Application Note

Comparison Between Stacked Die and Side-by-side Die Implementations in Dual-die Magnetic Position Sensors

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ABSTRACT

A hall effect sensor like the TMAG5170D can be used in angle detection systems like an electronic shifter where redundancy is necessary for critical system operation. This document examines the advantages of the TMAG5170D approach of stacking the dual dies on top of each other compared to implementations where the dual dies are placed side by side.

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1 Introduction

When using hall effect sensors in an electronic-shifter (E-shifter) application, there can be numerous approaches to achieving the system objective of detecting relative shifter stick position. Figure 1-1 shows two possible approaches that can be explored for an e-shifter. For those two approaches a dual die sensing design can be desired for redundancy which is not uncommon for automotive applications that frequently have functional safety requirements. Preferably for a redundant system, two separate sensors measure identical results. Yet this type of redundancy often is impossible because two different sensors must occupy two different places in space. This document explores the different Hall-element placements available for dual die sensors and illustrates how a device similar to the TMAG5170D-Q1 has both die arranged for reducing the discrepancy in measurements desired in a redundant system. To substantiate this assertion, let us go through the design process for the approaches below, then show the absolute error, standard deviation in calculated angle difference, and max difference in calculated angle for various mechanical errors that can occur in assembly.

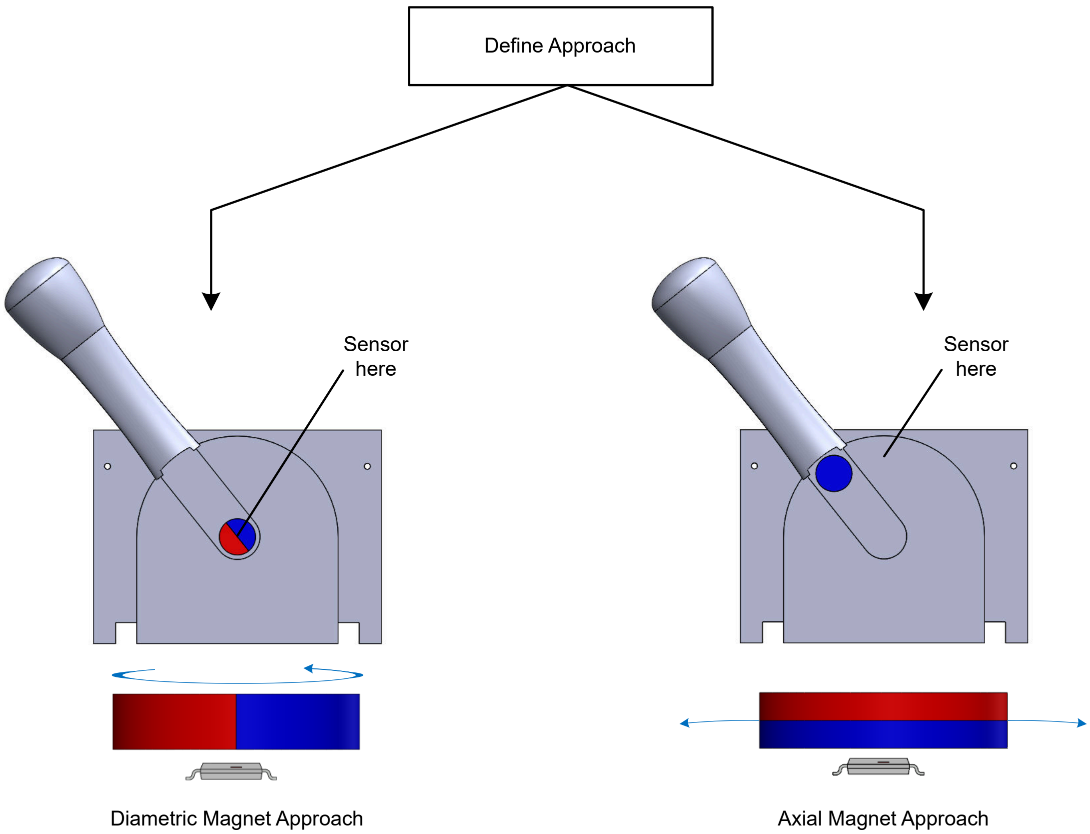

Figure 1-1. Define Approach

Typical development for a design iteration of a particular application can follow a flow similar to what is illustrated in Figure 1-2. In this case, the system objective is to track position in a lever similar to what can be found in E-shifter. The approaches considered are those found in Figure 1-1. The constraints for a design can be sensing device location, the board size at the sensing location, magnet size, cost, resolution, and so on. The following analysis is only constrained by the above mentioned approaches and magnet sizes similar to what can be readily purchased. Post processing magnetic field values from sweeping a magnet through the expected path of motion can help determine a good magnet size and location for better placement. From a derived point, further processing of subsequent magnet parameter sweeps can be performed to quantify the possible error that can be observed for various mechanical assembly tolerances.

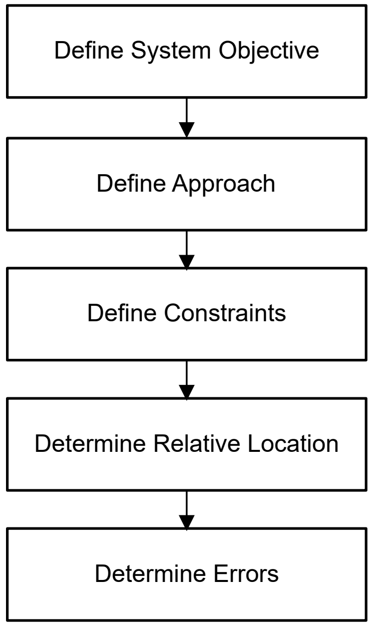

Figure 1-2. General Design Flow

2 Diametric Magnet Approach

Let's first consider the approach with the diametric magnet axis at the shifter stick fulcrum. For a point centered under the magnet when the magnet is centered on the axis of rotation like in Figure 2-2, the magnetic flux density (B-fields) look similar to Figure 2-1. Taking the arctan of these fields we can get a linear slope of values directly related to lever position, shown as the angle in Figure 2-1. Assuming there is a flexibility in placement of our device, we can sweep the sensor offset from the magnet in the z-axis, like in Figure 2-3, to determine the bounds of where the device is too close or too far from the magnet. Neglecting the space occupied by the device or magnet, the device is too close when the b-field saturates the sensor for more than two singular angle values over a 360° magnet rotation. The device is too far from the magnet, when more than two singular angle values are beneath the device noise floor over a 360° magnet rotation. Figure 2-3 shows that an N42, 12.7-mm diameter, 3.175-mm thick magnet does not fall outside the sensing bounds of the TMAG5170 for any z-offset from the magnet origin within -8 mm and -2.5 mm.

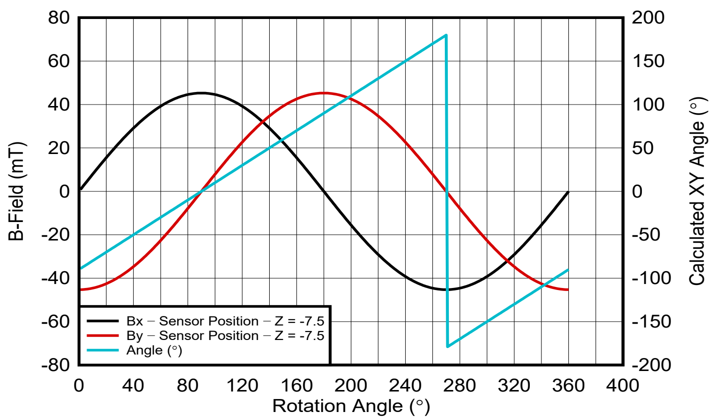

Figure 2-1. Field Behavior

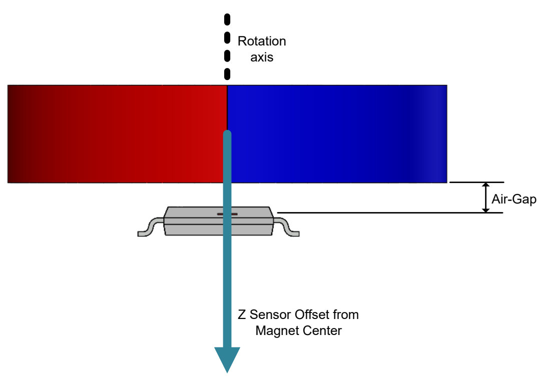

Figure 2-2. Sensor Z-offset Sweep Diagram

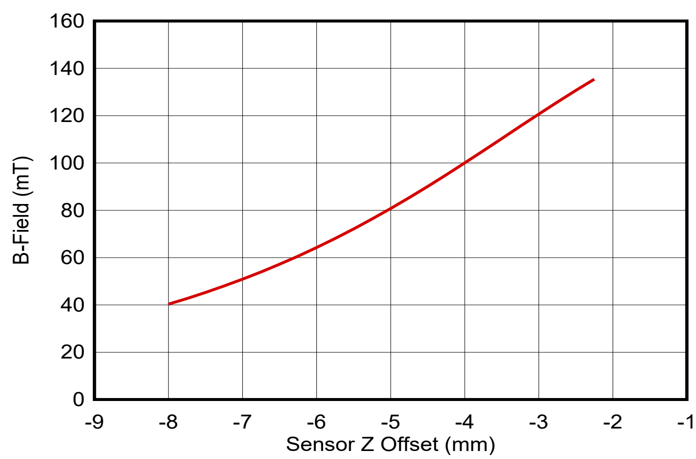

Figure 2-3. Max Bx or By Field Versus Sensor Z Offset

Other notable metrics to gauge prior to proceeding with a specific design include the impact of magnet diameter and thickness on error when the device is offset in the xy plane from the ideal location, such as captured in Figure 2-4 and Figure 2-5. Whatever tolerance can be expected with assembly in fabrication is good to use for this analysis. This paper assumes ±1.5-mm offset. For Figure 2-4 the sensor z-offset was fixed at 7.5 mm. For the Figure 2-5, the diameter was fixed at 12 mm and the sensor z-offset was adjusted such that the air gap remained constant. The air gap is the distance between the magnet surface and the sensor plane.

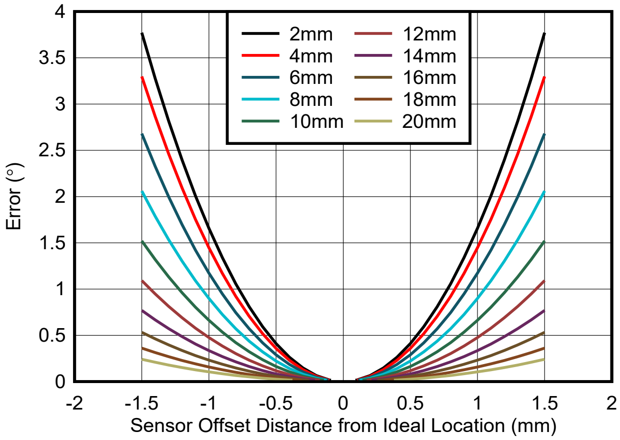

Figure 2-4. Diameter Sweep

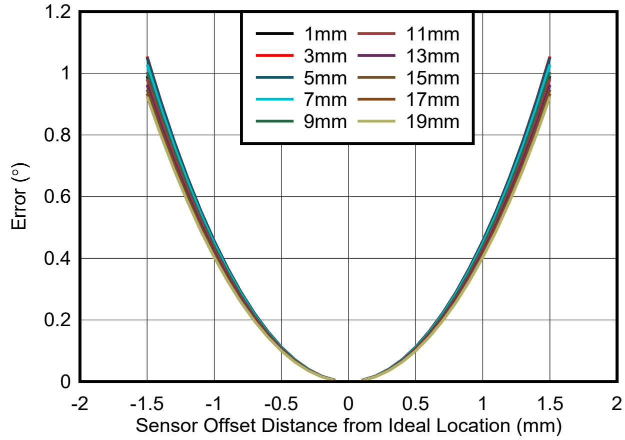

Figure 2-5. Thickness Sweep

Figure 2-4 indicates that smaller diameters are less forgiving in error for the same offset. Based on a large group of simulation data not shown, offsets less than 10% of the magnet diameter length frequently appear to provide less than 1° error. As for magnet thickness, Figure 2-5 suggests that only a slight change in angle error is observed for different thicknesses.

Figure 2-4 and Figure 2-5 are based on measurements from a single sensor. For automotive applications, there is often a desire to have redundancy to satisfy safety requirements. As redundancy requires multiple devices, and multiple devices cannot physically occupy the same space, at least one if not both sensors will measure fields different from the lone sensor above. Also with mechanical manufacturing and assembly tolerances, there can be increased discrepancies between sensor measurements. The deviation from the ideal behavior and the discrepancy between sensors is dependent on relative sensor placement. Two common sensor placements are side by side and stacked as shown in Figure 2-6. Stacked die is the arrangement found in the TMAG5170D-Q1 and those die are typically vertically separated by 0.123 mm. For the side-by-side die, around 1 mm of separation horizontally is not uncommon.

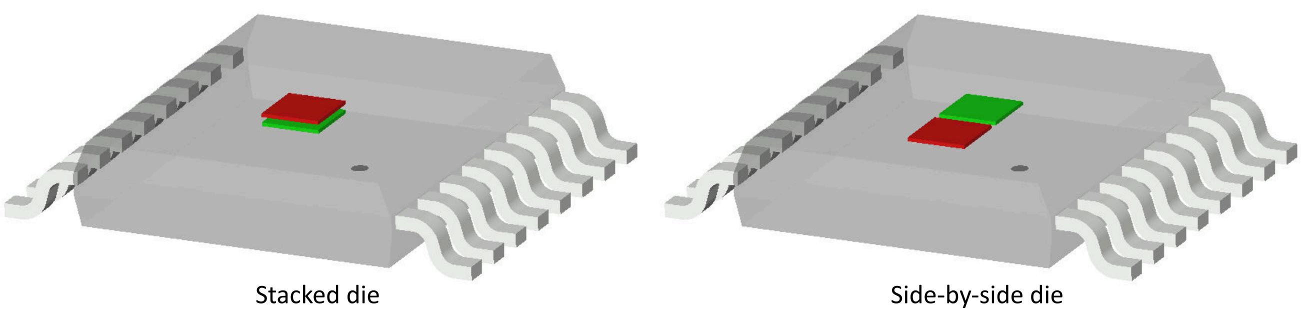

Figure 2-6. Dual Die Placements

2.1 Errors and Redundancy for Diametric Magnet Approach

The conditions for the subsequent data are defined in Table 2-1. Data was collected through the *Texas Instruments Magnetic Sense Simulator (TIMSS)* tool and post processed in excel. With mechanical assembly, there is the possibility that the sensing device can be offset from the intended location, the magnet tilted, or the magnet can not be correctly centered on the axis of rotation. Consequently, multiple separate tests were performed to see the impact of each of these possible error sources.

All parameters in Table 2-1 correspond to input parameters available in the TIMSS tool in Table 2-1.

Table 2-1. Simulation Parameters

Simulation Parameter in TIMSS	Die Configuration	Test	TIMSS Simulation Parameter Value
Magnet Shape	Both	All	Diametric Cylinder
Poles	Both	All	2
Magnet	Both	All	Sintered Neodymium, N42
Outer Diameter	Both	Sensor Offset, Magnet Tilt, Magnet Offset, Diameter Tests	12.7 mm
		Diameter tests	6 mm, 8 mm, 12.7 mm
Height	Both	All	3.175 mm
Magnet Position	Both	Sensor Offset, Magnet Tilt, Diameter Tests	x = 0 mm, y= 0 mm, z = 0 mm
		Magnet Offset Test	x = 0 to 2-mm steps of 0.5 mm, y= 0 mm, z = 0 mm
Magnet Angle	Both	Sensor Offset, Magnet Offset, Diameter Tests	x = 0 ° y= 0 °, z = 0 °
		Magnet Tilt Test	x=0° to 20° steps of 5°, y=0° , z=0°
Arc Length	Both	All	360 °
Sensor Position x	Stacked-die	Sensor Offset X offset	-1.5 mm to 1.5 mm, steps of 0.1 mm
		Sensor Y Offset, Magnet Tilt, Magnet Offset, Diameter Tests	0 mm
	Side-by-side die	Sensor Offset X offset	-1.96 mm to 1.04 mm for one Hall element and -1.04 to 1.96 for the other Hall element, steps of 0.1 mm
		Sensor Y Offset, Magnet Tilt, Magnet Offset, Diameter Tests	-0.46 mm, 0.46 mm
Sensor Position y	Both	Sensor X-offset, Magnet Tilt, Magnet Offset, Diameter Tests	0 mm
		Sensor Y-Offset Test	-1.5 mm to 1.5 mm, steps of 0.1 mm
Sensor Position z	Stacked-die	Sensor Offset Tests	-2.9385 to -4.9385 for one Hall element and -3.0615 to -5.0615 for the other Hall element, steps of 1 mm
		Magnet Tilt and Magnet Offset Tests	-4.0615 mm, -3.9385 mm
	Side-by-side die	Sensor Offset Tests	-3 mm to -5 mm, steps of 1 mm
		Magnet Tilt and Magnet Offset Tests	-4 mm

2.2 Sensor Offset Results

One metric for a design is how accurate the calculated angle from the sensor measurements are to the angle expected when the device is in the intended location. Offsets in placement leads to the calculated error being different than what is expected and warranting calibration depending on how large the error is and how much accuracy is desired. Figure 2-8 and Figure 2-9 indicate how many degrees of error result from the sensor being offset along the x and y axis. The ideal sensor position is considered to be centered on the magnet z-axis at the average of the z-offset for both sensors.

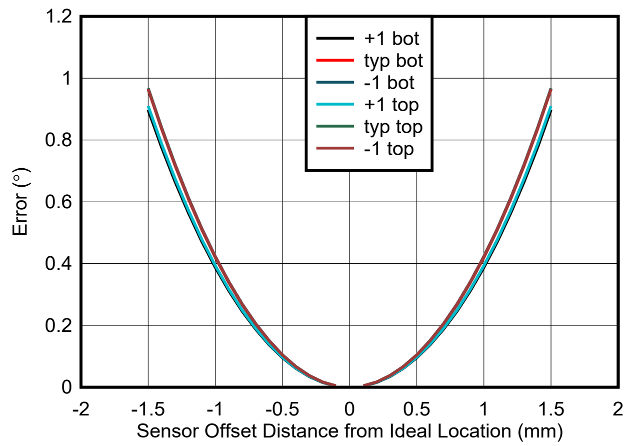

Figure 2-7. Stacked Die Absolute Angle Error Versus Sensor X or Y Offset at Different Sensor Z Offsets

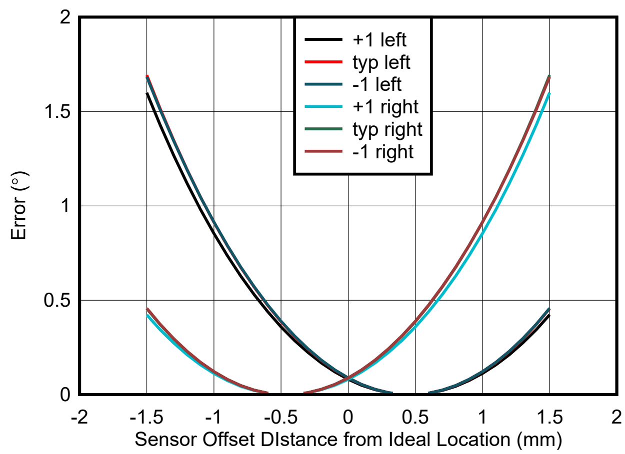

Figure 2-8. Side-by-Side Die Absolute Angle Error Versus Sensor X Offset at Different Sensor Z Offsets

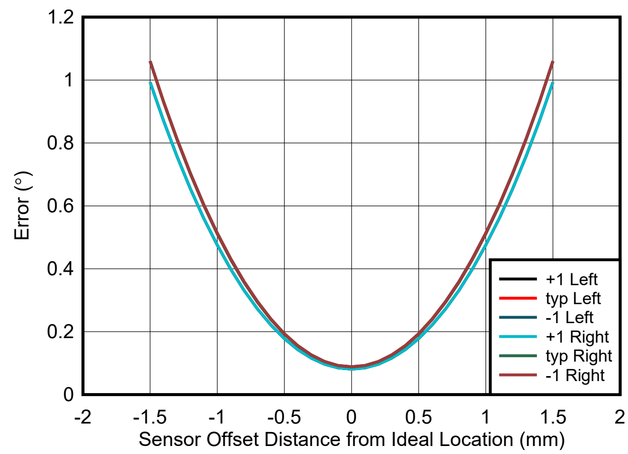

Figure 2-9. Side-by-Side Die Absolute Angle Error Versus Sensor Y Offset at Different Sensor Z Offsets

Figure 2-7 indicates that a ±1.5 mm offset along the x or y axis leads to <1° error for the stacked die device and that the error observed by both sensing elements is nearly identical which contrasts with what is observed for side-by-side sensing elements in Figure 2-8. Depending on the direction of offset, the deviation from the ideal measurement is 1.5°, additionally the two sensing elements exhibit mirror symmetry which has an impact on the standard deviation of measurement difference or max measurement difference for calculated angles between the two die, both of which are important metrics for redundancy of a dual sensor devices. In this application, the desire is that the measured angle, derived from the measured Bx and By fields, is identical. Any difference between measured angles constitutes error. Unless the error is uniform and applicable to all possible measurable points, the standard deviation is smaller than the max difference and a smaller standard deviation indicates that the difference in data tends to be smaller. Figure 2-10 shows the standard deviation of difference angle measurement for the stacked die, while Figure 2-11 and Figure 2-12 show the standard deviation for the side-by-side die.

Figure 2-13 shows the max difference in angle measurement for the stacked die while Figure 2-14 and Figure 2-15 show the max difference in angle measurements for the side-by-side die.

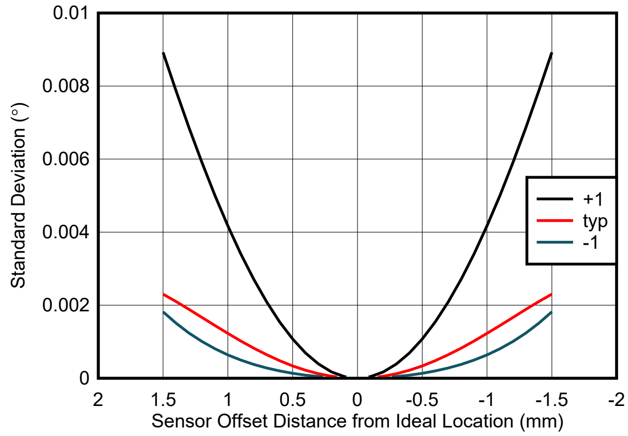

Figure 2-10. Stacked Die Standard Deviation of Difference Versus Sensor X Offset at Different Sensor Z Offsets

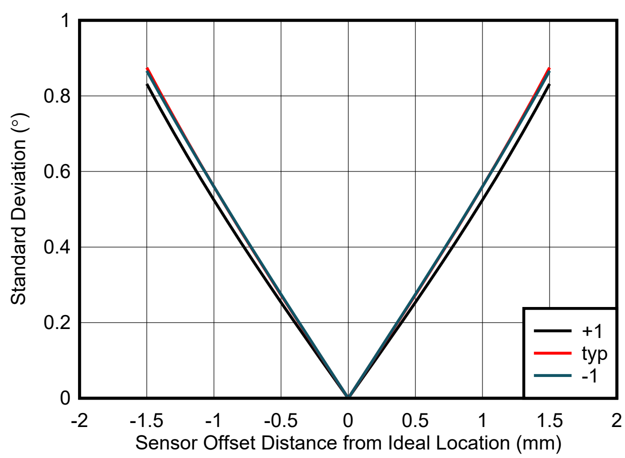

Figure 2-11. Side-by-Side Die Standard Deviation of Difference Versus Sensor X Offset at Different Sensor Z Offsets

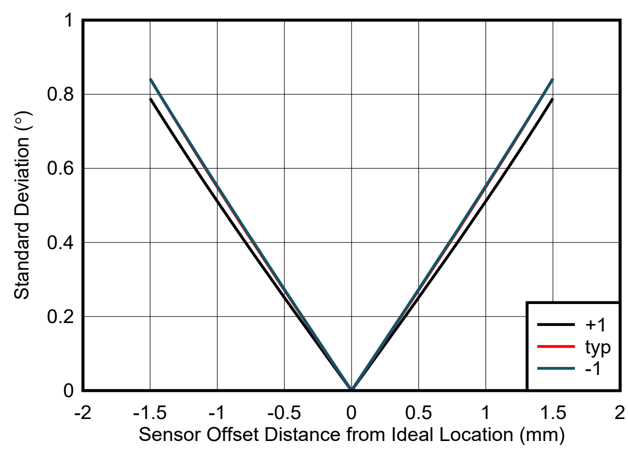

Figure 2-12. Side-by-Side Die Standard Deviation of Difference Versus Sensor Y Offset at Different Sensor Z Offsets

Figure 2-10 shows that the majority of the calculated angles over the full 360 degree rotation are within .01 degrees of the ideal angle even for the worst case x-offset. Alternatively for the side-by-side shown in Figure 2-13 and Figure 2-12, the standard deviation is nearly 1°.

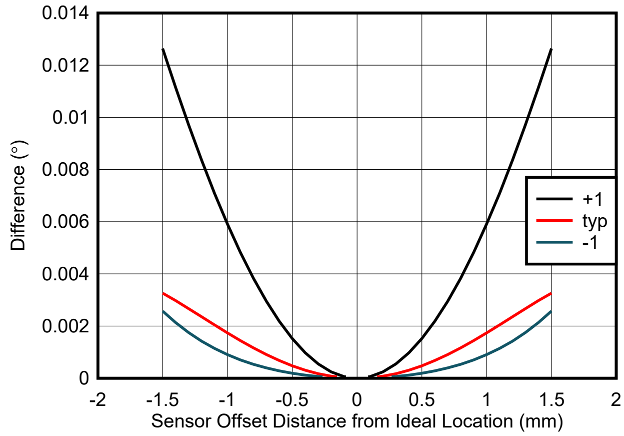

Figure 2-13. Stacked Die Max Difference Versus Sensor X or Y Offset at Different Sensor Z Offsets

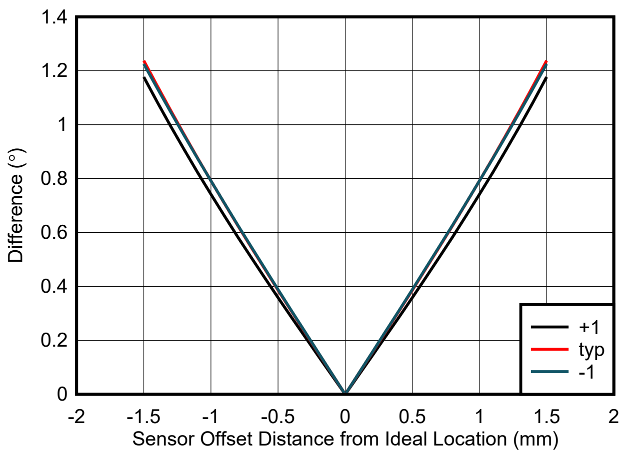

Figure 2-14. Side-by-Side Max Difference Versus Sensor X Offset at Different Sensor Z Offsets

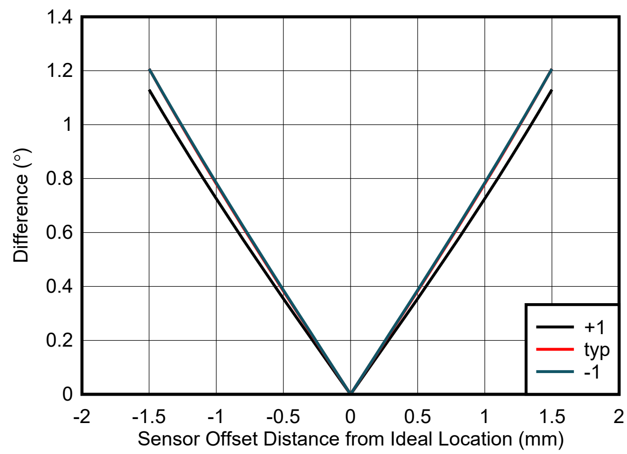

Figure 2-15. Side-by-Side Max Difference Versus Sensor Y Offset at Different Sensor Z Offsets

Figure 2-13 indicates that the max difference in angle calculation for the stacked die is 100x smaller than that of the side-by-side die shown in Figure 2-14 and Figure 2-15.

2.3 Magnet Tilt Results

Depending on how tight the assembly control is, the magnet can exhibit some tilt, such as in Figure 2-16. Figure 2-17 and Figure 2-18 illustrate the impact of tilt from a 12.7 diameter magnet. In the plots, "bot" refers to the sensor element below the "top" sensor element in the stacked die. "Left" and "right" are used to distinguish the two sensing elements found in the side-by-side die.

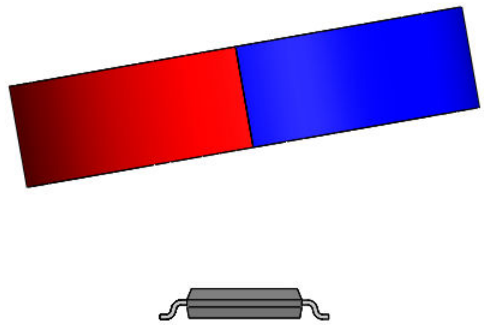

Figure 2-16. Magnet Tilt

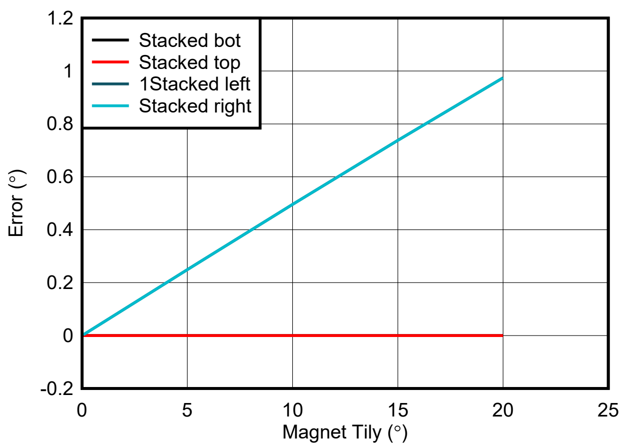

Figure 2-17. Absolute Error Versus Magnet Tilt

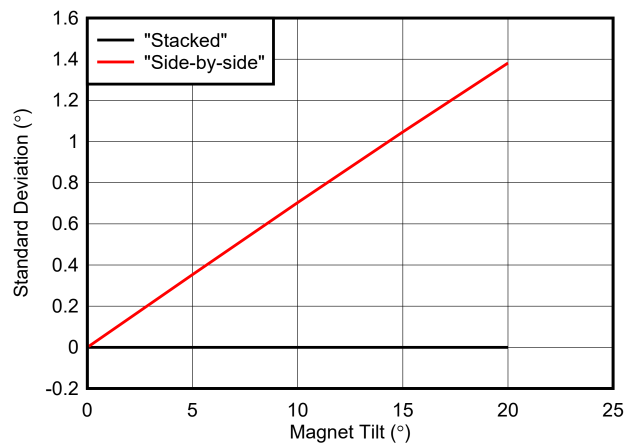

Figure 2-18. Standard Deviation of Difference Versus Magnet Tilt

The maximum tilt considered here is 20°. As the tilt increases, the absolute error and standard deviation in difference between angle calculations also increases for the side by side die, whereas the impact on the stacked die is relatively indiscernible.

2.4 Magnet Offset Results

Magnet offset, also known as run out or eccentricity, is when the magnet axis is not concentric with the axis of rotation. So 1 mm of eccentricity corresponds to the magnet center being offset 1 mm from the rotation axis. Figure 2-19 shows conceptually what eccentricity looks like for rotating a magnet 360°. Figure 2-20 and Figure 2-21 show the impact of eccentricity.

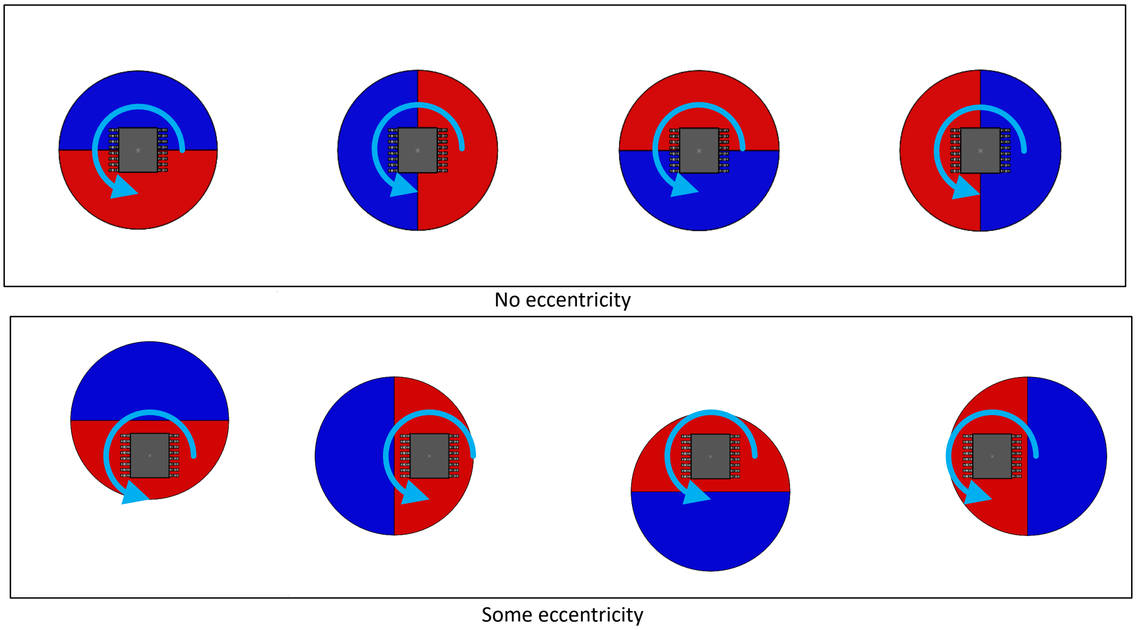

Figure 2-19. Magnet Offset (Eccentricity)

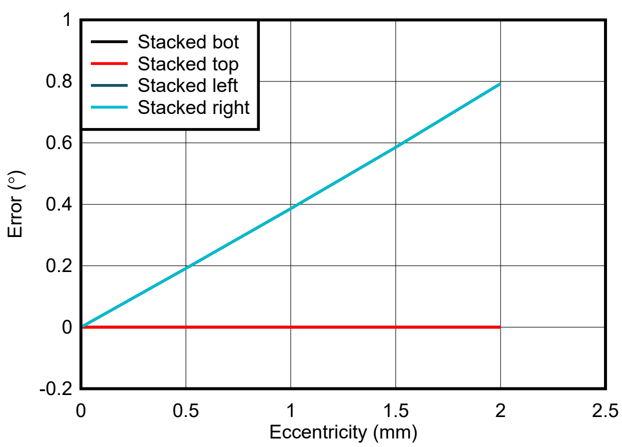

Figure 2-20. Absolute Angle Error Versus Eccentricity

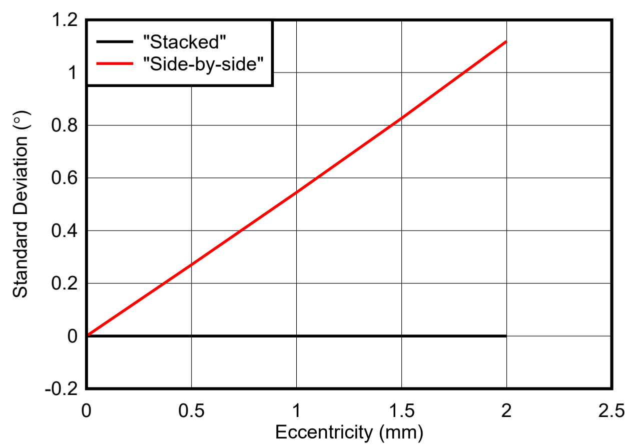

Figure 2-21. Standard Deviation of Difference Versus Eccentricity

Worst case magnet offset considered here is 2 mm, which is 15% the size of the magnet diameter. In this case, the absolute error and standard deviation of difference both increase linearly with the magnet offset for the side by side die, while the stacked die centered on the axis of rotation has comparatively negligible error or variation.

2.5 Magnet Diameter Results

Variation in magnet fabrication is a source of error. However, the manufacturing variation in dimension for a chosen magnet is usually relatively small, so the impact can be unsubstantial. However, making the intended size of the magnet diameter smaller, creates more pronounced errors for large system assembly tolerances.

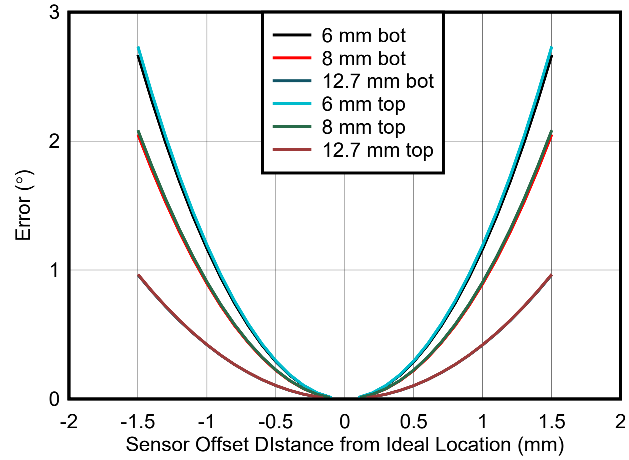

Figure 2-22. Stacked Die Absolute Angle Error Versus Sensor XY Offset for Different Magnet Diameters

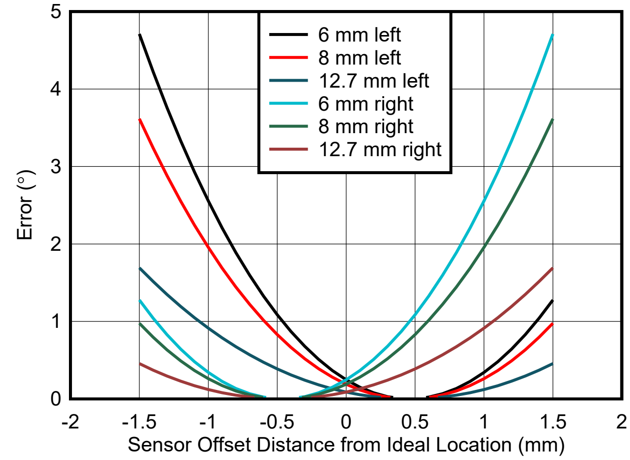

Figure 2-23. Side-by-Side Die Absolute Angle Error Versus Sensor XY Offset for Different Magnet Diameters

In Figure 2-22 and Figure 2-23, the larger diameter magnet exhibits greater immunity to the sensor being offset from the ideal location centered right beneath the axis of rotation for the magnet. The 6-mm diameter magnet exhibits the greatest error, more than 2x what is observed for the 12.7-mm diameter. Worst case error for the side-by-side die is nearly double that of the stacked die.

3 Axial Magnet Approach

Having assessed the Diametric approach, lets now consider the approach with the axial magnet spaced some radial distance from the shifter stick fulcrum. The general b-field profile for an axial magnet rotating past a hall sensor in approach, like the one featured in Figure 1-1, is shown in Figure 3-1. Based on such field behavior, we can expect that taking the arctan of Bz and Bx yields a linear output similar to Figure 3-2. For best results, one of the field values must be scaled such that the global max for each curve is the same prior to processing.

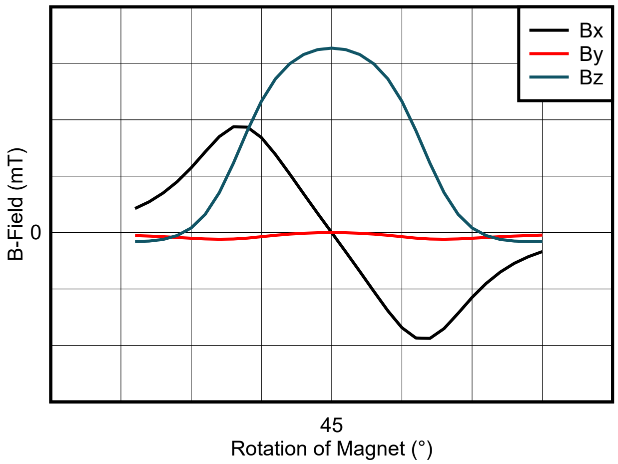

Figure 3-1. B-Field Behavior

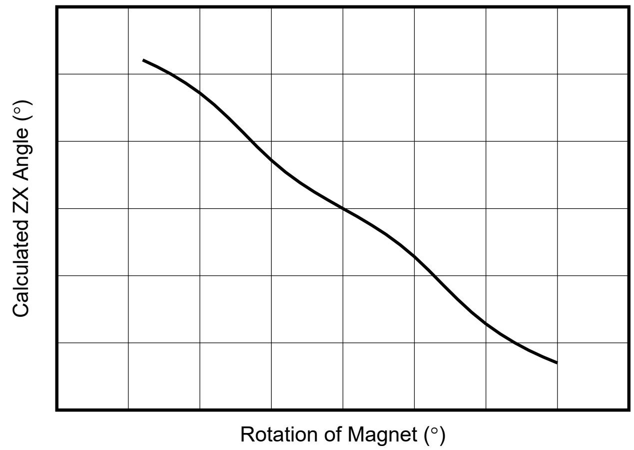

Figure 3-2. ZX Angle

With intuition of the behavior above, an initial attempt at design can be pursued. Similar to the axial approach, an initial head-on sweep of the axial magnet along the z-axis of the device can be performed to determine if there are any restrictions on vertical offset from the device. For this example, involving a Ferrite, C11 grade, 9.52 mm diameter, 3.18 mm thick magnet, a typical 4 mm offset along the z-axis is sufficiently strong when centered over the device to neither saturate a TMAG5170 output nor provide a field indistinguishable from noise. Hence, the next step is to determine what flexibility there is with offset radial from the shifter stick fulcrum. Figure 3-4 and Figure 3-5, illustrate the field Bz and Bx field characteristics for the magnet and device spaced radially from the fulcrum. These figures show that as the radial distance increases, the curve behavior appears to change more rapidly. Operating within the region prior to the device slowly asymptotically approaching 0 mT, is advised. Therefore, increasing radial offset, reduces the measurable range of shifter stick rotation.

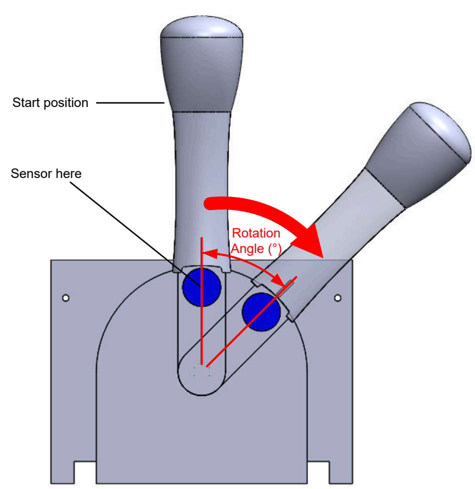

Figure 3-3. Axial Magnet Movement in Radial Sweep Test

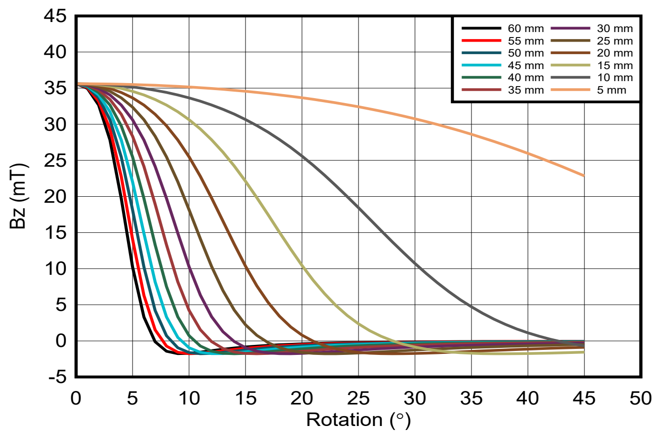

Figure 3-4. Bz Versus Rotation Per Radial Offset

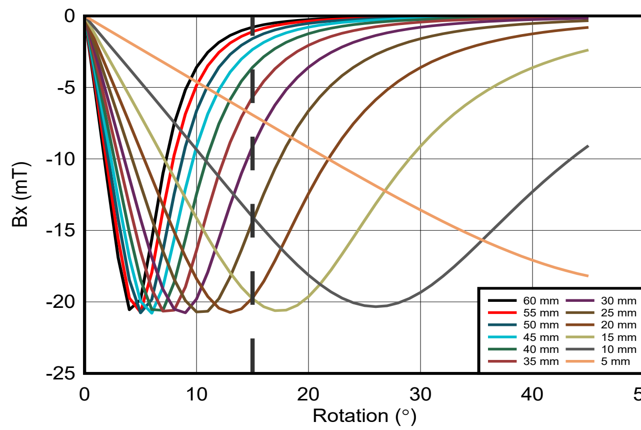

Figure 3-5. Bx Versus Rotation Per Radial Offset

These plots suggest, Figure 3-5 in particular, that for 40 mm radial offset, a range of about 15° is possible. This is the angle from the starting position shown in Figure 3-3. Due to symmetry, this corresponds to ±15°, which is a total distance of 30°. The subsequent sensor comparison proceeds from this radial spacing constraint.

3.1 Errors and Redundancy for Axial Magnet Approach

The conditions for the subsequent data is defined in Table 3-1. Data was collected through the TIMSS tool and post processed in excel. With mechanical assembly, there is the possibility that sensing device is offset from the intended location. The following analysis evaluates the device being offset ±1.5 mm along the x or y axis and ±1 mm along the z-axis.

Table 3-1. Simulation Parameters

Simulation Parameter in TIMSS	Die Configuration	Test	TIMSS Simulation Parameter Value
Magnet Shape	Both	All	Axial Cylinder
Poles	Both	All	2
Magnet	Both	All	Ferrite, C11
Outer Diameter	Both	All	9.52 mm
Height	Both	All	3.18 mm
Magnet Position	Both	All	start at x = 28.2842 mm, y= 28.2842 mm (45°) , z = 0 mm
Magnet Angle	Both	All	x = 0° y= 0°, z = 0°
Arc Length	Both	All	90° with steps of 1°; however only 30°-60° analyzed in postprocessing.
Sensor Position x	Stacked Die	X offset	-1.5 mm to 1.5 mm, steps of 0.1 mm
		Y offset	0 mm
	Horizontal Side-by-side	X offset	-1.96 mm to 1.04 mm for one Hall element and -1.04 to 1.96 for the other Hall element, steps of 0.1 mm
		Y offset	-0.46 mm, 0.46 mm
	Vertical Side-by-side	X offset	-1.5 mm to 1.5 mm, steps of 0.1 mm
		Y offset	0 mm

Table 3-1. Simulation Parameters (continued)

Simulation Parameter in TIMSS	Die Configuration	Test	TIMSS Simulation Parameter Value
Sensor Position y	Stacked Die	X offset	40 mm
		Y offset	40 mm +(-1.5 mm to 1.5 mm), steps of 0.1 mm
	Horizontal Side-by-side	X offset	40 mm
		Y offset	40 mm +(-1.5 mm to 1.5 mm), steps of 0.1 mm
	Vertical Side-by-side	X offset	39.54 mm, 40.46
		Y offset	39.54 mm +(-1.5 mm to 1.5 mm), steps of 0.1 mm for one sensor and 40.46 mm +(-1.5 mm to 1.5 mm), steps of 0.1 mm for the other sensor
Sensor Position z	Stacked Die	All	-2.9385 mm to -4.9385 mm for one Hall element and -3.0615 mm to -5.0615 mm for the other Hall element, steps of 1 mm.
	Horizontal and Vertical Side-by-side	All	-3 mm to -5 mm, steps of 1 mm.

3.2 Offset Results

Figure 3-6, Figure 3-7, and Figure 3-8 provide insights into how the dual sensing element devices deviate in ideal placement for x or y offset. Figure 3-6 shows the stacked die placed for these tests. However, as both die are centered on the magnet's center point, the device package can be rotated 90° and the impact from x or y offset shall be the same. Figure 3-7 and Figure 3-8 show two different scenarios that can be observed for side-by-side die depending on board layout.

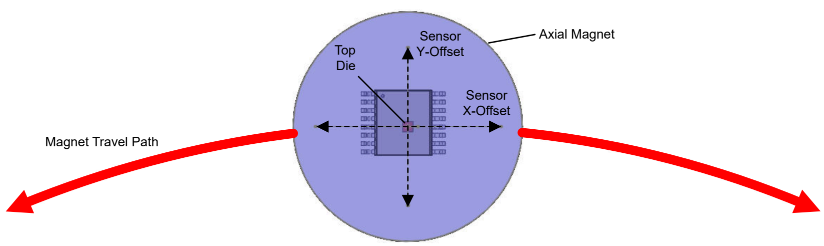

Figure 3-6. Axial Approach Stacked Die x and y Offsets

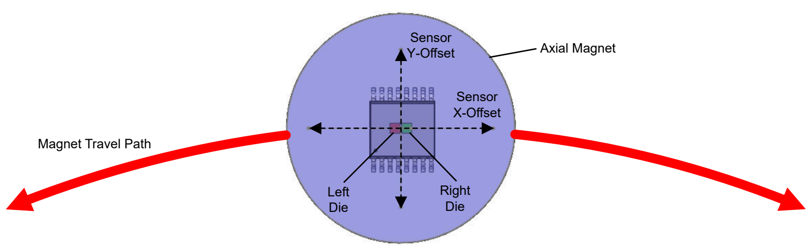

Figure 3-7. Horizontal Side-by-Side Die (Along X axis)

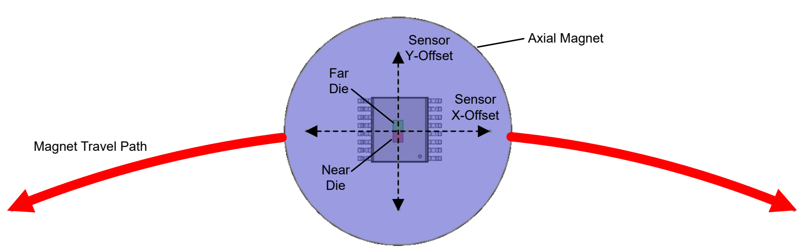

Figure 3-8. Vertical Side-by-Side (Along Y axis)

As in the prior analysis involving the diametric magnet, absolute angle error, standard deviation in angle difference, and max deviation in angle difference are all important parameters in determining accuracy and redundancy of the different dual die configurations. Figure 3-9 through Figure 3-11, show the deviation in calculated angle from the ideal angle different x-offsets. Figure 3-12 through Figure 3-15 show the standard deviation in differences between angles calculated from the different die. Figure 3-16 through Figure 3-18 show the max difference in angle calculation between die that is observed for a die configuration. Each set of figures precedes with the stacked die figure and proceed with the side-by-side die figures.

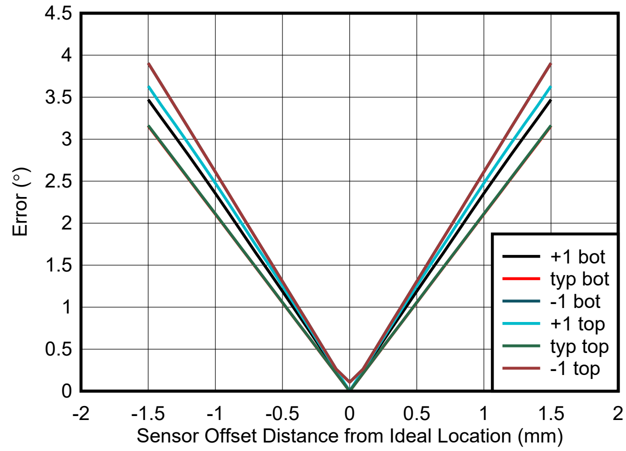

Figure 3-9. Stacked Die Absolute Angle Error Versus Sensor X at Different Sensor Z Offsets

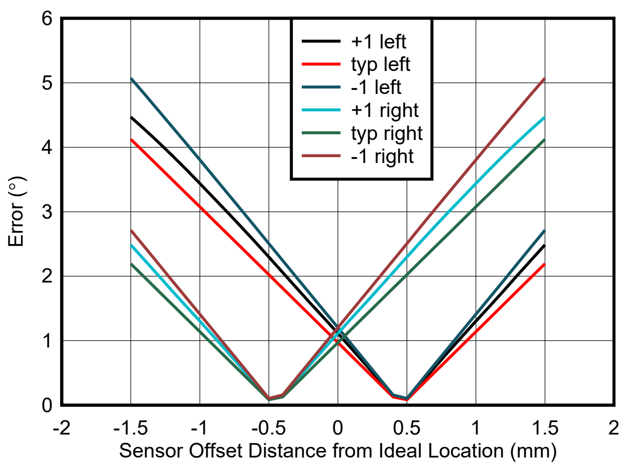

Figure 3-10. Horizontal Side-by-Side Absolute Angle Error Versus Sensor X Offset at different Sensor Z Offsets

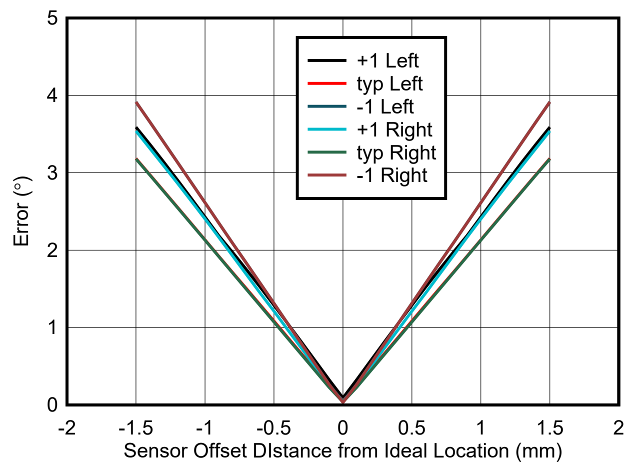

Figure 3-11. Vertical Side-by-Side Absolute Angle Error Versus Sensor X Offset at different Sensor Z Offsets

Here, we see that depending on the orientation of the side-by-side die it is worse or equivalent to the stacked die design. When the side-by-side die is aligned along the x-axis, the error observed is only identical at a 0-mm offset, otherwise as one sensing element error decreases, the other sensing element increases as the sensing element moves even further from the ideal sensing location leading to max error that is a full degree higher than the stacked die.

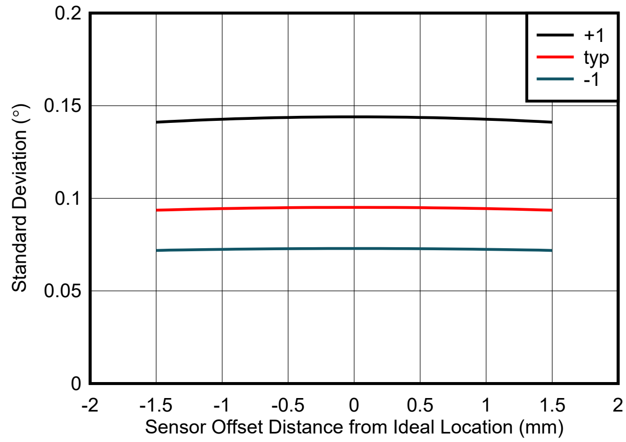

Figure 3-12. Stacked Die Standard Deviation of Difference Versus Sensor X Offset at different Sensor Z Offsets

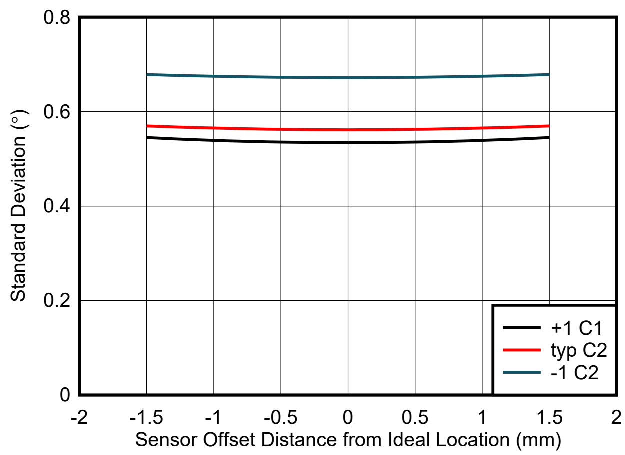

Figure 3-13. Horizontal Side-by-Side Standard Deviation of Difference Versus Sensor X Offset at different Sensor Z Offsets

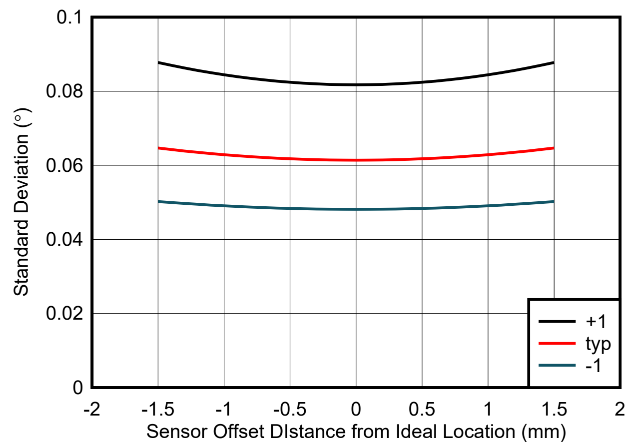

Figure 3-14. Vertical Side-by-Side Standard Deviation of Difference Versus Sensor Y Offset at different Sensor Z Offsets

In this case, the variation in error for side-by-side die depends on the orientation with the sensor elements aligned along the x-axis exhibiting the highest variation all greater than half a degree. When the sensing elements for the side-by-side are aligned along the y-axis, then it has slightly better variation than the stacked die.

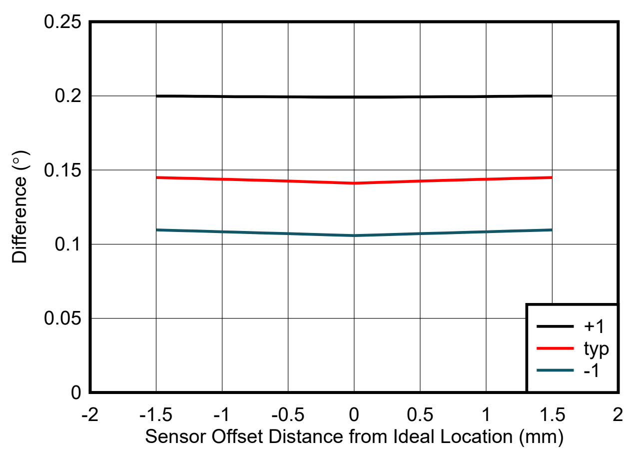

Figure 3-15. Stacked Die Max Difference Versus Sensor X Offset at different Sensor Z Offsets

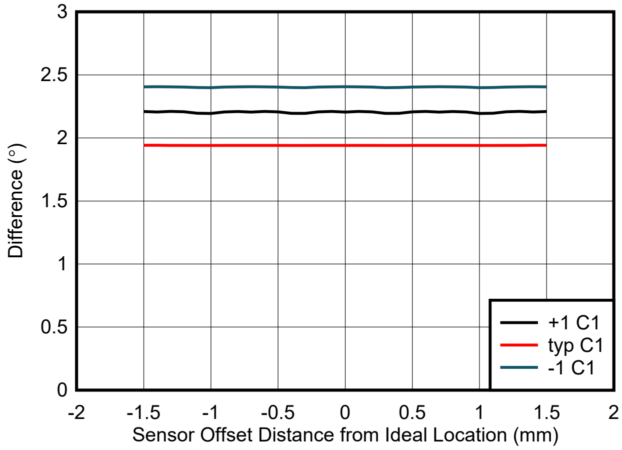

Figure 3-16. Horizontal Side-by-Side Max Difference Versus Sensor X Offset at different Sensor Z Offsets

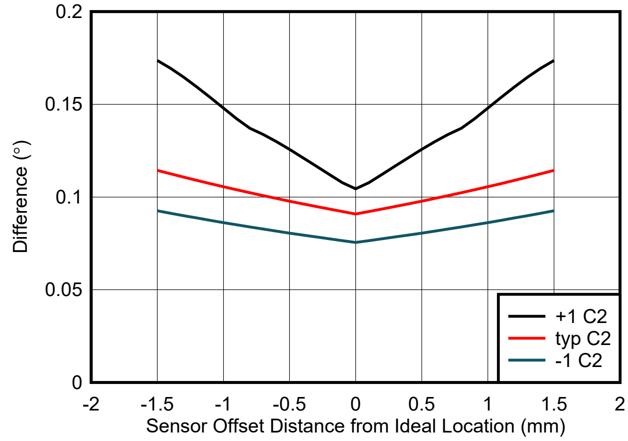

Figure 3-17. Vertical Side-by-Side Max Difference Versus Sensor X Offset at different Sensor Z Offsets

Not only does the side-by-side die have greater variation when the sensing elements are aligned along the x-axis, it has significantly higher difference between angle calculations, with the max difference being above 1.9°. As for the stacked die, it does have a slightly higher max difference than the other side-by-side configuration; however, the max difference is relatively the same over the swept range.

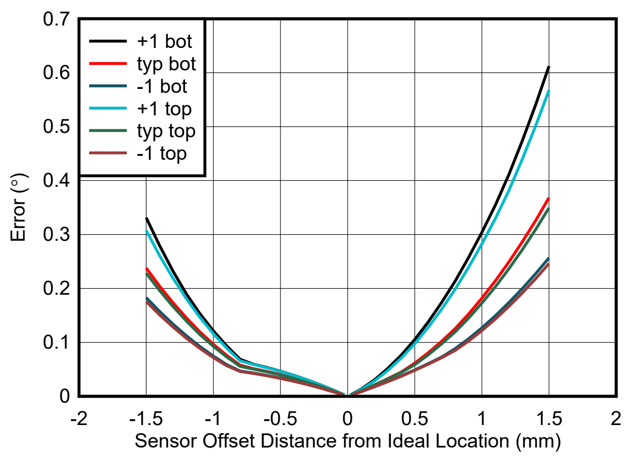

Figure 3-18. Stacked Die Absolute Angle Error Versus Sensor Y Offset at different Sensor Z Offsets

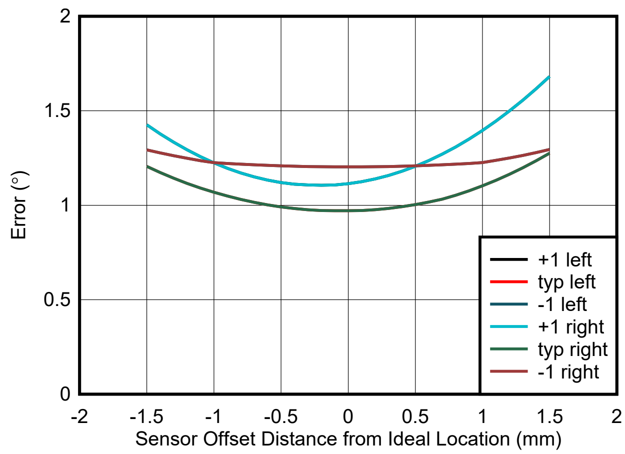

Figure 3-19. Horizontal Side-by-Side Absolute Angle Error Versus Sensor Y Offset at different Sensor Z Offsets

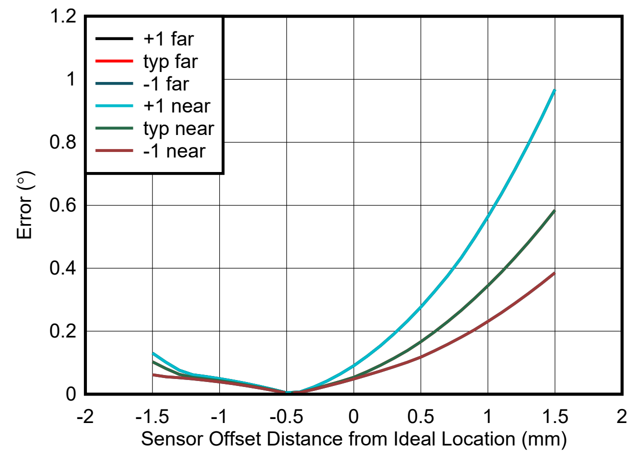

Figure 3-20. Vertical Side-by-Side Absolute Angle Error Versus Sensor Y Offset at different Sensor Z Offsets

If the device is offset along the y-axis, the stacked has the lowest worst case error at around 0.6° when the device is furthest from the fulcrum of the rotating magnet.

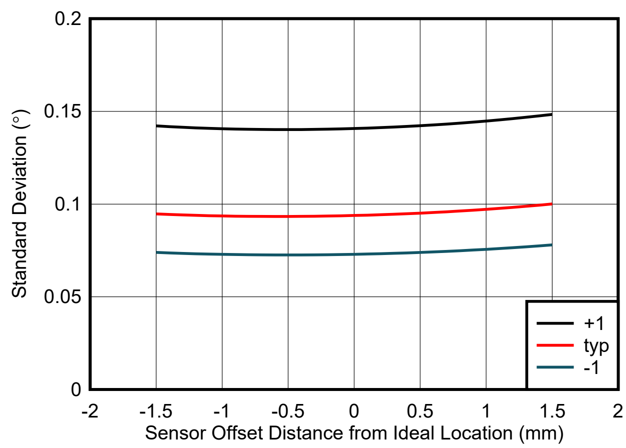

Figure 3-21. Stacked Die Standard Deviation of Difference Versus Sensor Y Offset at different Sensor Z Offsets

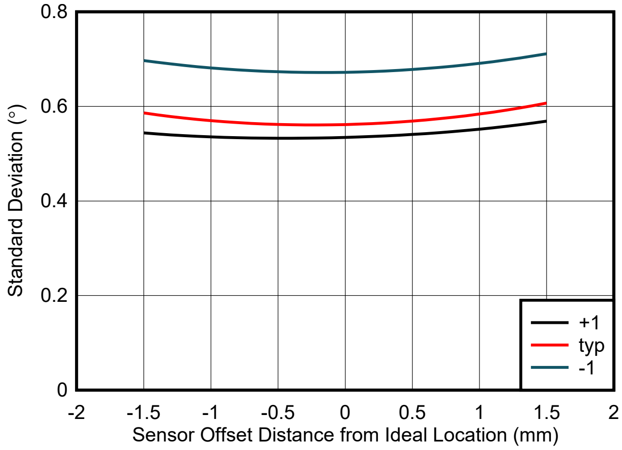

Figure 3-22. Horizontal Side-by-Side Standard Deviation of Difference Versus Sensor Y Offset at different Sensor Z Offsets

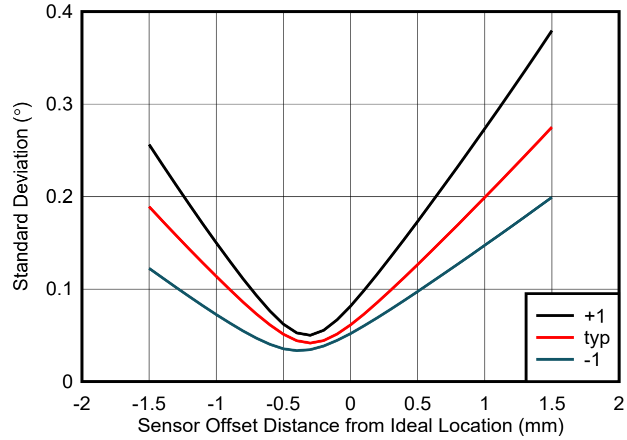

Figure 3-23. Vertical Side-by-Side Standard Deviation of Difference Versus Sensor Y Offset at different Sensor Z Offsets

In this instance the stacked die difference in calculation has a little more variation than the side-by-side. However, the expected variation is relatively the same across sensor y-offset.

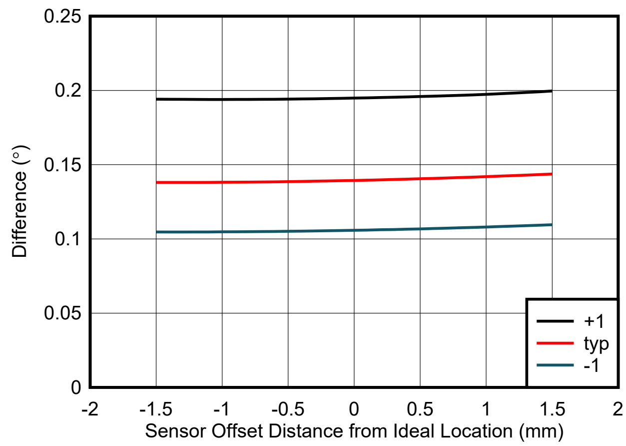

Figure 3-24. Stacked Die Max Difference Versus Sensor Y Offset at different Sensor Z Offsets

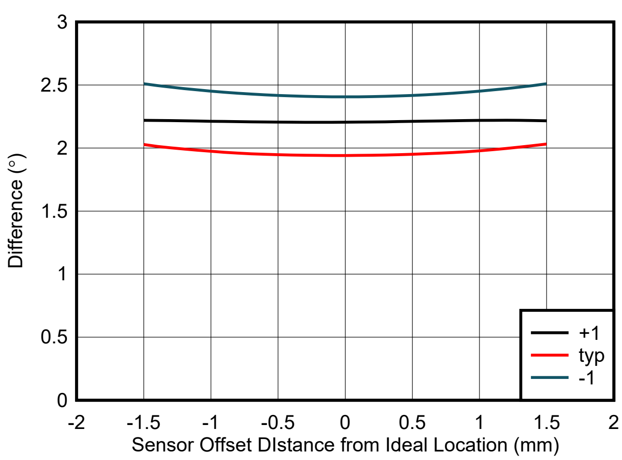

Figure 3-25. Horizontal Side-by-Side Max Difference Versus Sensor Y Offset at different Sensor Z Offsets

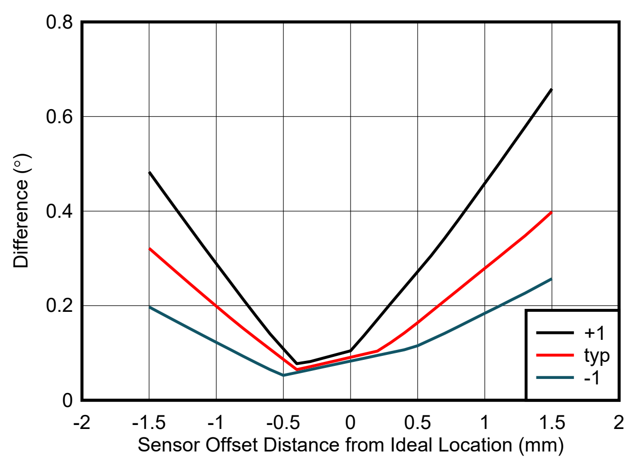

Figure 3-26. Vertical Side-by-Side Max Difference Versus Sensor Y Offset at different Sensor Z Offsets

Here, we can see that side-by-side for one orientation only has a low max angle difference for a small offset range and outside of that it quickly exceeds the max observed for the stacked die configuration. Additionally, if the horizontal orientation is used, the max difference can be 10x larger than the stacked die.

4 Summary

There are at least two approaches to sensing lever position such as found in an e-shifter. Tools like TI's TIMSS can streamline the process evaluating field behavior for a given magnet moved in an arc around a fulcrum point. The key metrics for comparing the die configurations for the two approaches demonstrated in this report are deviation from the ideal angle and difference between angle calculations, which affects redundancy. For the diametric magnet approach, the stacked die consistently has less angle error, smaller differences in angle calculation, and less variation in the observed difference. The starkest contrast in performance was observed for smaller magnet diameters, tilted magnet, and magnets with eccentricity. For the alternative lever approach using an axial magnet, the stacked die is roughly as good and, in some cases, better than the side-by-side die.

The main benefit with the stacked die for an axial magnet swinging past the magnet is flexibility in layout, which might be beneficial for boards that are space constrained with odd geometry. Side-by-side die can see degrees of difference between sensing elements if offset for a particular orientation, while stacked die is consistently well under a degree of difference regardless of orientation.

5 References

- Texas Instruments, *TMAG5170D-Q1: Automotive, High-Precision, 3D Linear Hall-Effect Dual-die Sensor with SPI Interface*, product page
- Texas Instruments, *TMAG5170D-Q1 Dual-Die High-Precision 3D Linear Hall-Effect Sensor With SPI*, data sheet.

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