

Tracking Slide-By Displacement With Linear Hall-Effect Sensors



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Introduction

A major benefit of using a Hall-effect sensor in position sense applications is that the sensor eliminates the physical contact required to determine position in mechanical designs. This occurs due to the permeation of magnetic flux from a nearby magnet, which can be used by a linear Hall effect sensor to produce an output that varies with the changing input field. The magnetic field permeates through air, dust and grime, plastics, and other generally non-ferromagnetic materials. As a result, the sensor can be conveniently placed anywhere a measurable magnetic field is present to provide feedback. One particular challenge that is present when using a linear output Hall effect sensor is that the magnetic flux density is inversely proportional to the square of the distance from the magnet. As a result, this adds some complexity to position calculations as linear steps produce a non-linear change on the output. While this can be calibrated for any particular magnet, one useful configuration is to orient the magnet and sensor in a slide-by configuration. Here, instead of traveling directly towards the sensor, the magnet travels just above the sensor in a linear path.

Slide-By for One Dimensional Sensors

As an example, consider the arrangement of a one-dimensional sensor, such as [DRV5055](#) shown in [Figure 1](#) with the magnet traveling either direction along the black line which is parallel to the Y axis. In this example, the pictured magnet is approximately 22mm thick with a radius of approximately 3mm.

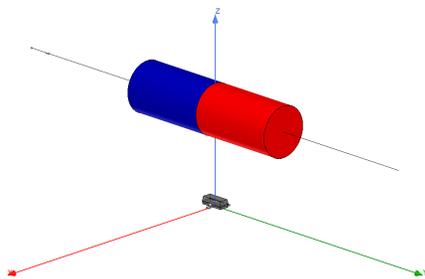


Figure 1. Slide-By Magnet Orientation

In this configuration, the sensor detects the component of the field vector, which is directed along the Z-axis. The resulting input to the sensor over the course of travel for this magnet has an interesting behavior. There is a region approximately the same length of the magnet which produces a linear change in field. With this input, it is now simpler to monitor change in position by measuring in the linear input region.

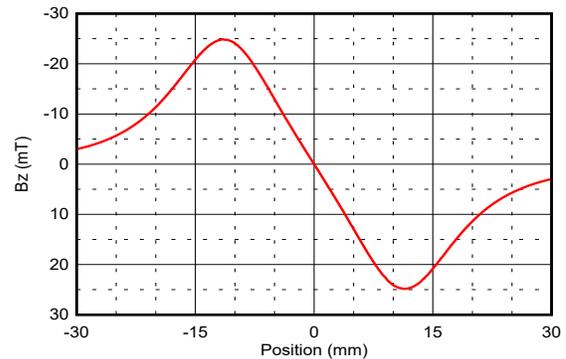


Figure 2. Slide-By Input Field

This can also be easily adapted to increase overall stroke length through the addition of multiple sensors. The process involved with this type of design is discussed in greater detail in the [Linear Hall Effect Sensor Array Design](#) application note.

Slide-By for 3D Sensors

The one-dimensional case is limited in range by the length of the magnet. Travel outside the linear input region produces uncertainty in position as there are now two positions that map to the same input magnitude. The uncertainty is resolved by using a three-dimensional sensor instead. With this sensor type, an input field shown in [Figure 3](#) is displayed.

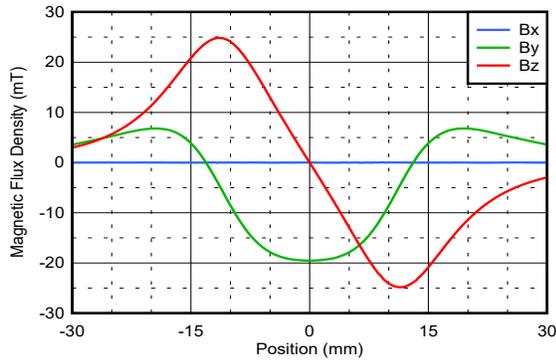


Figure 3. 3D Slide-By Input Field

Using this input, three distinct input regions can be defined. The linear region provides the best correlation for linear motion, but based on the Y component, it is now possible to distinguish the direction approach of the magnet in the non-linear regions as well. Suppose a -6mT limit is set for B_y to correspond to the peak values of B_z

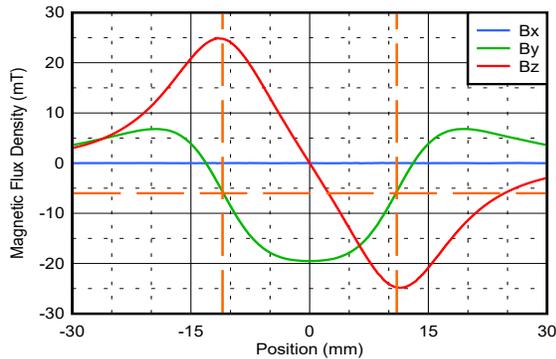


Figure 4. Input Field Regions

When B_y exceeds this threshold, the magnet is known to be in the linear sensing region. For B_y below the threshold, then the sign of B_z indicates whether the approach is from the right or left. Calibrations can be used to determine the position in this non-linear region, and accuracy diminishes as the magnet moves further from the sensor.

Slide-By Using Angle Calculations

A similar and advantageous approach uses a 3D sensor such as the [TMAG5170](#) or [TMAG5173-Q1](#), but this time the magnet pole is directed normal to the sensor face rather than parallel. The magnetic field profile across the magnet travel is similar to the previous example.

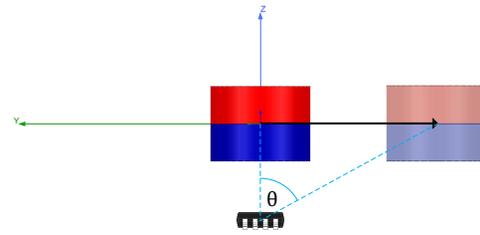


Figure 5. Slide-By Mechanical Angle

As the magnet is moved along the Y axis, this motion produces inputs as shown in [Figure 6](#). In this case, the magnet is much smaller than before with an approximate thickness of 5mm and a radius of 3mm. As a result of the orientation change of the magnet, the linear region is now observed on the B_y component. The width of this region for this particular case is only 6mm.

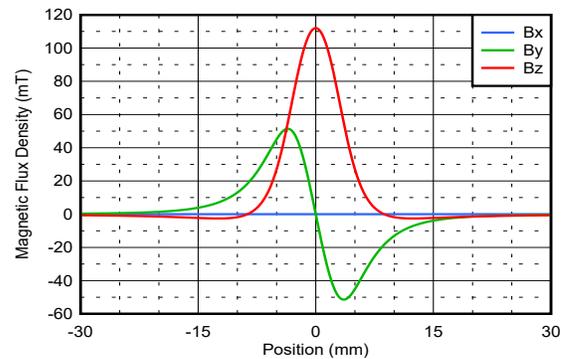


Figure 6. Angle Measurement Inputs

Using this data, it is possible to use only B_y to track position, but using the arctangent function enables position detection over a much wider range.

$$\text{Electrical Angle: } \theta = \text{atan2}(B_z, B_y) \quad (1)$$

Comparing the calculated electrical angle based on the magnetic field inputs to the actual mechanical angle between the magnet and sensor reveals an interesting behavior.

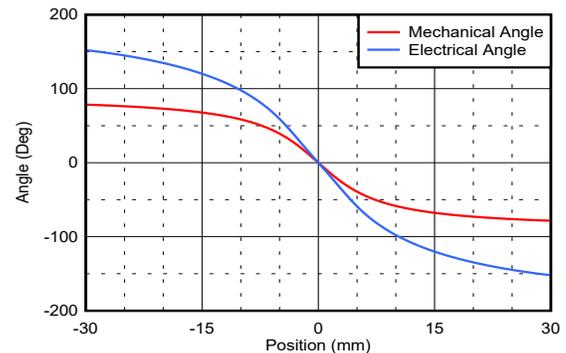


Figure 7. Measured Angle vs. Position

While there is a significant error between these two calculations as a result of using magnetic field inputs which do not strictly follow a sinusoidal behavior, it is apparent that the general form of the electrical angle calculation follows the behavior of the mechanical angle. Given this similarity, it can be possible to adjust the electrical calculation to match the actual mechanical angle.

When using [TMAG5170](#) or [TMAG5173-Q1](#), it is possible to apply both a gain and offset correction to a single channel which can be represented as α and δ , respectively. Additionally, it is apparent that a second scalar can be beneficial to decrease the overall magnitude. This scalar is represented by β . This correction can be applied by a microcontroller which is recording the outputs of [TMAG5170](#) or [TMAG5173-Q1](#). Closer analysis also shows that a scaling factor, γ , that increases with angle, can also be helpful in aligning the asymptotic behavior of the two curves at the furthest magnet positions. An example equation-based alignment with each of these factors is shown in [Equation 2](#) and [Equation 3](#).

$$\theta' = \text{atan2}(\alpha \times (B_z + \delta), B_y) \quad (2)$$

$$\theta = \beta \times \theta' - \gamma \times \sin(\theta') \quad (3)$$

Bench Evaluation Tool

To enable demonstration of this function, see the attachment for [TMAG5170 EVM](#) shown in [Figure 8](#). Files to enable 3D printing this attachment and physical geometry are available in the [TMAG5170 Slide-By Attachment](#) user's guide.

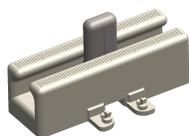


Figure 8. TMAG5170 Slide-By Attachment

Based on the simulation data and results of [Equation 2](#) and [Equation 3](#), there are multiple possible implementations with various resulting accuracies. These values and respective errors were determined through inspection. Other methods of linearization, including multipoint calibration, can also prove successful approaches to linearize results. In the following examples three configurations are shown. Configuration 1 applies a scalar correction to the Z axis, and then scales the magnitude of the resulting angle output. Configuration 2, uses these factors as well, but includes an additional intentional offset to help expand the sensitivity range. To help limit error

further, configuration 3 adds the final correction factor to help further extend the viewable range of the sensor to the point where input referred noise can become the predominant factor for position accuracy.

Table 1. Configurations and Measurement Ranges

Configuration	α	β	δ	γ	Range	Accuracy
1	0.6075	0.786	0	0	$\pm 11\text{mm}$	$\pm 0.06\text{mm}$
2	0.6145	0.795	0.43	0	$\pm 21\text{mm}$	$\pm 0.25\text{mm}$
3	0.534	0.87	0.24	-7.25	$\pm 23\text{mm}$	$\pm 0.1\text{mm}$

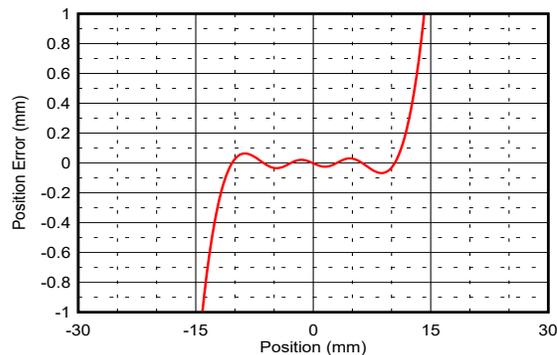


Figure 9. Configuration 1

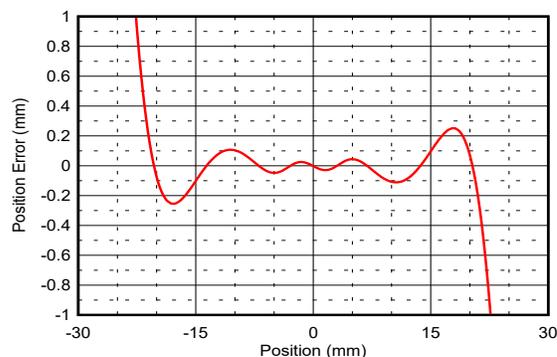


Figure 10. Configuration 2

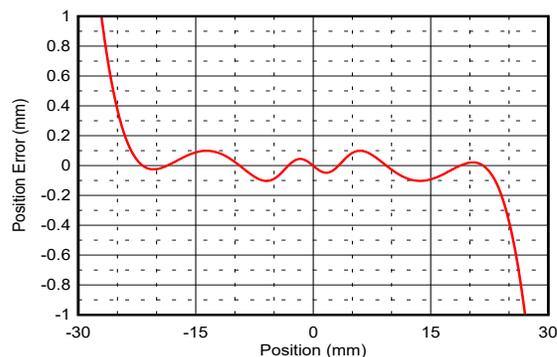


Figure 11. Configuration 3

These results can vary from system to system as sensitivity error, offset, noise, and mechanical variations. These variations can impact these results, which are the theoretical best case behavior.

Additional calibration factors can be implemented to improve overall accuracy.

Table 2. Alternative Device Recommendations

Device	Characteristics	Design Considerations
DRV5055 (DRV5055-Q1)	Commercial (Automotive) single axis bipolar linear Hall effect sensor with Analog output available in SOT-23 and TO-92 packages.	Analog outputs are subject to electrical noise and calculations require MCU computations. Single axis sensitivity constrains the ability to track movement in free space.
DRV5057 (DRV5057-Q1)	Commercial (Automotive) single axis bipolar linear Hall effect sensor with PWM output available in SOT-23 and TO-92 packages.	PWM outputs require conversion, but are less susceptible to coupled noise. Single axis sensitivity constrains the ability to track movement in free space.
TMAG5170 (TMAG5170-Q1)	Commercial (Automotive) grade linear 3D Hall effect position sensor with SPI available in 8 pin DGK package.	Complete magnetic vector sensitivity. This device is able to track a wide range of magnet positions, though careful planning is still required to make sure all input conditions map to a unique position.
TMAG5170D-Q1	Automotive grade dual die linear 3D Hall effect position sensor with SPI available in 16-pin TSSOP package.	Is a dual device design capable of sensing all field components and integrates angle calculation and field normalization. Developed for functional safety with resources supporting design up to ASIL D.
TMAG5273	Linear 3D Hall-effect position sensor with I2C interface available in 6-pin SOT-23 package.	TMAG5170 has a tighter sensitivity tolerance and TMAG5273 operates over I2C.
TMAG5173-Q1	Automotive grade Linear 3D Hall-effect position sensor with I2C interface available in 6-pin SOT-23 package.	Similar to the TMAG5170, but operates over I2C with wider sensitivity tolerance specifications.

Table 3. Related Technical Resources

Name	Description
Linear Hall Effect Sensor Array Design	A guide to designing sensor arrays for tracking motion across long paths.
Intro to Linear Hall Effect Sensors: Achieve Contactless Accurate Position Sensing	A discussion on the differences between a linear output and switched output Hall-effect sensors.
What is a Hall-effect Sensor?	A discussion about the Hall-effect and how the Hall effect is used to create magnetic sensors.
TMAG5170UEVM	GUI and attachments incorporate angle measurement using a precise three dimensional linear Hall-effect sensor.
TMAG5170DEV	GUI and attachments incorporate angle measurement using both precise three dimensional linear Hall-effect sensors.
TMAG5273EVM	GUI and attachments incorporate angle measurement using a three dimensional linear Hall-effect sensor.
DRV5055EVM	EVM incorporates a digital display with various sensitivities aligned linearly along a ruler face.
TMAG5173EVM	GUI and attachments incorporate angle measurement using a three-dimensional linear Hall-effect sensor.
TI Precision Labs - Magnetic Sensors	A helpful video series describing the Hall effect and how the Hall effect is used in various applications.

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