EFFECT OF RING MAGNET DIMENSIONS ON DIFFERENTIAL SPEED SENSOR PERFORMANCE

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INTRODUCTION

Speed sensors are used with magnetic targets to provide position information in order to calculate speed and direction. These magnetic targets can either be magnetic encoders with magnetic poles, commonly called ring magnets, or ferrous targets. The latter requires a back-biased magnet in addition to the speed sensor.

As each customer has its own specific targets or set of targets with different dimensions, speed sensors must keep their performance over a wide variety of targets.

In this document, a description of how ring magnet dimensions affect speed sensor performance is given. While the following content holds true for Allegro wheel speed or transmission sensors used with ring magnets, it does not apply to ferrous target applications, where additional target parameters can impact the sensor overall performance.

TARGET PITCH EFFECT

In this section, a definition of the target pitch will be given as well as its effect on both the differential signal amplitude and the phase difference between differential signals when using Allegro speed and direction sensors.

Target Pitch and Differential Signal Amplitude Relation

The target pitch is the length of one target pole pair and is defined by the following formula:

Equation 1:

$$\mathrm{Target_{pitch}} = \mathrm{diameter} \times \frac{\pi}{\mathrm{number\ of\ Pole\ Pair}}$$

In the case of radial target (see figure 1), the diameter used is the outer diameter, OD. For axial targets, the sensing elements are generally aligned with the middle of the magnetic track with diameter $(\mathrm{OD}+\mathrm{ID})/2$, where ID represents the inner diameter. In this case, the middle diameter is used instead in the target pitch formula.

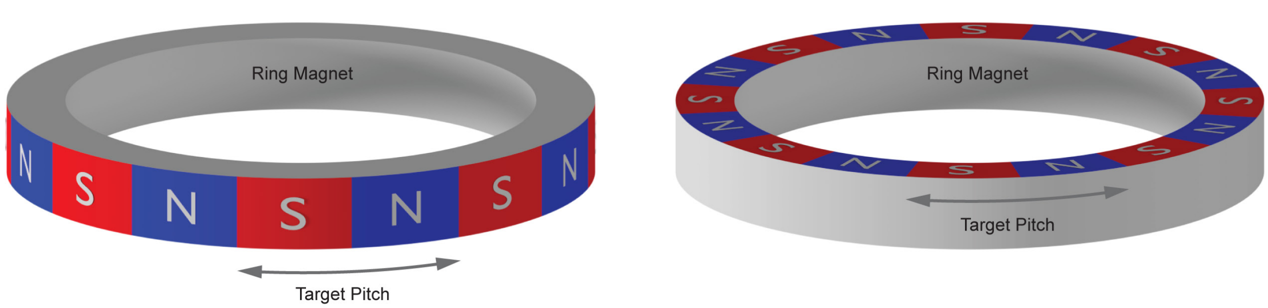


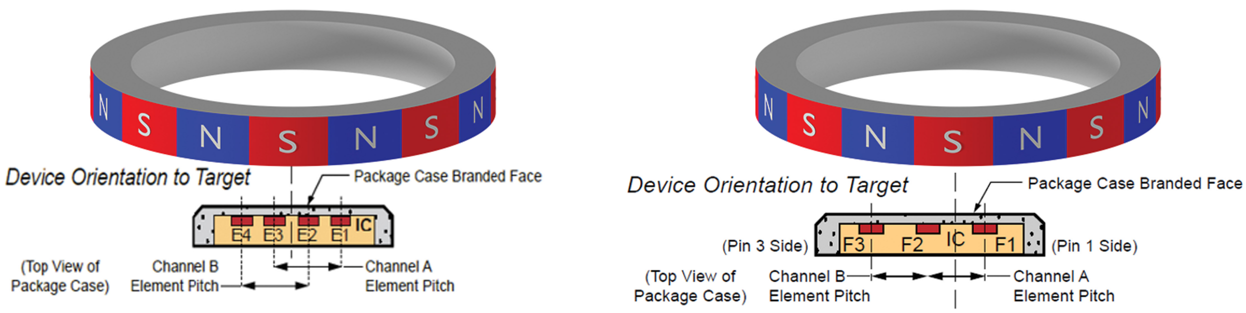
Figure 1: Example of radial (left) and axial (right) ring magnet

Common speed sensors use differential signals obtained from the difference between two sensing elements. Differential sensing offers inherent rejection of interfering common-mode magnetic fields.

The element pitch is defined by the distance between two sensing elements used for one differential signal. Figure 2 is an example of Allegro speed and direction sensors with two differential signals (labelled as Channel A and Channel B) based on four sensing elements (labelled E1 to E4) in the case of GMR speed and direction sensors and three sensing elements (labelled F1 to F3) in the case of Hall-based speed and direction sensors. The element pitch for channel A is the distance between E1 and E3 for GMR sensors and F1 and F2 for Hall sensors.

For Hall-based sensors, the middle Hall plate is usually shared and used in both differential signals.

For speed-only sensors, one channel is enough, the second channel being used for direction detection.



$$Channel\ A\ element\ pitch = E1 - E3$$

$$Channel\ B\ element\ pitch = E2 - E4$$

$$Channel\ A\ element\ pitch = F1 - F2$$

$$Channel\ B\ element\ pitch = F3 - F2$$

Figure 2: Element pitch representation for GMR (left) and Hall (right) speed and direction sensors

The target pitch and the element pitch affect the differential signal amplitude as expressed in Equation 2, which holds true for a perfect sinusoidal differential signal and should only be used for feasibility study. Contact Allegro for more accurate results.

Equation 2:

$$\mathrm{Bdiff}_{\text{peak-peak}} = \mathrm{B}_{\text{peak-peak}} \times (2\sin\left[\pi \times \frac{\mathrm{Element}_{\text{pitch}}}{\mathrm{Target}_{\text{pitch}}}\right]$$

B is the single-ended magnetic field measured in the GMR or Hall element pitch. Tangential field is considered for GMR sensors, and radial field is considered for Hall-based sensors.

For GMR speed sensors, B can be sensed in two different sensor orientations as shown on Figure 3.

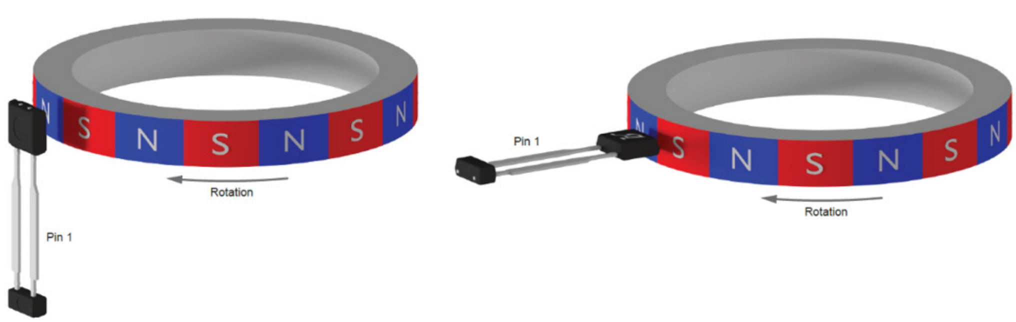


Figure 3: Magnetic field orientation on Allegro Hall based (left only) and GMR (left and right sensor installation) speed sensor

Equation 2 indicates that the maximum differential signal amplitude occurs when

$$\frac{\text{Element}_{\text{pitch}}}{\text{Target}_{\text{pitch}}} = \frac{1}{2}.$$

The influence of the element pitch to target pitch ratio on the differential signal is illustrated in Figure 4.

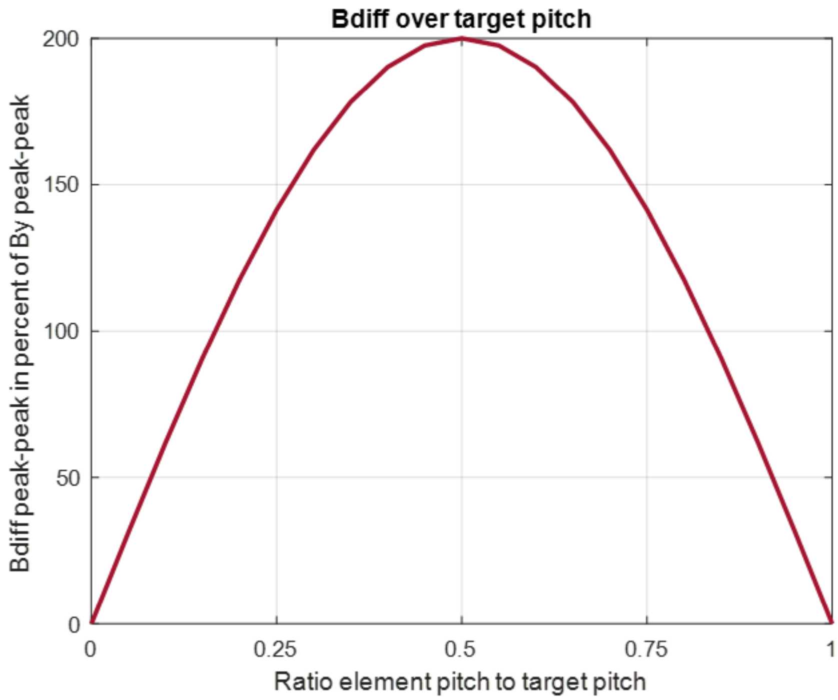


Figure 4: Influence of element pitch to target pitch ratio on differential signal amplitude

Deviations from the ratio $\frac{\text{Element}_{\text{pitch}}}{\text{Target}_{\text{pitch}}} = \frac{1}{2}$ will cause an amplitude reduction on the differential signal and large sensor air gap (see radial axis in Figure 3) performances can be impacted.

In this case, signal-to-noise ratio in the signal processing is reduced and affects output pulse repeatability, commonly called "jitter".

The maximum operating sensor air gap, which is the distance between the target to sensor package in the z axis (Figure 3), is also reduced. In Allegro ICs, all sensor performance is guaranteed up to a minimum differential signal amplitude. Beyond this value, performance degradation may occur.

In the last section, three methods to determine the differential signal amplitude over sensor air gap are provided.

TARGET PITCH AND PHASE DIFFERENCE RELATION

Allegro speed and direction sensors use two differential signals in the signal processing for direction detection, resulting in a total of four sensing elements in the case of GMR speed sensor and three for Hall-based sensor (Figure 2).

The channel pitch is the distance between the center of each differential signal element pitch whose expression can be simplified as following and refers to Figure 2.

Equation 3: $\text{Channel pitch (GMR)} = \text{E1} - \text{E2}$ [mm]

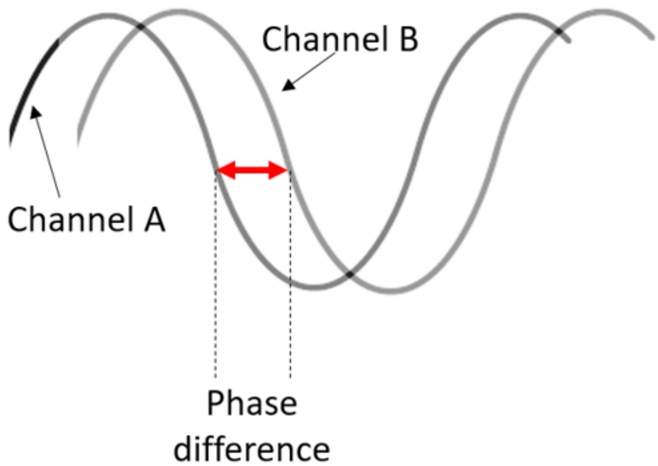
Equation 4: $\text{Channel pitch (Hall)} = (\text{F1} - \text{F3}) / 2$ [mm],

(note that F1-F2 do not always equals F2-F3; in such cases, simply use channel pitch F1-F2).

The channel pitch and the element pitch can be retrieved in Allegro datasheets from the package outline drawing on the last page which defines all sensing element positions.

The target pitch and the channel pitch define the phase difference between the differential signals according to Equation 5 and is illustrated in Figure 5.

Equation 5: $$\text{Phase difference} = \frac{\text{Channel pitch}}{\text{Target pitch}} \times 360$$



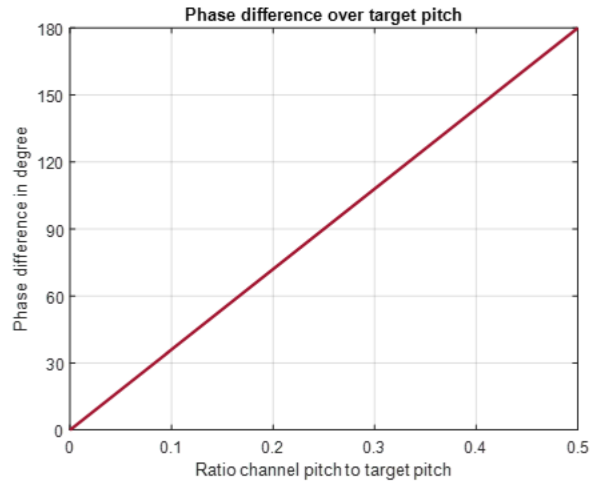


Figure 5: Impact of channel pitch to target pitch ratio on phase difference between differential signals

A minimum phase difference between both differential signals is necessary for correct direction detection. Allegro defines in datasheets a minimum switch point separation required between both differential signals as shown on Figure 6 by $B_{diff(SP)}$ amplitude. The minimum switch point separation ratio $B_{diff(SP\text{-}SEP)}$ is expressed in percent peak to peak. Allegro generally recommends using a ratio in percent of minimum 20%. For the exact value of the device of interest, verify from the datasheet.

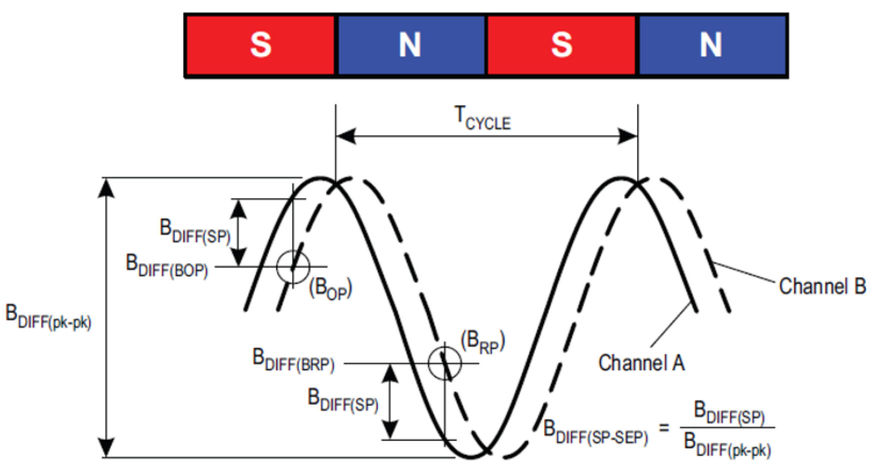


Figure 6: Definition of switch point separation. Bop and Brp represent respectively rising and falling switch points.

The phase difference corresponding to the minimum switch point separation ($B_{Diff(SP\text{-}SEP)}$ = 20% in this case) can mathematically be retrieved as shown in Equation 6, Equation 7, Equation 8, and Figure 7. The below paragraph considers a differential signal to be a sinusoidal signal but Allegro performs such phase difference calculations on real target mappings as well.

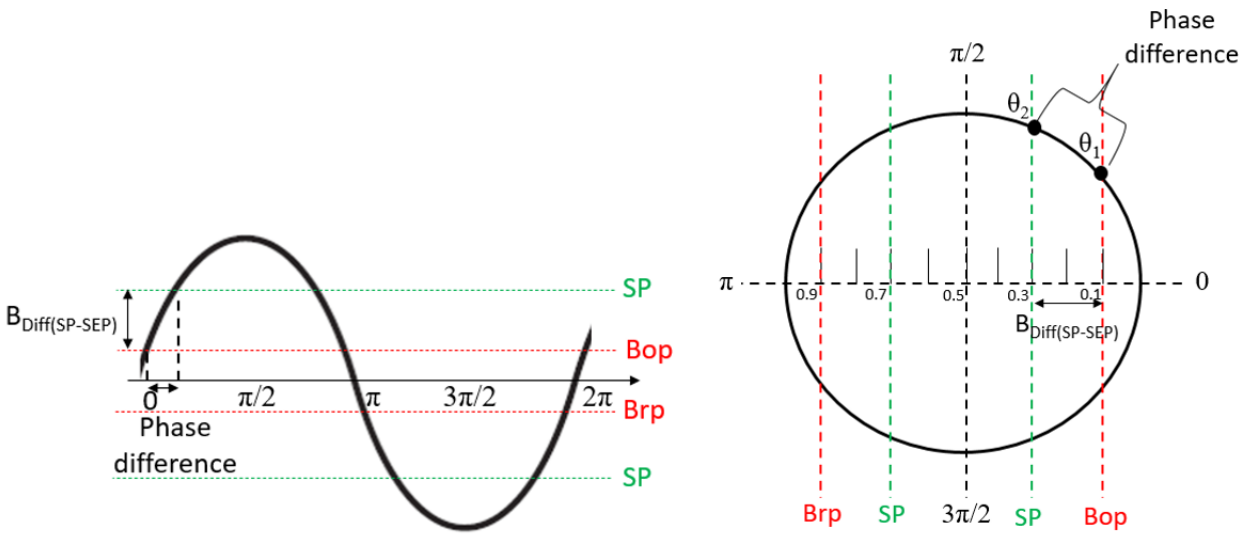


Figure 7: Sine wave (left) and phasor (right) representation of the differential signal. B_{OP} (red), B_{RP} (red) and SP (green) thresholds respectively represent rising, falling switch point, separation of 20%. In this figure, B_{OP} and B_{RP} are set to 60% and 40%. Other switch points may be used depending on the sensor of interest and are specified on the datasheet.

Equation 6:	$\theta_1 = \arcsin((B_{OP}\% - 50\%) \times {}^{2}/_{100})$, with $B_{OP} = 60\%$	[radian]
Equation 7:	$\theta_2 = \arcsin((B_{OP}\% + B_{Diff(SP\text{-}SEP)} - 50\%) \times {}^{2}/_{100})$, with $B_{Diff(SP\text{-}SEP)} = 20\%$	[radian]
Equation 8:	Phase difference $= (\theta_2 - \theta_1) \times {}^{180}/_{\pi} = 25.3329°$	[degree]

1 and θ_2 correspond respectively to the angle of the sinusoidal at B_{OP} and at B_{OP} + 20%.

In the case of switch points (B_{OP} and B_{RP}) set at 60% and 40% and a minimum switch point separation defined at 20%, the phase difference between differential signals calculated in Equation 5 must be higher or equal to 25.33° when using Allegro speed sensors with a ring magnet.

The same exercise (referring to Equations 6 to 8) can be done for switch points set to 70% and 30%.

SIGNAL DIFFERENTIAL PEAK TO PEAK AND MAXIMUM AIR GAP DETERMINATION

Different methods exist to determine the differential signal peak to peak. This section will describe three different methods, one using a gauss probe or linear magnetic sensor, a second using the target parameters in simulation, and a third involving a target mapping to determine the maximum air gap for a customer target. Methods 1 and 2 will determine the single-ended field B over air gap (radial axis referring to Figure 3) in order to retrieve the differential signal peak to peak using formula (2), while method 3 will directly lead to the maximum sensor air gap for a specific target. Once the differential field across sensor air gap is obtained, it can be compared against the minimum differential field value from the datasheet to retrieve the maximum air gap.

Method 1: Gauss Probe or Linear Magnetic Sensor

Linear sensing of the magnetic field over air gap can be done either with gauss probe which directly measures the magnetic field or with a linear magnetic sensor that can give a correlation between its output and the measured magnetic field. Both devices can be placed in front of the target and measure the magnetic field over air gap. If a linear magnetic sensor (e.g., Hall-based sensor) is used, the device must be oriented such that the sensing field corresponds to the radial field (see Figure 3).

Method 2: Mathematical Determination

Allegro can mathematically determine the magnetic field in the radial, tangential, and axial orientation over sensor air gap via simulation. To do so, target geometry and material must be known.

Method 3: Maximum Air Gap Correlation with Target Mapping

Allegro can also perform target mapping which is a technique that measures the sensor differential signal amplitude used in the algorithm post-processing to define the maximum sensor air gap on a customer target. The sensor is positioned in front of the customer target and the differential signal value is recorded over target angle for different sensor air gaps.

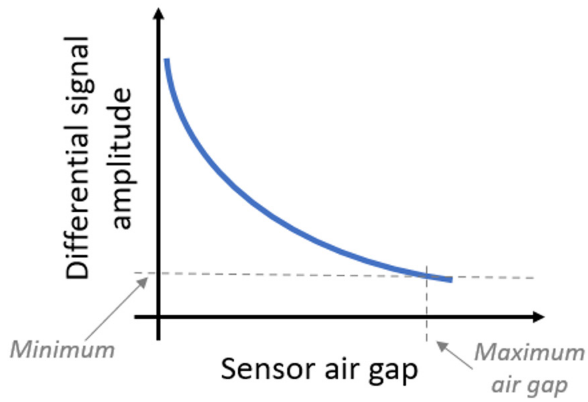


Figure 8: Maximum air gap determination using target mapping

Method 1 is the easiest option to determine the maximum air gap for a specific target. Contact Allegro for further detailed analysis.

CONCLUSION

A method to determine the differential signal amplitude over sensor air gap is given, enabling customers to define the maximum air gap of Allegro speed sensors used with ring magnets.

For speed and direction sensors, the phase difference between differential signals becomes important to detect valid direction. An example is given to calculate the minimum phase difference required by an Allegro IC as well as a formula to retrieve the phase difference for each ring magnet. The differential signals amplitude and the phase difference between both signals are used to verify a customer's ring magnet compatibility with Allegro speed and direction sensors.

Revision History

Number	Date	Description	Responsibility
–	November 17, 2021	Initial release	S. Bastien

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