z-direction.

This magnet type may similarly be installed onto a shaft, but may not be used to measure rotary angle due to the radial symmetry of this magnet type. Instead, it may be more practically used to detect changes in linear position.

3.2.7 Multi-Pole Ring (Radial)

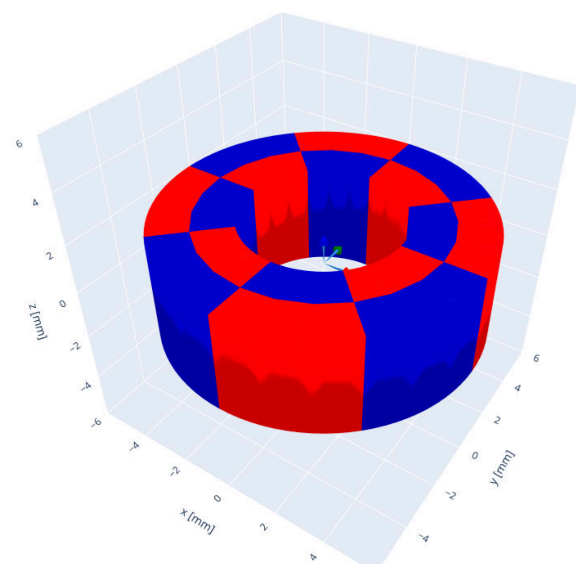

Figure 3-14. Multi-Pole Ring Magnet (radial)

The multi-pole radial ring magnet is a custom magnet type made possible with a ring shape. In this magnet type, the magnet will be divided into alternating sections with radial polarization. Pole count for this magnet type is set by selecting the number of visible poles (North and South) when traversing the outer circumference. The number of poles should always be even.

Due to the radial polarization, the inner circumference shows a pattern of alternating poles, which is opposite that of the outer circumference. This accurately reflects the direction of the field vectors along each circumference, although the inner circumference poles are not included in the total pole count.

A multi-pole ring magnet is useful when implementing rotary encoding using a 2D latch. The magnet pictured in Figure 3-14 produces eight polarity transitions per revolution. This can be divided into four North-South pole pairs. As each pair passes, four unique output states are produced by the 2D latch, with each state change representing a 22.5° change in rotation. Alternately, a 3D linear device can be used to calculate relative angle at a 4:1 turn ratio with the same magnet. Sensors are typically placed radially outward from the magnet center.

3.2.8 Multi-pole Ring (Axial)

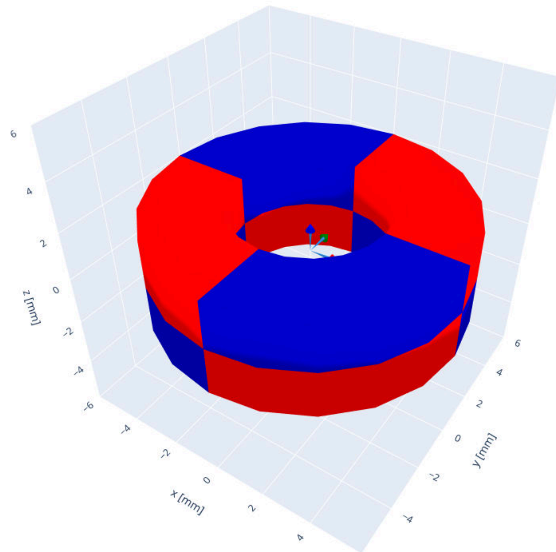

Figure 3-15. Multi-Pole Ring Magnet (axial)

The axial ring magnet is also a subdivided ring magnet, and each pole pair alternates in the Z-direction in even increments about the magnet. It is configured by selecting "Axial Ring" and then setting the pole pairs to any multiple of 4. The number of poles includes the divisions between top and bottom of the magnet. In Figure 3-15, the magnet has been defined using eight poles.

This magnet type is less common than the radial ring magnet, but can be used similarly. It is particularly useful when placing the sensor parallel to the circular face of the magnet.

3.2.9 Sphere

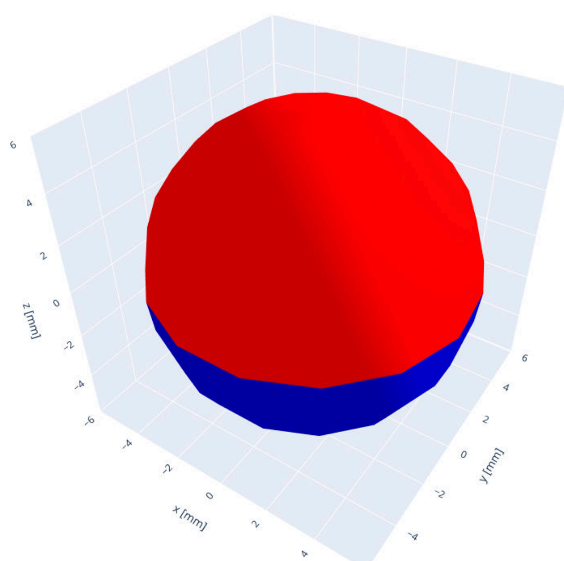

Figure 3-16. Sphere Magnet

Spherical magnets are created in the tool by selecting "Sphere" for Magnet Shape. This magnet type is a dipole magnet and only requires that the user enter the diameter in the Magnet Geometry section.

Spherical magnets can be difficult to align properly during installation, but provide the best overall symmetry in magnetic field. As a result they may be used to track tilt and rotation common in joysticks if the challenge of alignment can be resolved.

4 Device Emulation

The input field for any sensor type is helpful, but does not provide a complete reference for device behavior. A key use for this tool is to analyze magnetic field inputs for a given device and then to model output behavior. This provides a bridge between mechanical design and electrical signals which are ultimately used to process the behavior of the mechanism.

4.1 Device Types

Device emulation may be included in the simulation results by setting device parameters before clicking "Start Simulation". A pre-loaded set of devices available at www.ti.com/halleffect may be selected by first choosing a device family. If only magnetic data is needed, this may be left blank or set to "N/A". The following options are available:

- Analog Linear
- Digital Linear
- Switch
- Latch

For each family of sensors, the user will be required to select the device, sensitivity variant, and package option. While package options are shown for each sensor type, display of package shape and dimensions are not yet supported by this tool.

All devices will require the user to enter an operating supply voltage, and additional fields may be available depending on the sensor type. All fields shown with a grey background are fixed device parameters and are locked from being modified by the user.

4.1.1 Analog Linear

Analog linear devices are sensors that produce an output voltage that varies linearly with respect to the input magnetic field. These devices may be sensitive to either a single polarity or to either polarity magnetic field. Sensitivity is shown in units of mV/mT, and input referred noise is modeled as part of the device response.

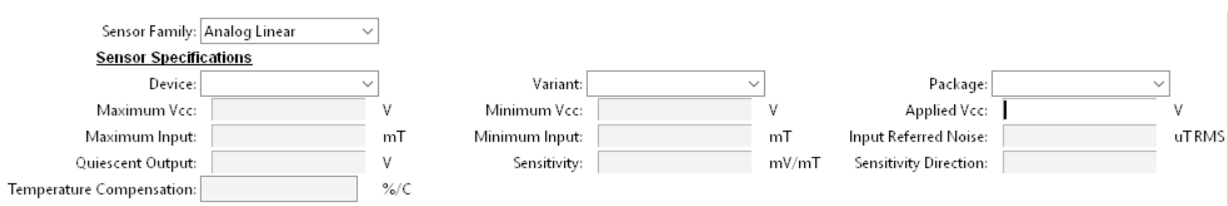

Figure 4-1. Analog linear user inputs

Many of these devices are ratiometric, therefore, the sensitivity varies with the supply voltage. This is particularly helpful when using the supply voltage as the reference voltage of an ADC to help minimize the effect of VCC fluctuations on the measurement accuracy. Once the VCC voltage has been entered, and the user clicks outside of the input field, the sensitivity updates accordingly.

4.1.2 Digital Linear

Digital Linear devices include an ADC as part of the device, and therefore are able to output conversion results in units of LSB/mT. These devices require a VCC voltage to perform simulations, but also allow the user to select from programmable settings such as sensitivity range (which is set using the drop-down option for "Maximum Input"), temperature compensation, and over-sampling averages. Increasing the total number of samples used to complete a conversion increases the effective number of bits (ENOB) of the ADC and results with a less observed noise in the output measurement.

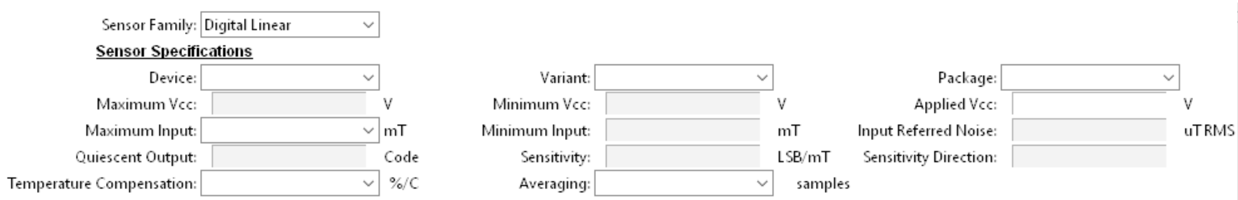

Figure 4-2. Digital Linear User Inputs

Output for these devices is converted to an integer output code depending on the device mode selected. It is important to remember that with averages set to '1' that the standard conversion result may be 12-bit, while increasing averages above this value typically produce a 16-bit result.

4.1.3 Switch

Switch type devices are typically offered in two varieties. Uni-polar sensors are sensitive to either a positive or negative field in the direction of sensitivity for the sensor. Whenever the input field exceeds the operating point threshold (B_{OP}), the output toggles to the active state. Once in this state, the field must return below the release point threshold (B_{RP}). If BOP and BRP were set at the same level of magnetic input, then the device may operate unpredictably due to mechanical vibration or electrical noise. To prevent this, some amount of hysteresis (B_{HYS}) are typically included into the device design.

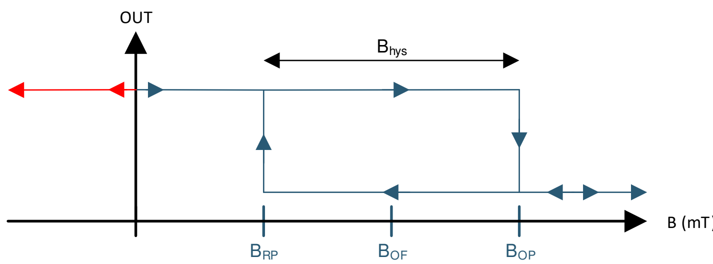

Figure 4-3. Unipolar Switch Output

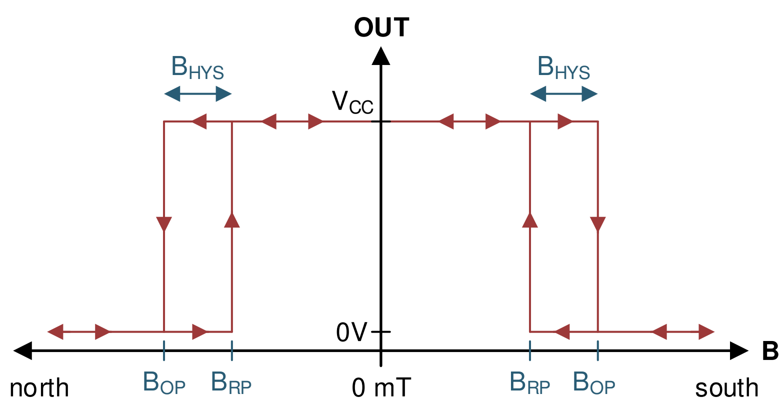

Figure 4-4. Omnipolar Switch Output

Omnipolar switches operate similarly, however the key difference is that the output may toggle with either polarity of magnetic input. A major advantage for this device type is that the sensor can be agnostic to the orientation of the magnet. This means that the magnet may be installed quickly during product assembly.

When configuring a simulation to use a switch type device, the input fields will appear as shown in either Figure 4-3 or Figure 4-4.

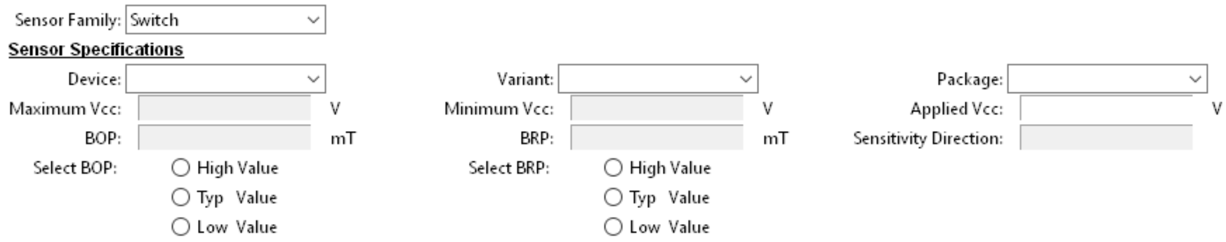

Figure 4-5. Switch User Inputs

To assist with design, radio buttons that allow the user to select minimum, typical, and maximum threshold values are enabled. While B_{HYS} for any individual sensor should fall within the published limits in the device-specific data sheet, it can be helpful to design functionality around the worst case scenario. For this, it is typically recommended to check against B_{OP} Max and B_{RP} Min from the device-specific data sheet. These values must be selected for the simulation to run.

4.1.4 Latch

A latch type device operates similarly to a unipolar switch with thresholds at B_{OP} and B_{RP}. The key difference is that B_{HYS} is set such that $B_{RP} = -B_{OP}$. For this case, the sensor requires an alternating input field for the device to be able to switch between output states. This is particularly useful for cases that use rotating magnets such as in incremental angle encoders or when the magnet may travel past the sensor in two directions, such as might occur in a toggle switch.

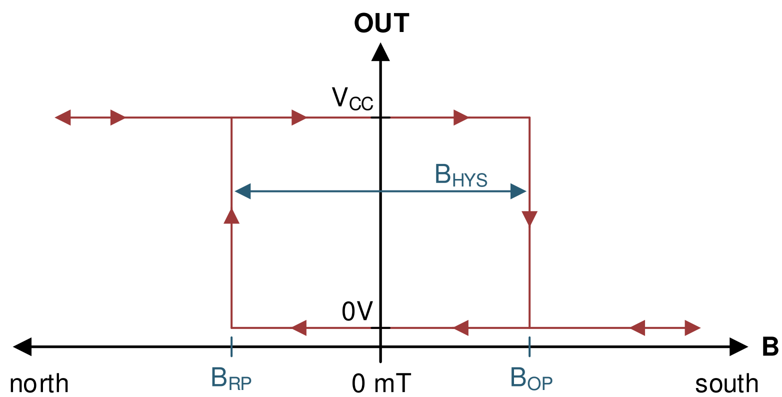

Figure 4-6. Latch Output

Configuring a latch device similarly allows radio buttons for selecting threshold limits based on published data sheet parameters. It is likewise recommended to check mechanical design against B_{OP} Max and B_{RP} Min to ensure all devices observe conditions sufficient to achieve the desired output response.

Latch user inputs appear similar to the inputs required for a switch device.

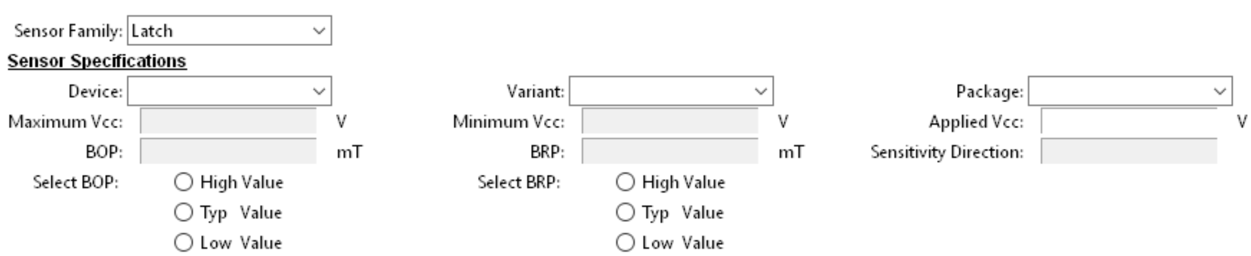

Figure 4-7. Latch User Inputs

5 Simulation Outputs

Upon clicking "Start Simulation" the tool starts by modeling the motion of the magnet and evaluating the magnetic field present at all magnet positions. Again, these positions are defined by the "Step Size" field. Fewer steps result in a faster simulation, but fine resolution will be lost.

Three tabs will open in the most recent instance of the system default internet browser. These will display the local data generated by the tool for ease of understanding, and a save file prompt will open asking where to save the data on the local machine.

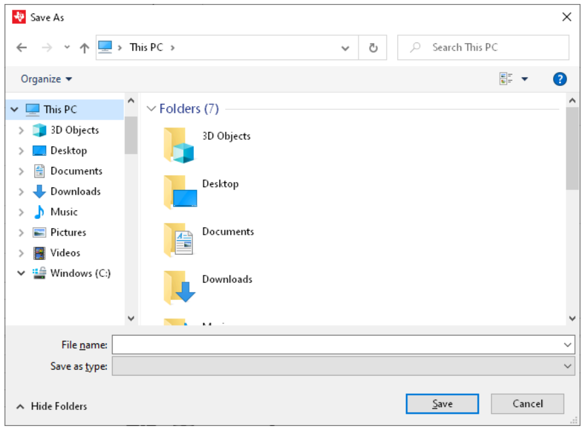

Figure 5-1. Save Prompt for .csv File

The first tab displayed shows an animated 3D plot displaying the magnet and sensor location. A blue line displays the path of travel for the magnet. The user may left-click on the plot area and drag the mouse to orbitally rotate the view. To pan the view, the mouse should instead be right-clicked. The mouse scroll-wheel may be used to adjust the zoom.

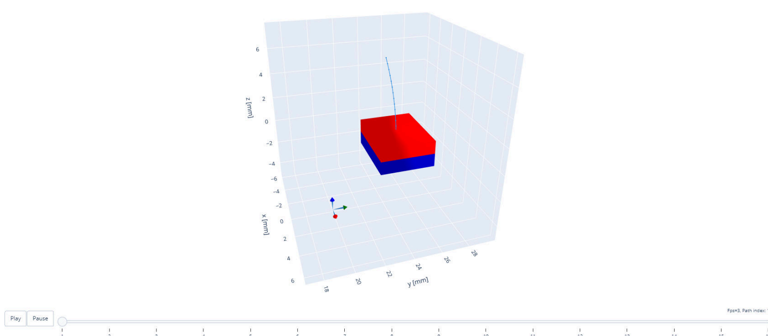

Figure 5-2. Animated Motion

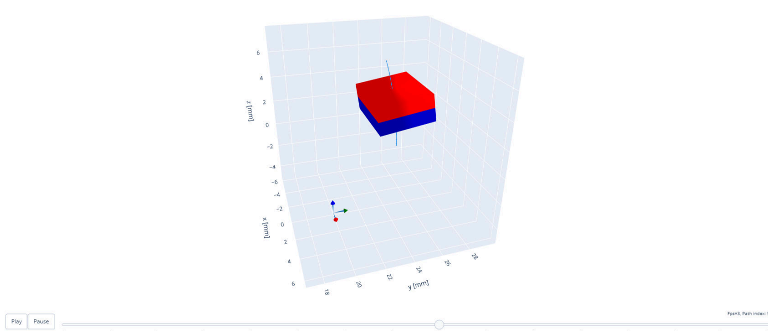

Figure 5-3. Animated Motion

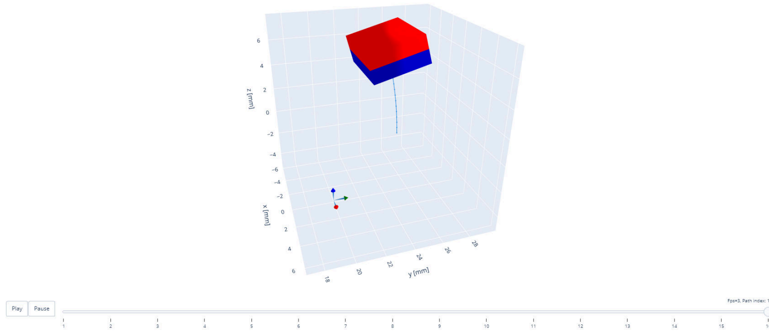

Figure 5-4. Animated Motion

The second tab contains a reference static image of the 3D plot alongside a plot of the magnetic field inputs observed at the sensor location. The static 3D plot may have its view adjusted similar to the animated plot on the previous tab.

The graph of magnetic field inputs and device outputs are color coded to match the RGB marker that represents the XYZ axes, which are shown to represent the sensor location and orientation. Each plot allows the user to zoom on a particular region by clicking and dragging to highlight the region of interest.

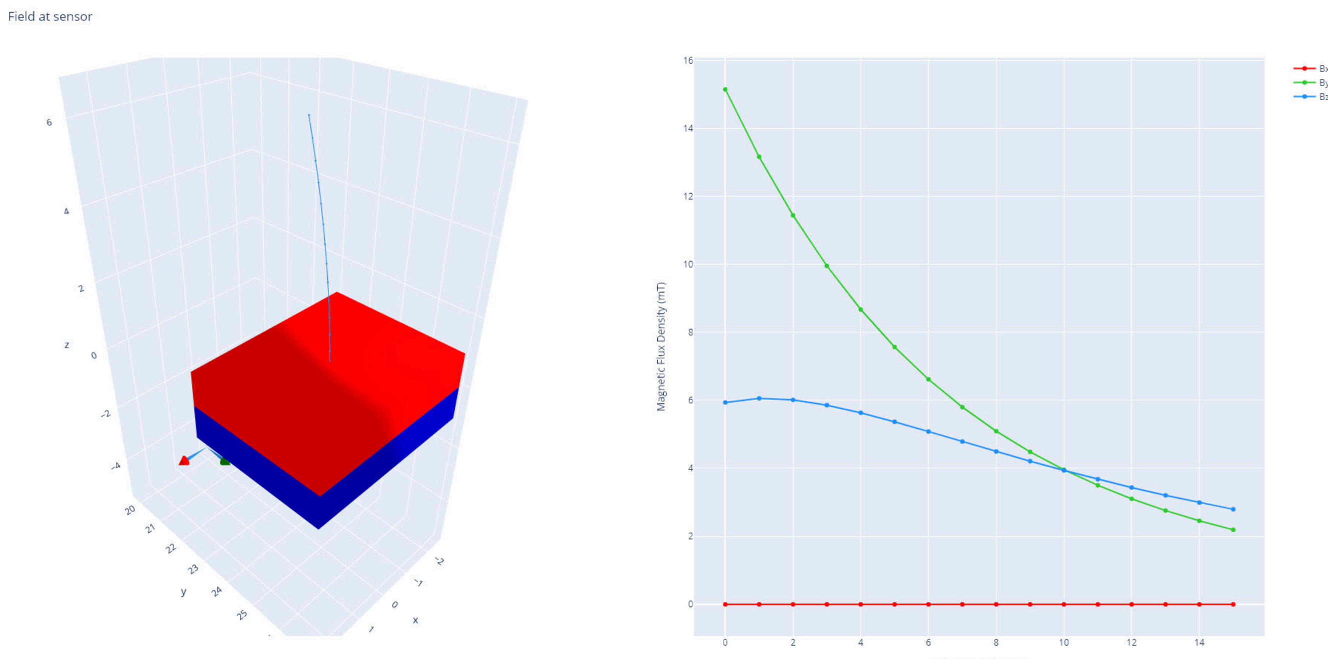

Figure 5-5. Magnetic Field Simulation Results

The third (and sometimes fourth) tab displays device outputs for the selected sensor type. If no sensor has been selected these tabs do not open. Device output is plotted against the type of motion that has been simulated. Whenever the input field saturates the input range of the sensor, the output is displayed at the maximum output level marked in the data sheet.

For analog and digital linear devices the output may vary between the specified output range. If the magnetic field input saturates the output range of the device, the output is displayed at the limit values. Switch and latch devices only have two outputs states that will display outputs at the digital logic levels V_{OH} and V_{OL}.

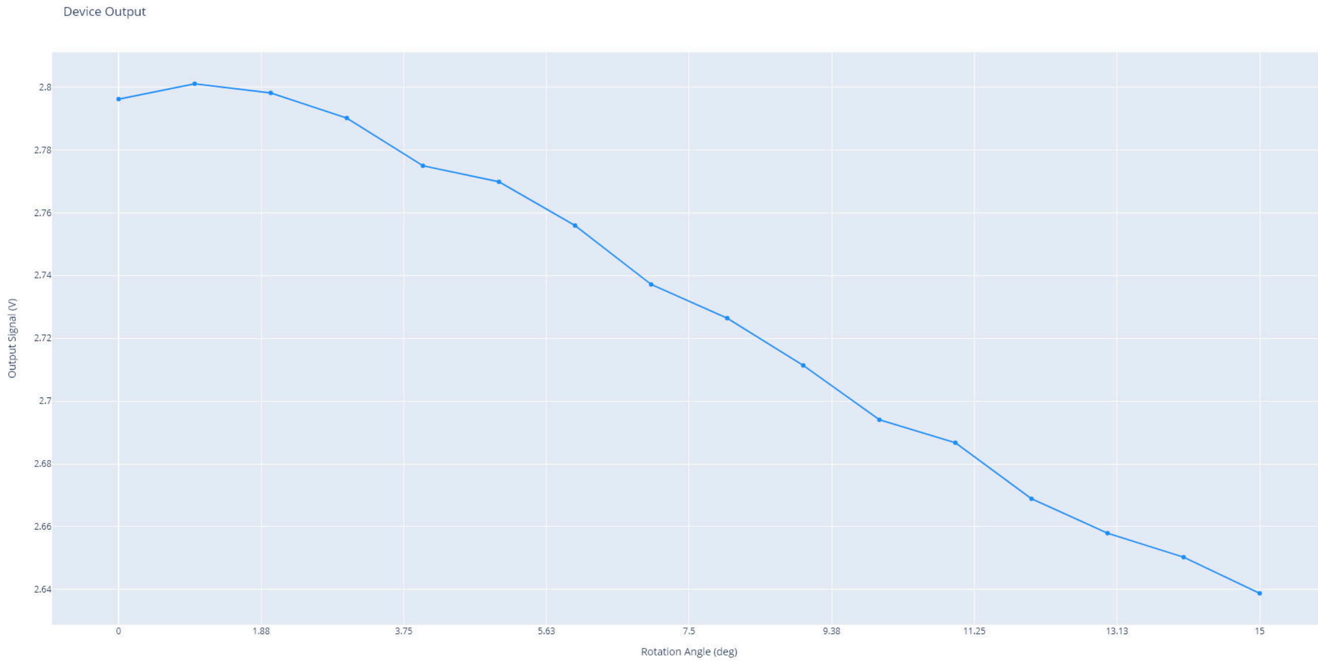

Figure 5-6. Analog Linear Sensor Output

For analog linear devices, the output plot includes input referred noise in the output response of the sensor. If the signal-to-noise ratio (SNR) of the sensor is not sufficiently large, this helps to demonstrate possible uncertainty in mechanical position that may occur. Successive simulation runs help to visualize the impact of 6-sigma noise on the sensor output. It is possible to reduce the impact of noise in application through the addition of an output filter, but this is at the cost of maximum output bandwidth. In Figure 5-6, a hinge motion is observed using DRV5055A2 is used to measure the Z-component of the magnetic field shown in Figure 5-5.

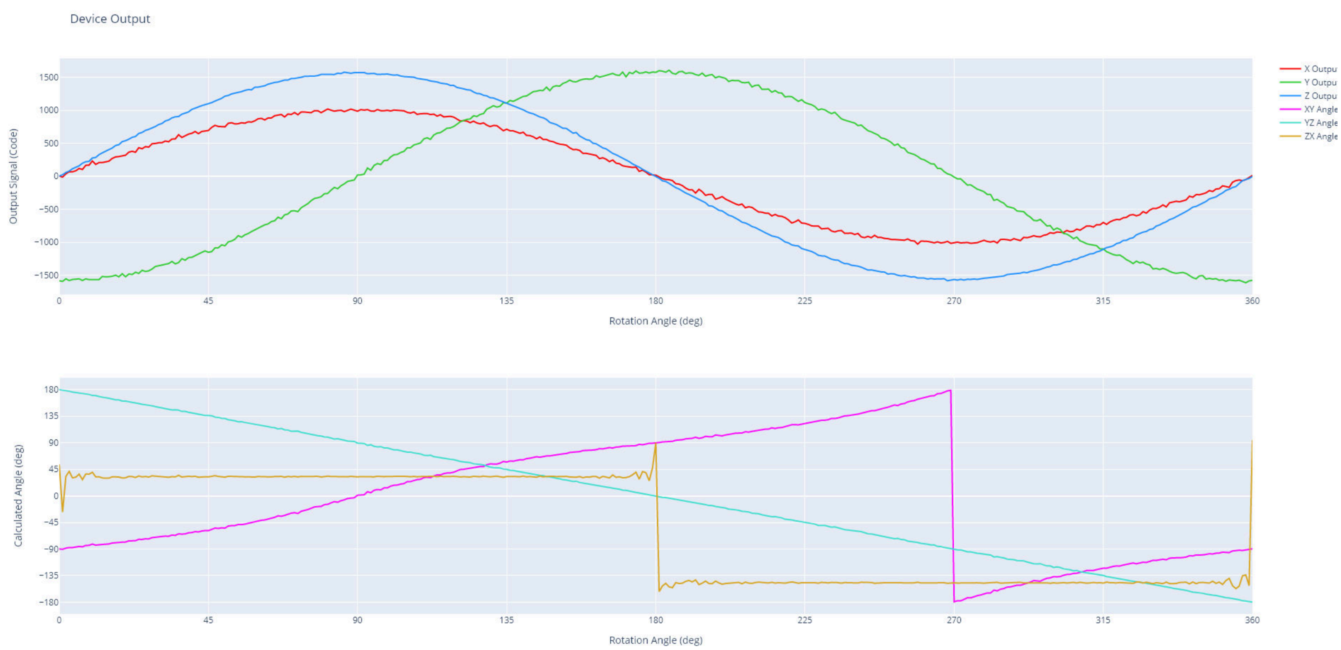

Figure 5-7. Digital Linear Sensor Output

Digital linear devices similarly includes the input referred noise as it impacts the ADC conversion result for the device. The output result also shows output codes spanning across the n-bit conversion range for the sensor to demonstrate quantization effects on the measurement result. Additionally, when two or more axes of output results are produced by the sensor, the tool plots a calculated angle when simulating magnet rotation. When the input magnetic fields are equal amplitude and sinusoidal with a 90° phase difference, the resulting angle is linear with respect to the magnet rotation. Amplitude mismatch, offset and phase errors may result from mechanical sources. This can be seen comparing the TMAG5170 calculated angle results shown in Figure 5-7. Notice that the YZ angle result is linear while the XY angle result is less ideal.

Amplitude mismatch and offset may be corrected using register settings in many devices, but calibration may be required to reach the highest accuracy results. For more information about improving angle accuracy, see *Achieving Highest System Angle Sensing Accuracy*.

Figure 5-8. Switch Sensor Output

Switch type devices generate a plot displaying sensor response to both forward and reverse motion of the magnet. This overlay is to highlight the impact of B_{HYS} on the device operation. It is recommended to evaluate both directions of travel to verify that the intended response to the mechanical input matches expectations.

For any device with dual uni-polar outputs, such as DRV5032DU, a fourth tab will appear. This tab separately displays the second output of the device. Both outputs that result from pulling an axial cylinder magnet past DRV5032DU are shown in Figure 5-8.

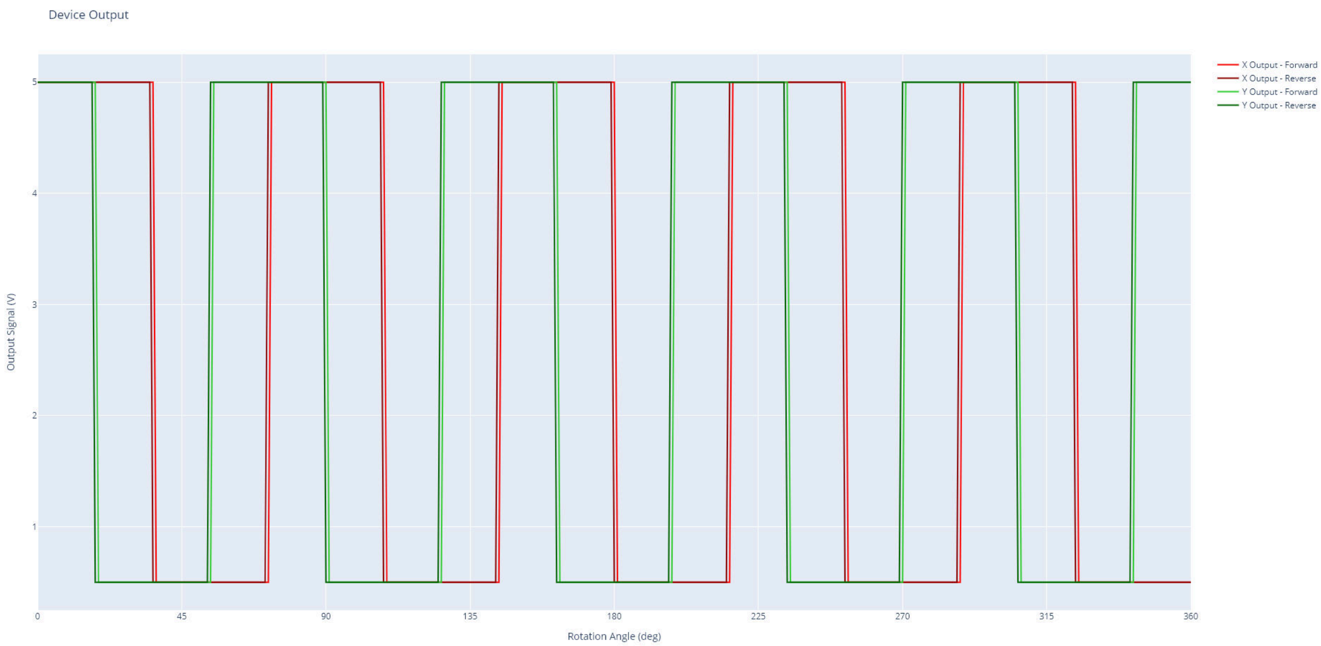

Figure 5-9. Latch Sensor Output

For latch type devices, a forward and reverse plot is displayed similar to the latch type devices. In the case of 2D latches, the display plot shows the response of both axes that are being sensed. If needed, the plot may be hidden by clicking the plot name in the legend.

As an example, plots showing TMAG5110 placed adjacent to a rotating 10-pole magnetic ring are available in Figure 5-9.

6 Additional Resources

For additional guidance designing particular functions, see the reference material in Table 6-1.

Table 6-1. Magnetic Sensing Function Guides

Document Name	Motion Type	Typical Magnets	Applications
Head-on Linear Displacement Sensing Using Hall-Effect Sensors	Linear	Axial Cylinder, Bar	• Power tool trigger • Liquid Level detection • Pressure
Absolute Angle Measurements for Rotational Motion Using Hall-Effect Sensors	Rotation	Diametric Cylinder	• Robotics • Gimbals • Steering
Brushless DC Motor Commutation Using Hall-Effect Sensors	Rotation	Diametric Cylinder	• Motor Commutation
Measuring 3D Motion With Absolute Position Sensors	Joystick	Axial Cylinder	• Game Controller • Steering column controls
Limit Detection for Tamper and End-of-Travel Detection Using Hall-Effect Sensors	Linear	Axial Cylinder, Bar	• Electricity meter tamper detection • End of Travel
Tracking Slide-By Displacement with Linear Hall-Effect Sensors	Linear	Axial Cylinder, Bar	• Linear Motor Transport • Slider Controls • Industrial automation
Using Hall-Effect Sensors For Contactless Rotary Encoding and Knob Applications	Rotation	Ring	• White goods • User interface controls
Multi-State Position Selection Using Hall-Effect Sensors	Linear	Axial Cylinder, Bar	• Control switches • Power tools • Safety harnesses
Two-State Selector Using Hall-Effect Sensors	Linear	Axial Cylinder, Bar	• Toggle switches • End of travel
Incremental Rotary Encoders	Rotation	Ring	• Water meter • Gas meter • Wheel speed
Transition Detection Using Hall-Effect Sensors	Hinge	Bar	• Laptop lid closure • Door position • White-goods

Further materials can be found by browsing products at www.ti.com/halleffect.

To find more details regarding the open-source Python library used to develop this tool, visit:

https://authors.elsevier.com/sd/article/S2352711020300170

or

https://magpylib.readthedocs.io/en/latest/

Magnetic material parameters were obtained from:

https://amazingmagnets.com/magnetic-grade-chart

7 References

- Texas Instruments: *Head-on Linear Displacement Sensing Using Hall-Effect Sensors*
- Texas Instruments: *Absolute Angle Measurements for Rotational Motion Using Hall-Effect Sensors*
- Texas Instruments: *Brushless DC Motor Commutation Using Hall-Effect Sensors*
- Texas Instruments: *Measuring 3D Motion With Absolute Position Sensors*
- Texas Instruments: *Limit Detection for Tamper and End-of-Travel Detection Using Hall-Effect Sensors*
- Texas Instruments: *Tracking Slide-By Displacement with Linear Hall-Effect Sensors*
- Texas Instruments: *Using Hall-Effect Sensors For Contactless Rotary Encoding and Knob Applications*
- Texas Instruments: *Multi-State Position Selection Using Hall-Effect Sensors*
- Texas Instruments: *Two-State Selector Using Hall-Effect Sensors*
- Texas Instruments: *Incremental Rotary Encoders*
- Texas Instruments: *Transition Detection Using Hall-Effect Sensors*
- Texas Instruments: *Linear Hall-Effect Sensor Array Design*
- Texas Instruments: *Magnet Selection for Linear Position Applications*
- Designing Joysticks with Hall-effect Sensors
- Texas Instruments: *Reducing Quadrature Error for Incremental Rotatry Encoding Using 2D Hall-effect Sensors*
- TIDA-060040
- Texas Instruments: *Achieving Highest System Angle Sensing Accuracy*

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265