Application Information

Using the A1335 in a Short Stroke Application

By Loïc Messier
Allegro MicroSystems Europe, Ltd

Introduction

In many applications where the angle of a rotating shaft is monitored, the useful measurement range may be limited by design choice or mechanical constraints to less than a full rotation.

Allegro has designed angular position sensors with features to address these specific applications by offering the ability to rescale limited sensing range into full-scale output to match the application requirements.

This application note is dedicated to short-stroke magnetic applications using Allegro angular position sensors based on circular vertical Hall (CVH) technology. Analyses and data used in this document are based on the A1335 angle sensor IC.

Definitions

Magnet and Sensor Orientation

The magnet used in this document is a simple diametrically magnetized NdFeB disc (6 mm × 4 mm thickness, B_r = 0.4 T, 600 G pk-pk at 0.5 mm) mounted in off-shaft configuration as shown in Figure 1.

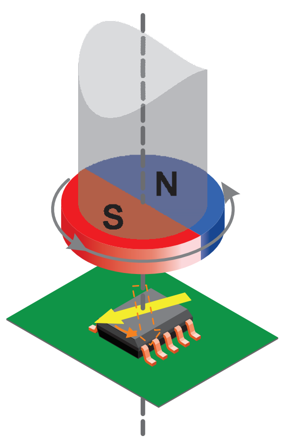

Figure 1: Sensor and magnet orientation – end of shaft

The short-stroke sensing range used in this document is from 0 to 45°, but any range between 0 to 360° can be used.

Air Gap

The air gap is defined as the distance from the magnet to the top of the sensor housing, also referred to as package air gap.

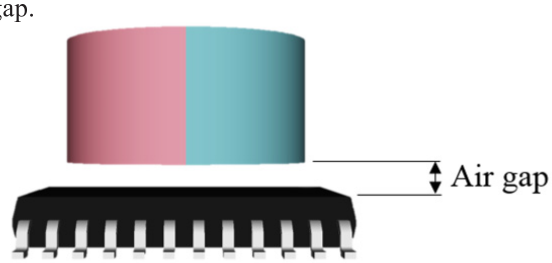

Figure 2: Air gap definition

Angle Error

The angle error corresponds to the deviation from the angle measured by the device to the actual position of the magnet, measured by a high-resolution encoder. Figure 3 shows an example of angle error representation.

$$Angle\ Error = \propto_{Sensor} - \propto_{Real}$$

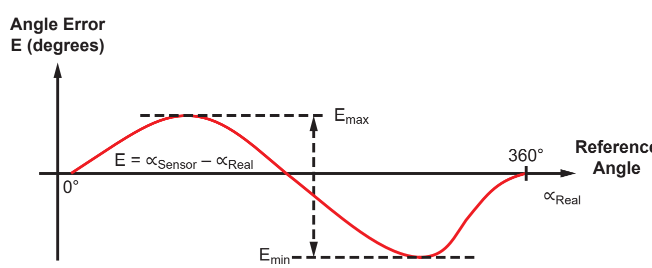

Figure 3: Angle error definition

The angle error is due to two main sources of error:

- Sensor related (intrinsic nonlinearity, noise, parametric temperature drift)
- Magnetic input related (field nonlinearity and strength) caused by magnet and placement error

Accuracy Error

The angle accuracy error corresponds to the angle error amplitude over a full magnet rotation, or in the case of short stroke, over the full measured range. Accuracy error is defined in the equation below:

$$Angle\ Accuracy\ Error = (E_{max} - E_{min}) / 2$$

Output Format

The angle value is commonly represented in degrees, but may also be expressed in different units such as duty cycle, percentage, and digital code.

The output for the A1335 is expressed in LSB with a full scale equal to 4095 LSB (12-bit digital code).

In a short stroke application, the output value is rescaled; therefore, it is practical to express it as percentage of the sensing range.

Formulas below show how to represent the angle in these different formats:

$$Angle\text{ [deg]} = (Angle\text{ [LSB]}) / (4095\text{ [12bit]}) \times 359.912^*$$

$$Angle\text{ [\%]} = (Angle\text{ [LSB]}) / (4095\text{ [12bit]}) \times 100$$

$$Angle\text{ [LSB]} = (Angle\text{ [deg]}) / (359.912^*) \times 4095$$

*359.912° corresponds to 4095LSB (360° – 1 LSB).

Short Stroke Implementation

The short stroke calibration consists of two-points programming where the device angle is measured at two positions, called position 1 and position 2 (start angle and stop angle). Figure 4 shows an example of position 1 and 2.

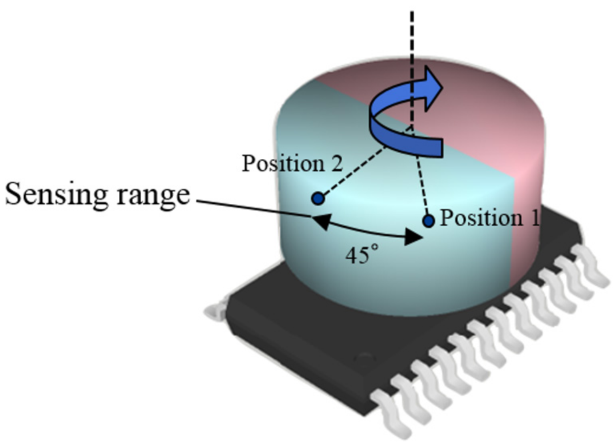

Figure 4: Short stroke range on 6 mm × 4 mm magnet and dual die device (TSSOP-24 package)

Using the angle values read at these positions, the Offset and Gain parameters required to rescale the device output are calculated according to the formula below:

$$Offset = read\ value\ pos_1 - desired\ value\ pos_1$$

Offset is expressed in a 12-bit digital code. To convert from angle in degrees to digital code, refer to Output Format definition above.

$$Gain = \frac{desired\ value\ pos_2 - desired\ value\ pos_1}{read\ value\ pos_2 - read\ value\ pos_1}$$

In order for the Gain to remain positive, the angle/digital value in position 2 must always be higher than in position 1.

If the angle at position 2 is lower than position 1, the magnet rotation direction can be changed into the device EEPROM by setting the polarity bit (on A1335, this is done with the LR bit).

To write the calculated gain into the A1335 EEPROM, it must be converted into a digital code using the formula below:

$$Gain\ code\text{ [LSB]} = 256 \times Gain\ factor + 1$$

These parameters can be manually calculated and written into the device EEPROM, or they can be automatically calculated and programmed using the Allegro-provided software “Allegro A1335 Samples Programmer”.

Short-stroke programming can be summarized with the following sequence based on the A1335 device:

1. Ensure short stroke is initially disabled in EEPROM (set SS bit to 0, bit 24 SRAM 0x306).
2. Adjust ORATE setting (optional) to get best performances by increasing output resolution.
3. Measure angle value at position 1 and position 2; if angle value at position 2 is lower than position 1, change the state of the LR bit in EEPROM to reverse the direction of the angle sensor IC (LR bit, bit 18 SRAM 0x306). Remeasure position 1 and 2 in case the direction was reversed.
4. Calculate Offset and Gain as described and write the values into corresponding EEPROM blocks. (GAIN_OFFSET [31:16], GAIN [15:0] SRAM 0x314).
5. Enable short-stroke mode in EEPROM (set SS bit to 1, bit 24 SRAM 0x306).
6. Program Max and Min angle limits (optional) (MAX_ANGLE [23:12], MIN_ANGLE [11:0] SRAM 0x315).
7. Program clamps high and low (optional) (ClampHi [31:16], ClampLo [15:0] SRAM 0x316).
8. Program linearization (optional).

See A1335 programming reference for more details.

Once written into the device EEPROM, the short-stroke Offset and Gain and other parameters will be applied internally by the IC to post-process the measured angle and rescale it into the selected short stroke range.

ALLEGRO microsystems
Allegro MicroSystems
955 Perimeter Road
Manchester, NH 03103-3353 U.S.A.
www.allegromicro.com

Error Analysis

Angle Error versus Sensing Range

The short-stroke angle error is equivalent to the corresponding angle error on the full sensing range, as the applied gain and offset have no effect on the absolute error.

Figure 5 shows typical angle error at room temperature and 0.5 mm air gap before short-stroke calibration on the full sensing range from 0 to 360° (blue curve) and after the short stroke calibration on the reduced sensing range from 0 to 45° (red curve).

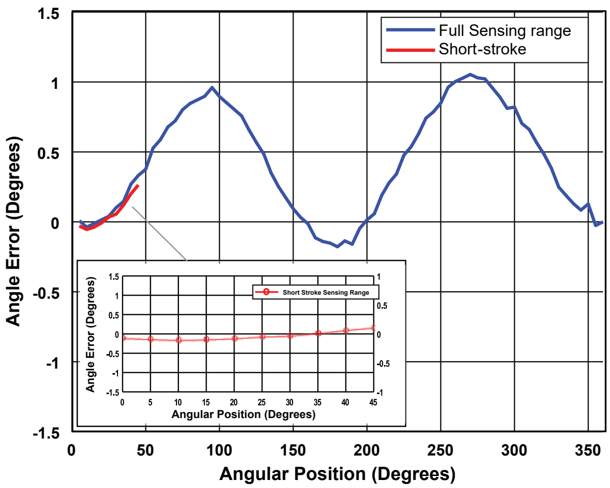

Figure 5: Angle error on full sensing range vs. stroke range

As illustrated in Figure 5, the short-stroke error will follow the same error shape. The short stroke represents only a portion of it and depends on position 1 and position 2 definitions.

Angle Error Short Stroke

The angle error after short-stroke calibration is shown in Figure 6, with a finer step size (1°) for each angular position of the reduced sensing range (0 to 45°); error is illustrated as percentage of the sensing range (45°).

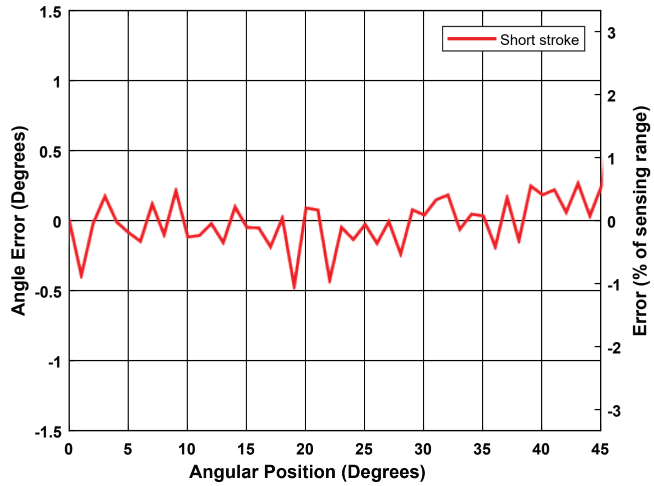

Figure 6: Short stroke angle error at 0.5 mm air gap

The angle error may be higher at some angular positions due to nonhomogenous magnetic input, noise, and intrinsic error of the sensor.

In a nonideal system, position 1 and 2 can be selected based on the magnet pole orientations in order to minimize the error. But considering an ideal magnetic input (magnet homogenously magnetized with no placement error), the definition of position 1 and 2 (start and stop angle) for short stroke will have no effect on device accuracy error.

Allegro MicroSystems
955 Perimeter Road
Manchester, NH 03103-3353 U.S.A.
www.allegromicro.com

Error Over Air Gap

The angle accuracy error over air gap (from 0.5 to 2.5 mm) at room temperature after the short stroke calibration at 0.5 mm is shown in Figure 7. Accuracy error is also illustrated as a percentage of the sensing range.

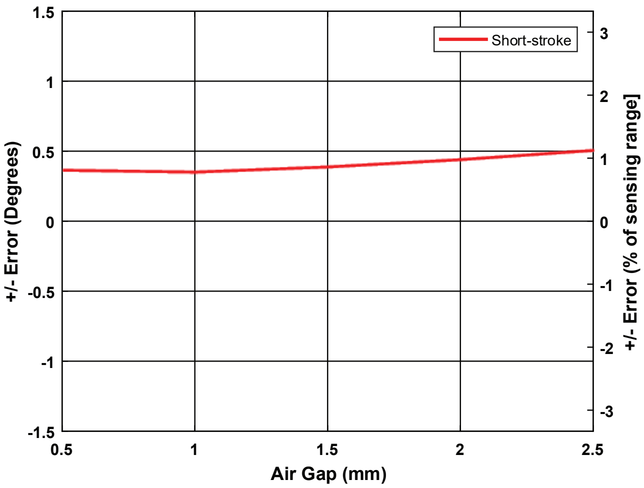

Figure 7: Short stroke accuracy error across air gap

The field strength reduction over air gap and device placement error relative to the center of the magnet will cause the accuracy error to increase with the air gap.

Output Range Limitation and Diagnostics

Maximum and Minimum Angle

User-defined maximum and minimum raw angle values can be programmed into the A1335 device to limit angle readings within a certain range. If enabled, any raw input angle outside the specified range will be detected and reported as an error message by the IC.

These maximum and minimum angle limits are based on the raw angle measured by the IC after the short-stroke offset but before scaling by Gain.

Max and Min angles must be converted into digital values to be written into device EEPROM, using the formula on page 1.

Clamps Effect and Output Range Limitation

User-defined clamp values (clamp angles) can be programmed into the A1335 device as an option to limit the output value to a certain range. Clamping can be defined as the maximum and minimum output values provided by the device.

It may be preferable in some applications to limit the device output to only a percentage of the full range (12-bit). This forces the output to stay within a predefined range to adapt to the application requirements for minimum and maximum value.

Such a case is illustrated below in Figure 8, where a 45-degree stroke corresponds to 90% of the output range such that clamping occurs below 5% and above 95% of the output range (respectively 205 and 3890 LSB).

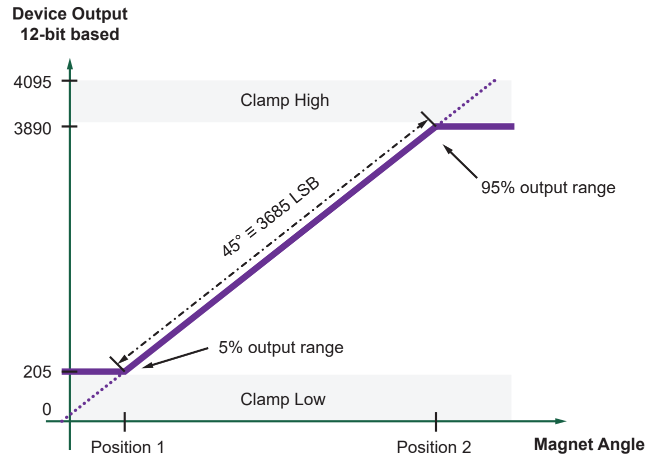

Figure 8: Clamps and output range limitation – short stroke on 45° using 90% of output range

Note that expressing the error as a percentage of the full output range (4095 LSB) instead of the sensing range would in this case give lower error due to output limited to 90% (sensing range is 0.9 × 4095 LSB). For consistency, the error in this document is only expressed as a percentage of the sensing range, which corresponds to the real error of the device.

Figure 9 shows the device output (in digital code) with this method applied when programming the A1335 device for short stroke.

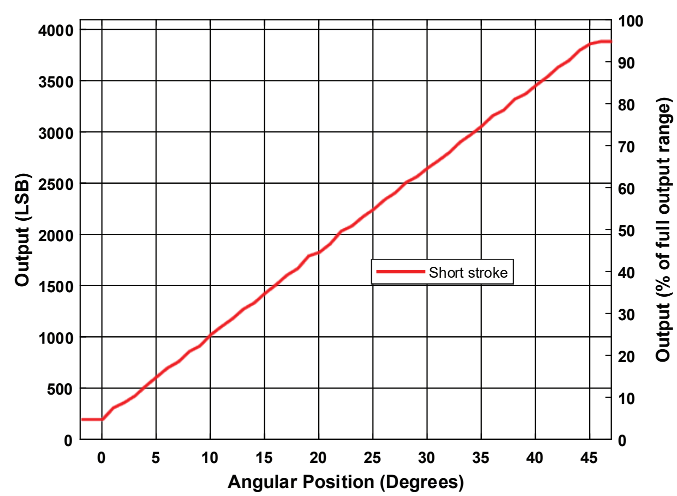

Figure 9: Device output with 45° short stroke limited to 90% of output range

As shown in Figure 9, the device clamps to the specified output values with a range limited to 90% of the full-scale 12-bit output. This method is equivalent to virtually increasing the stroke range of 10% to 50 degrees.

Allegro MicroSystems
955 Perimeter Road
Manchester, NH 03103-3353 U.S.A.
www.allegromicro.com

Linearization

For optimized accuracy, inherent error caused by nonhomogenous magnetic input and sensor intrinsic error can be compensated using the A1335 linearization feature after short-stroke calibration.

The benefit of linearization becomes less noticeable as the sensing range reduces, but in cases of placement error or mechanical play in the application, linearization can help to further reduce the accuracy error.

To demonstrate the effect of linearization, the device was programmed at 1 mm air gap with segmented linearization using 15 measurement points, from 0 to 45 degrees. Results are shown in Figure 10 and Figure 11.

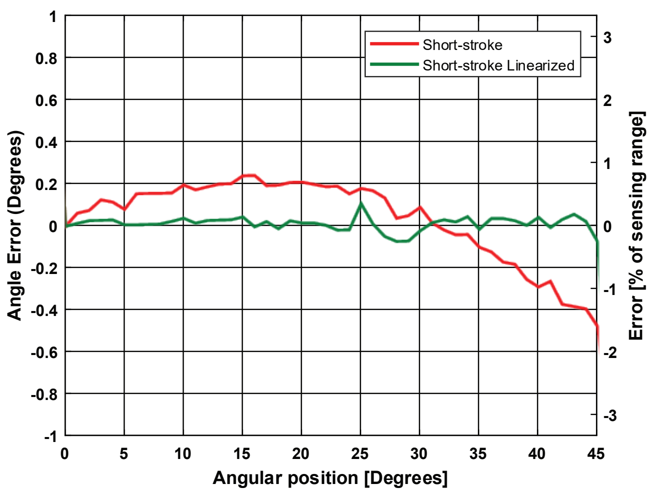

Figure 10: Short-stroke angle error at 1 mm air gap, with and without linearization

Figure 10 shows results of angle error at 1 mm air gap and room temperature before and after linearization. The effect of linearization is clearly visible in this case, resulting in a reduced error below ±0.5% across the 45 degrees sensing range.

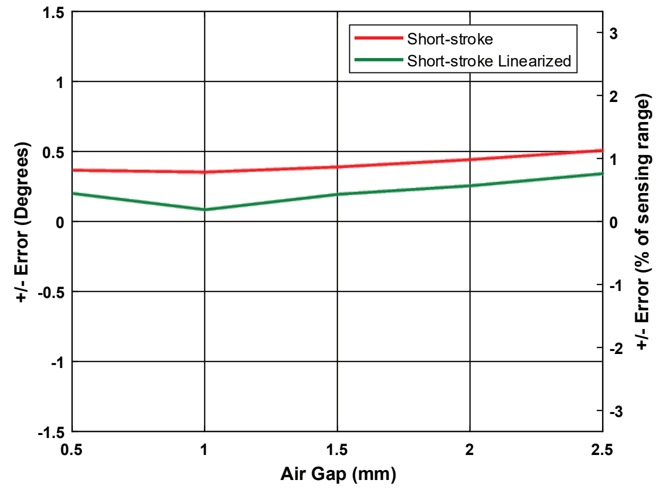

Figure 11: Accuracy error across air gap with and without linearization – short-stroke range

Figure 11 shows accuracy error across air gap at room temperature before and after linearization. The lowest error at 1 mm corresponds to the air gap where the linearization was performed.

For more details regarding linearization, see "Advanced On-Chip Linearization in the A1335 Angle Sensor IC" application note.

Conclusion

Allegro angle sensor ICs based on CVH technology such as the A1335 device are well-suited for short-stroke applications. With a magnetic sensing range of 360 degrees, these devices can be programmed to adjust to any shorter range while providing high accuracy and resolution.

Additionally, these devices offer advanced features such as programmable maximum and minimum field diagnostics, adjustable output clamps, and linearization options, allowing system designers to meet application requirements without additional complexity and cost.

ALLEGRO™ microsystems
Allegro MicroSystems
955 Perimeter Road
Manchester, NH 03103-3353 U.S.A.
www.allegromicro.com

Revision History

Number	Date	Description
–	December 17, 2018	Initial release
1	January 6, 2020	Minor editorial updates

Allegro MicroSystems
955 Perimeter Road
Manchester, NH 03103-3353 U.S.A.
www.allegromicro.com