AK74xx series

Application Note for Magnet Selection (Shaft-End)

1. Introduction

The AKM angle sensor (AK74xx) enables the measurement of magnetic fields (Bx, By) in parallel to the chip surface and can detect the absolute angle of magnetic field over the full range between 0 and 360 degrees with high accuracy and resolution.

Figure 1 shows Shaft-End configuration where the center of the magnet and the center of the sensor are aligned on the rotational axis. Figure 2 shows the operating magnetic fields (Bx, By) with respect to the angle for a Shaft-End configuration.

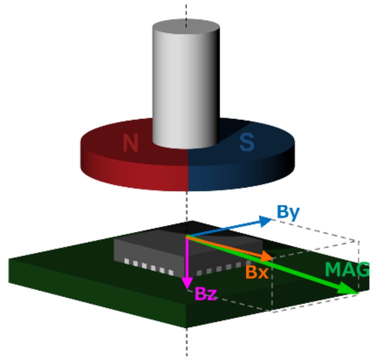

Figure 1. Shaft-End Configuration

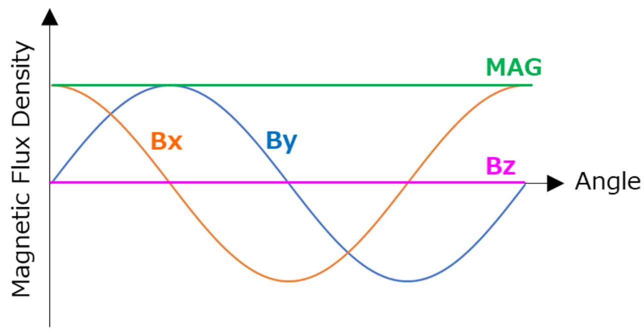

Figure 2. Magnetic Fields (Bx, By) vs. Angle

*Bz=0 if there is no misalignment in the Shaft-End

About This Document

This document provides an introduction to the magnet-selection.
In Chapter 3, how to use recommended magnet is described. Influences when the recommended magnet size is minor-changed due to a system-layout are described in Chapter 4 and 5, and influences when the shape or material of the magnet is changed in Chapter 6 and 7.
All of these are verified by the magnetic field simulation. About the angle error caused by IC, please refer to the datasheet of each product.

If the recommended magnet does not fit your application, please contact us.

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Definitions

Origin Point (0, 0, 0):
Figure 3 shows the origin point.
It is defined that the central point of the magnet surface on the side near the sensor is the coordinate origin (0, 0, 0). In this document, unless stated, length is all in millimeter (mm) unit.

Sensor (Sensor element):
This is the element that actually detects the magnetic field within the IC package. The position of the sensor will differ for each product. Please refer to the datasheet for each product for details on sensor position.

Gap:
The distance between the sensor and the nearest surface of the magnet

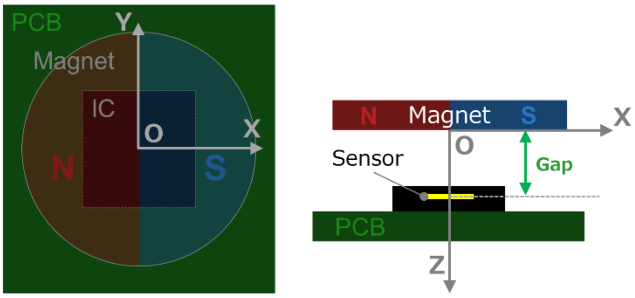

Figure 3. Origin Point and Gap

Magnetic Fields (Bx, By):
Bx and By are the magnetic field components detected by the AK74xx, which are parallel to the surface of the IC.

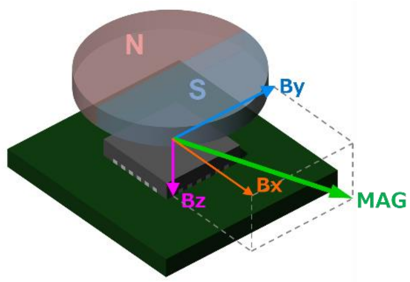

Figure 4. Magnetic Fields (Bx, By)

MAG and Operating Magnetic Field Range:
MAG is defined as $\mathrm{MAG} = \sqrt{B_x^2 + B_y^2 + B_z^2}$. The magnetic flux density range needed to detect the rotation angle is called the operating magnetic field range. The operating magnetic field range of the AK74xx is from 30 to 70 mT for a shaft-end configuration. If there is no mounting misalignment in the shaft-end configuration, MAG becomes a constant value. To account for the variation in mounting tolerances and ambient temperatures, it is recommended to install the sensor in a position where MAG is 50mT when there is no mounting misalignment. *Bz=0 if there is no misalignment in the Shaft-End.

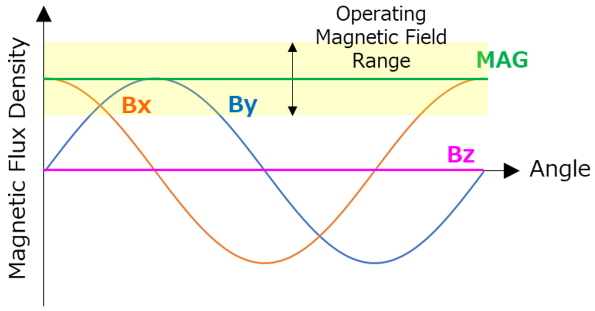

Figure 5. MAG and operating magnetic field range

Diametral Magnet:
A diametral magnetized magnet has magnetic field in the direction shown below.

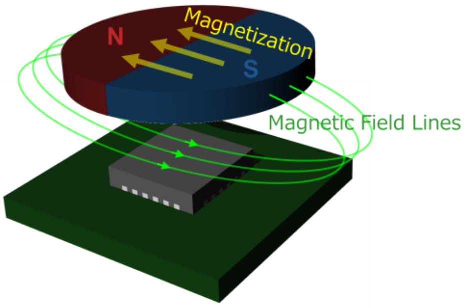

Figure 6. Diametral Magnet

Misalignment (mounting misalignment):
Ideally, the center of the magnet and the sensor center should be aligned on the rotational axis in the Shaft-End configuration. In this document, the distance from this sensor center to rotational axis is called misalignment.

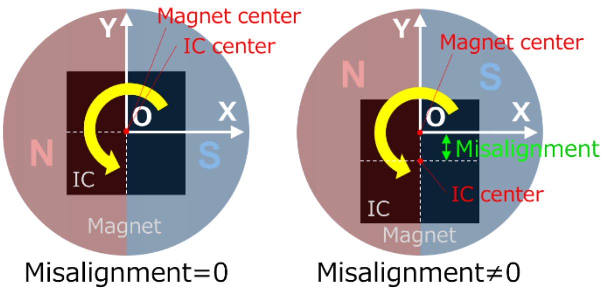

Figure 7. Misalignment

Sintered Magnet:
A magnet manufactured by pressing magnetic powders into a shape and baked by intense heat. This type includes ferrite magnets, samarium cobalt magnets and neodymium magnets. It is suitable to a standard shape such as cylinder and rectangular solid.

Neodymium Magnet (Nd-Fe-B) and Ferrite Magnet (Ferrite):
Permanent magnets can largely be classified into the ferrite magnets, the samarium cobalt (Sm-Co) magnets and the neodymium iron boron (Nd-Fe-B) magnets. In this document, sintered neodymium magnets and sintered ferrite magnets are introduced as magnets used in combination with the AK74xx series. Ferrite magnets are characterized by low cost and high productivity. Neodymium magnets are more expensive than ferrite magnets, but they are high-performance magnets with high residual magnetic flux density. The following values indicate the material characteristics of each magnet.

Sintered Neodymium Magnet (N35※);
Residual magnetic flux density “Br” = 1.17 to 1.25 T, Coercive force “Hcb” ≥ 859 kA/m
Sintered Ferrite Magnet;
Residual magnetic flux density “Br” = 0.38 to 0.42 T, Coercive force “Hcb” = 223 to 300 kA/m

*The upper temperature limit for N35 grade is generally 80 °C. It is necessary to change the grade of magnet according to your environment temperature. There is N35SH grade as a magnet that can be used even at 125 °C. Generally, there is almost no difference in residual magnetic flux density and coercive force performance between N35 and N35SH grades.

2. Table of Contents

3. Recommended Magnet

In this chapter, the recommended magnet that can be used in combination with the AK74xx series in the Shaft-End configuration are introduced. Possible mounting position of the sensor and the angle error due to the misalignment will be also described.

[Recommended Magnet]

Shape: Disk, Outer Diameter Φ: 8 mm, Height: 1 mm
Magnetization Direction: Diametral
Number of Pole: 2 Poles
Material Characteristics: Sintered Neodymium Magnet (N35)
(Residual magnetic flux density “Br” = 1.21 T at Room temperature*, Coercive force “Hcb” = 859 kA/m)
Ambient Temperature: -40 °C, Room temperature, 80 °C
* Br = 1.30 T (-40 °C) or Br = 1.13 T (80 °C)
+++

Gap vs MAG

The figure below plots MAG with respect to the gap for each environmental temperature. Gap is the distance from the magnet surface to the sensor. The area colored yellow indicates a magnetic field range of 30 to 70 mT, and the arrow indicates the gap range where the sensor can be installed. The recommended position for 50 mT detected magnetic field at each temperature is as follows. As the environmental temperature changes, the magnetic flux density changes. The recommended position of the sensor is where 50 mT can be obtained at room temperature.

Ambient Temperature	Sensor Position (50 mT)
-40 °C	(0, 0, 1.9)
Room Temperature	(0, 0, 1.7)*
80 °C	(0, 0, 1.5)

* Recommended Position

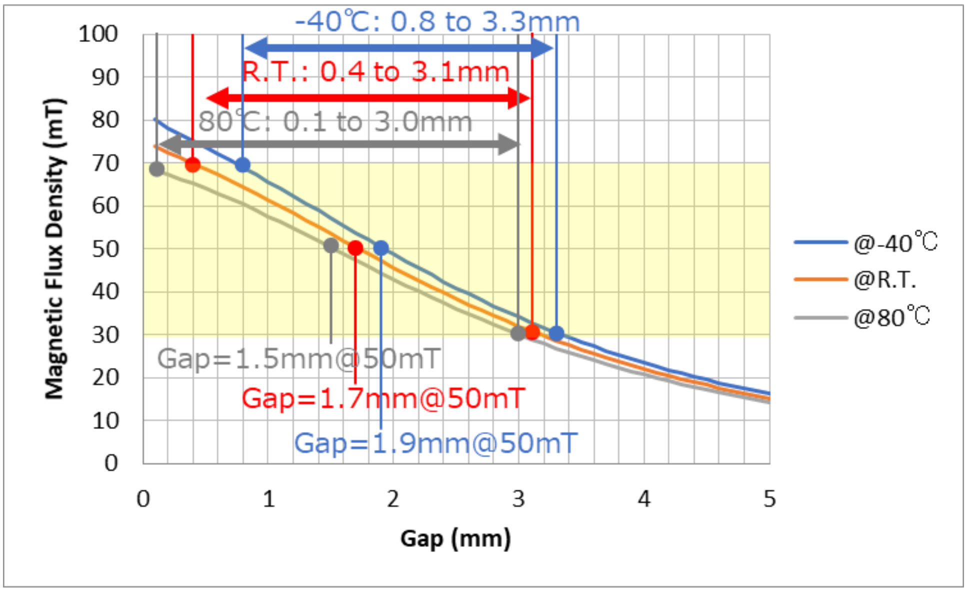

Figure 8. Gap vs MAG (with Recommended Magnet)

Misaligment vs Angle Error

The angle error with respect to misalignment for each MAG value (30 mT, 40 mT, 50 mT, 60 mT, 70 mT) with the recommended magnet is plotted in the following figure. The sensor position for each MAG is shown below.

Max. Magnetic Flux Density	Sensor Position
30 mT	(0, 0, 3.1)
40 mT	(0, 0, 2.4)
50 mT	(0, 0, 1.7)*
60 mT	(0, 0, 1.1)
70 mT	(0, 0, 0.4)

*Recommended Position

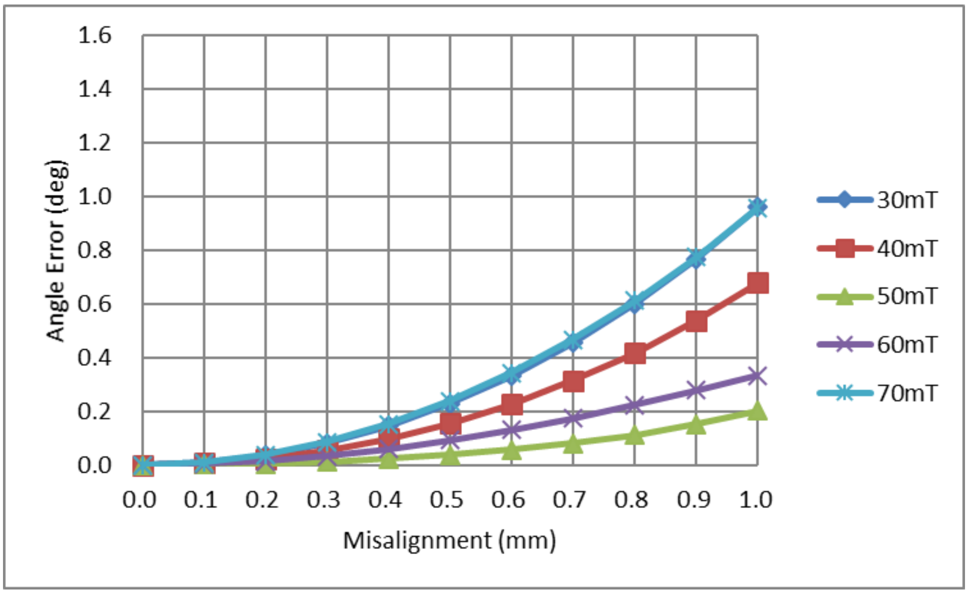

Figure 9. Misalignment vs Angle Error

Tendency on angle error due to misalignment differs depending on the sensor position (Gap). With the recommended magnet, the sensor position for 50 mT has the smallest angle error which is about 0.2 degrees even if the misalignment is 1.0 mm.

Angle vs Angle Error

With a recommended magnet at the position (0, 0, 1.7) where the recommended value of the detected magnetic field (50 mT) is applied under room temperature conditions, the angle error with respect to the angle when there is 0 mm, 0.5 mm or 1.0 mm misalignment is plotted.

The angle error varies in form of sin2θ with respect to the angle when there is a misalignment that is shown in the lower right figure.

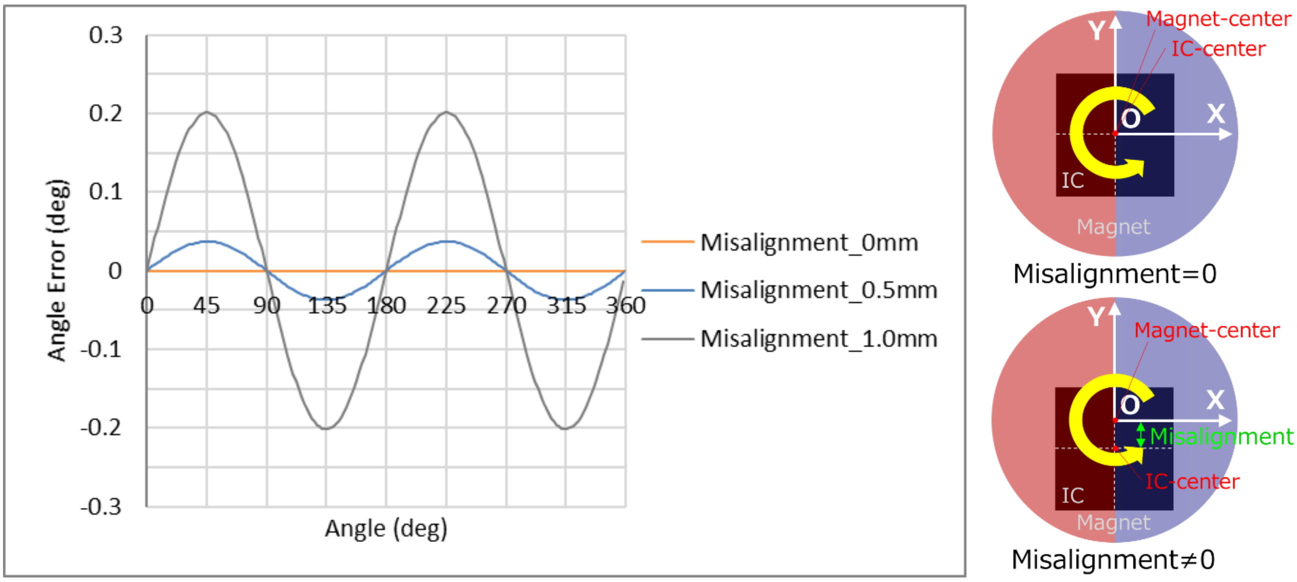

Figure 10. Angle vs Angle Error (misalignment: 0mm/0.5mm/1.0mm)

4. Case of Changing Magnet Size (Outer Diameter)

In this chapter, how the sensor installation position changes and the angle error with respect to misalignment changes when the outer diameter of the magnet is changed to Φ6 mm and Φ10 mm while keeping the height of the recommended magnet (height: 1 mm; outer diameter Φ: 8 mm) unchanged. The verification conditions are summarized below.

[Conditions**]**
Magnet Shape: Disk, Outer Diameter Φ: 6 mm, 8 mm or 10 mm; Height: 1 mm
Magnetization Direction: Diametral
Number of Pole: 2 Poles
Material Characteristics: Sintered Neodymium Magnet (N35)
(Residual magnetic flux density “Br” = 1.21 T, Coercive force “Hcb” = 859 kA/m)
Ambient Temperature: Room temperature
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Gap vs MAG

The MAG with respect to the gap is plotted as shown below. Arrows indicate the possible range of sensor installation position. The larger the outer diameter of the magnet, the wider the installation range. The sensor position which is applied 50 mT recommended value of the detected magnetic field for each magnet is as follows.

Magnet Type	Sensor Position (50 mT)
Outer Diameter Φ: 6 mm	(0, 0, 1.8)
Outer Diameter Φ: 8 mm*	(0, 0, 1.7)
Outer Diameter Φ: 10 mm	(0, 0, 1.3)

* Recommended Magnet

The larger the outer diameter of the magnet, the smaller the recommended gap of sensor position.

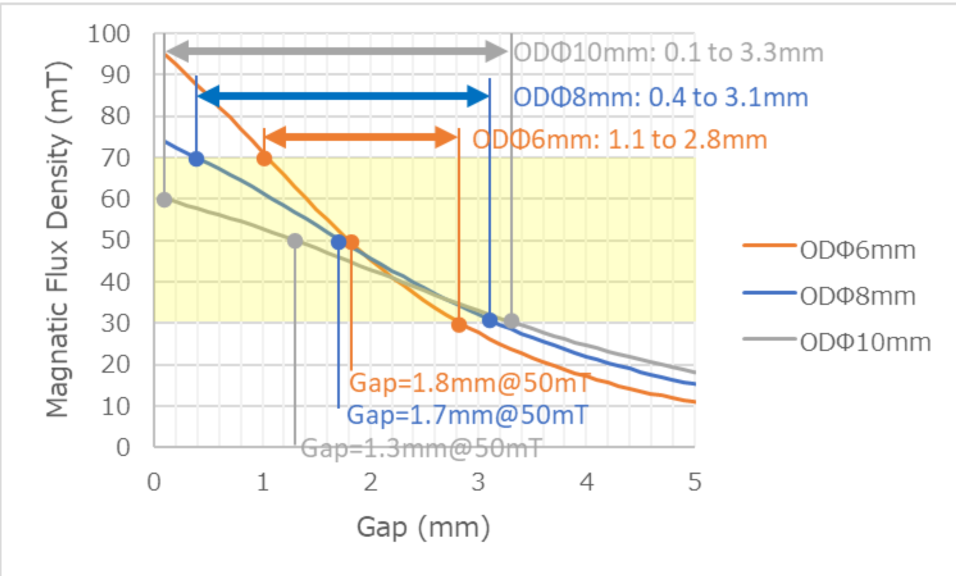

Figure 11. Gap vs MAG (with different outer diameter of the magnet)

Misalighment vs Angle Error

When the magnets with different outer diameters are used in the recommended arrangement (MAG: 50 mT), the angle error with respect to the misalignment is plotted. The angle error caused by the misalignment depends on the outer diameter of the magnet.

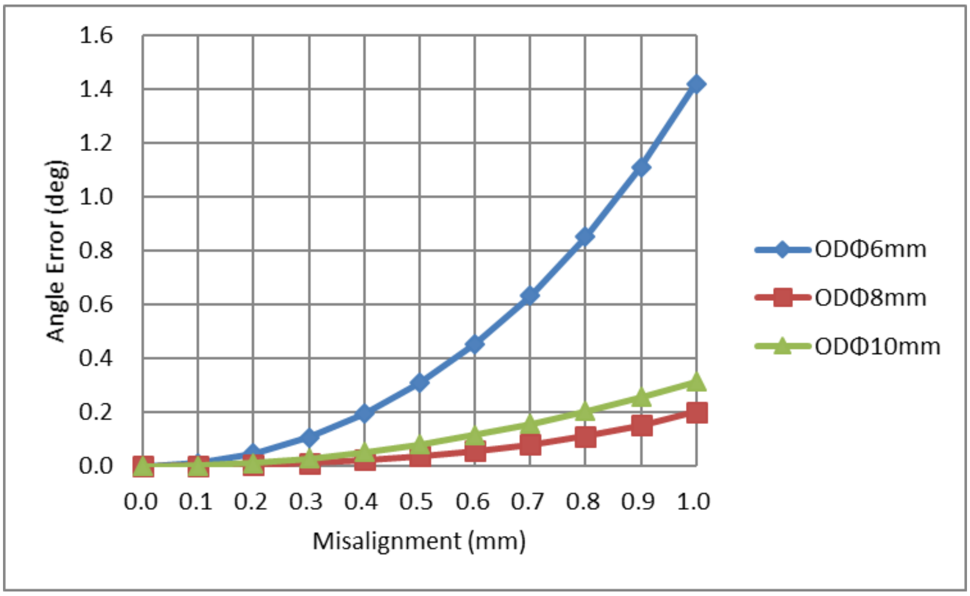

Figure 12. Misalignment vs Angle Error (with different outer diameter of the magnet)

5. Case of Changing Magnet Size (Height)

In this chapter, how the sensor position changes and the angle error with respect to misalignment when the height of the magnet is changed to 2 mm and 3 mm while keeping the outer diameter the recommended magnet (height: 1 mm; outer diameter Φ: 8 mm) unchanged. The verification conditions are summarized below.

[Conditions]
Magnet Shape: Disk, Outer Diameter Φ: 8 mm; Height: 1 mm, 2 mm or 3 mm
Magnetization Direction: Diametral
Number of Pole: 2 Poles
Material Characteristics: Sintered Neodymium Magnet (N35)
(Residual magnetic flux density “Br” = 1.21 T, Coercive force “Hcb” = 859 kA/m)
Ambient Temperature: Room temperature
++

Gap vs Maximum Magnetical Flux Density

Arrows indicate the possible range of sensor installation position. When using each magnet, the sensor installation position which is applied 50 mT recommended value of the detected magnetic field is as follows.

Magnet Type	Sensor Position (50 mT)
Height: 1 mm*	(0, 0, 1.7)
Height: 2 mm	(0, 0, 3.2)
Height: 3 mm	(0, 0, 3.8)

* Recommended Magnet

The thicker magnet, the larger the Gap of recommended sensor position.

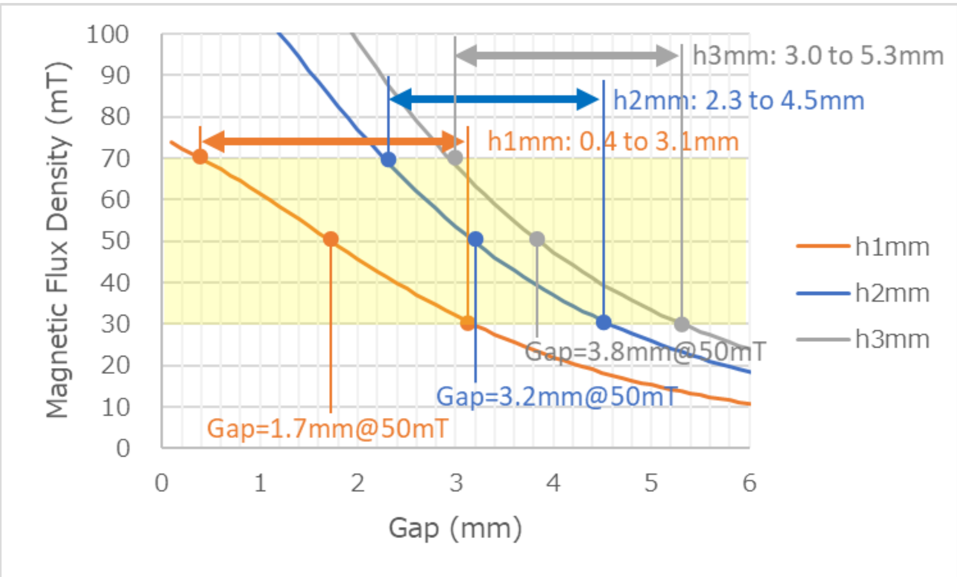

Figure 13. Gap vs MAG (with different height of the magnet)

Misalighment vs Angle Error

The angle error with respect to misalignment for each magnet is plotted in the figure below.

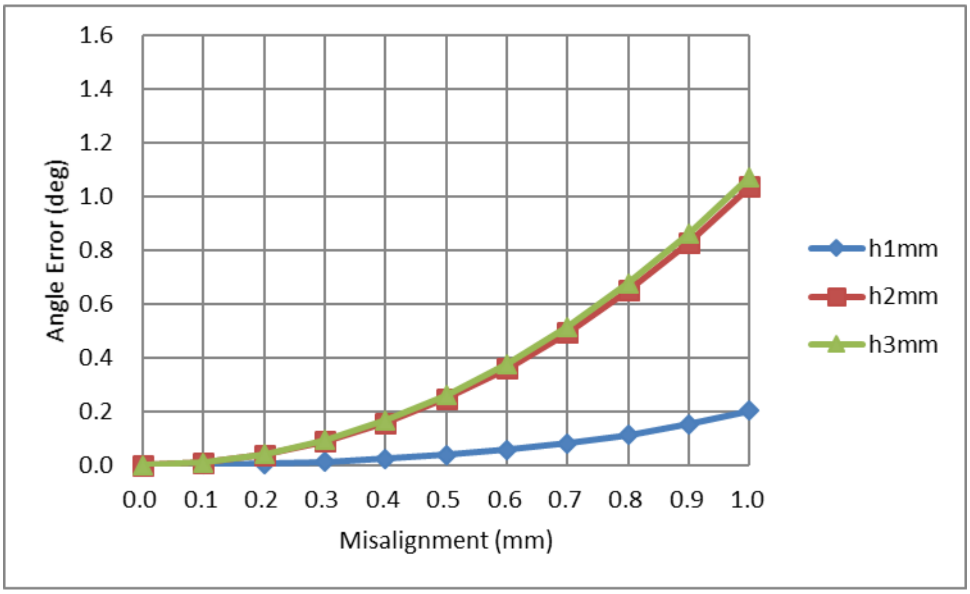

Figure 14. Misalignment vs Angle Error (with different height of the magnet)

Misalighment vs Angle Error (Out of Recommended Position)

The angle error with respect to the misalignment for each of 30 mT, 40 mT, 50 mT, 60 mT, and 70 mT is plotted for the two types of magnets with different height (1 mm and 2 mm). The tolerance to misalignment (angle error) depends on MAG applied, that is, the sensor position. The tendency of the variation depends on the height of the magnet. Comparing these results, the magnet with 2 mm height has less influence on the angle error caused by the misalignment of the Gap (Z position).

Height: 1 mm

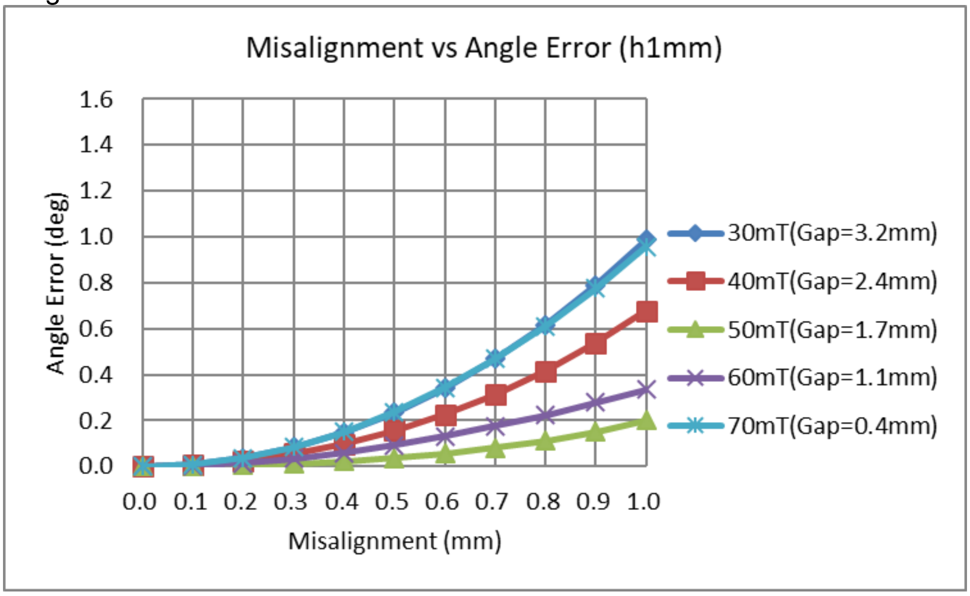

Figure 15. Misalignment vs Angle Error (Height: 1 mm)

Height: 2 mm

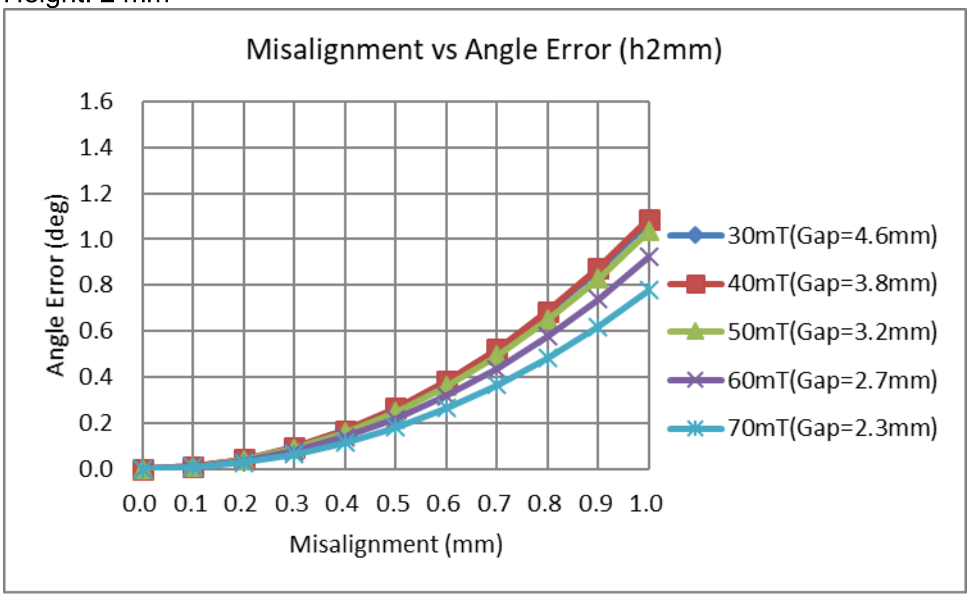

Figure 16. Misalignment vs Angle Error (Height: 2 mm)

6. Case of Ring Magnet

In this chapter, an example of the layout in which the IC is inserted inside the ring magnet in Figure 17. The conditions of the magnet are shown below.

[Conditions]
Magnet Shape: Ring, Outer Diameter Φ: 20 mm; Inner Diameter Φ: 12 mm; Height: 3 mm
Magnetization Direction: Diametral
Number of Pole: 2 Poles
Material Characteristics: Sintered Neodymium Magnet (N35)
(Residual magnetic flux density "Br" = 1.21 T, Coercive force "Hcb" = 859 kA/m)
Ambient Temperature: Room temperature

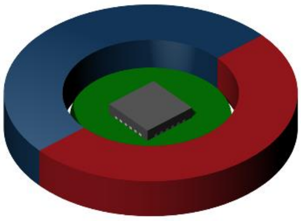

Figure 17. Example configuration with ring magnet

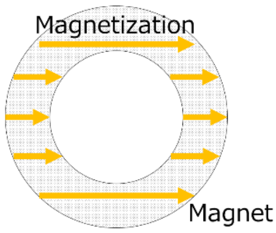

Figure 18. Magnetization

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Gap vs Maximum Magnetical Flux Density (Sensor installation position)

The definition of the Gap is the same as above, referring to the distance from the magnet surface to the sensor. Gap = 0 mm is the magnet surface, and Gap = -1.5 mm is the center of magnet height.

In the case of a ring magnet, a positive magnetic field is applied from the inner circumference of the magnet to the vicinity of the magnet surface (Zone A) under the influence of the magnetic field generated on the inner circumference side of the magnet.
The magnetic flux density is canceled at the point where the direction of the magnet field on the outer circumferential side is opposite to that of the inner circumferential magnetic field and magnetic flux density is 0 mT at the point (Point B). The area further away from the magnet surface, a negative magnetic field is applied (Zone C).

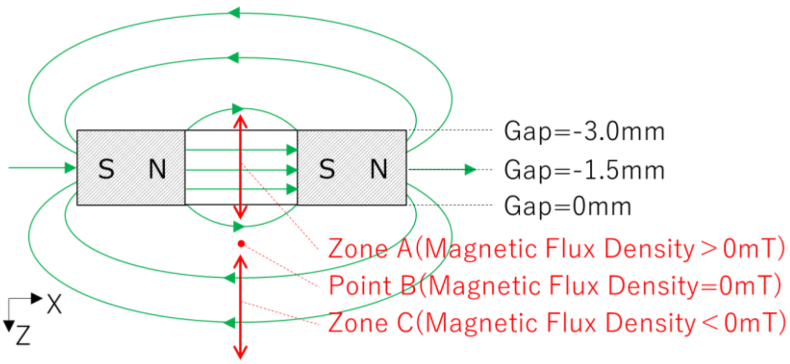

Figure 19. Magnetic Field of Ring Magnet

Arrow indicates the possible range of sensor installation position. The sensor position for the recommended detected magnetic field value (50 mT), is as follows.

Magnet Type	Sensor Position
Recommended Position (50 mT)	(0, 0, -2.5) (0, 0, -0.5)

There are two recommended sensor positions. However, they are located symmetrically with respect to the center of magnet height, and the characteristics will be same at these points.

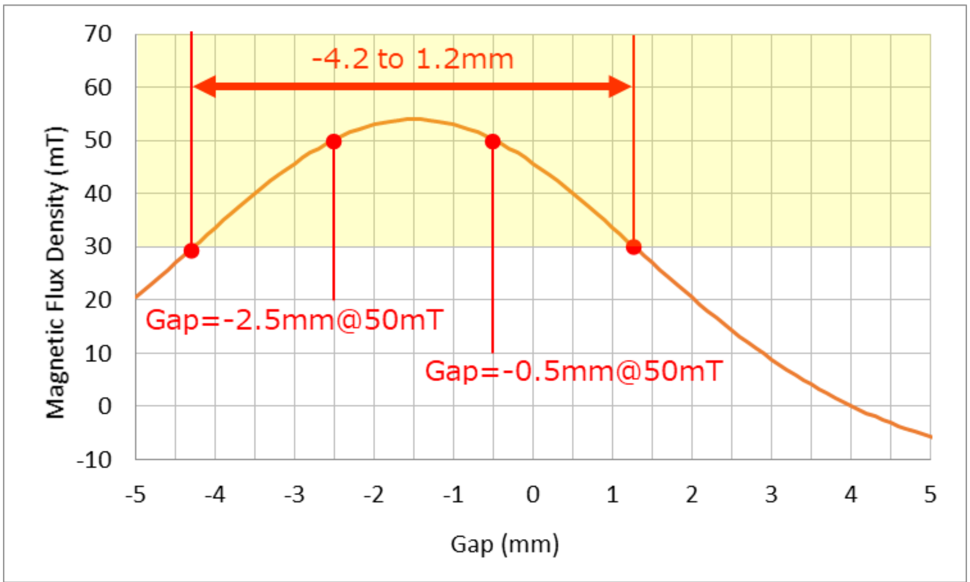

Figure 20. Gap vs MAG (Ring Magnet)

Misalighment vs Angle Error

The angle error with respect to misalignment is plotted below.

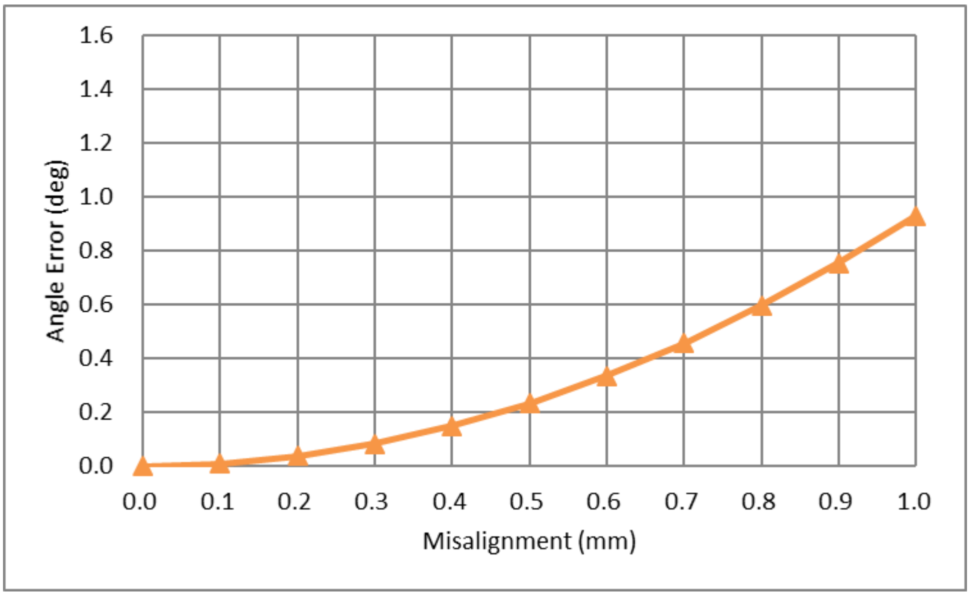

Figure 21. Misalignment vs Angle Error (Ring Magnet)

7. Case of Changing Magnet Material

This chapter introduces an example of a sintered ferrite magnet that can be used.
The verification conditions are summarized below. The sintered ferrite magnet verified in this chapter is not the same size as the recommended magnet.
This is because magnetic flux density is small of a sintered ferrite magnet that has ferrite magnet size (Outer Diameter Φ: 8 mm; Height: 4 mm) is used.

[Conditions]
Magnet Shape: Disk, Outer Diameter Φ: 8 mm; Height: 4 mm
Magnetization Direction: Diametral
Number of Pole: 2 Poles
Material Characteristics: Sintered Ferrite Magnet
(Residual magnetic flux density “Br” = 0.4 T, Coercive force “Hcb” = 261.5 kA/m)
Ambient Temperature: Room temperature
++

Gap vs Magnetic Flux Density

Arrows indicate the possible range of sensor installation position. For comparison, the case of the recommended neodymium magnet (outer diameter: 8 mm, height: 1 mm) is also plotted.

It is necessary to increase the magnet size to ensure the magnetic field necessary for detection since the magnetic force of ferrite magnet is weak. However, there is a case that the encoder system can be thinner when using a ferrite magnet because the sensor can be placed closer to the magnet than when using neodymium magnet.

The sensor position for the recommended magnetic flux density (50 mT) is shown below.

Type of Magnet	Sensor Position (50 mT)
Sintered Neodymium Magnet (N35) (Outer Diameter Φ: 8 mm, Height: 1 mm) *	(0, 0, 1.7)
Sintered Ferrite Magnet (Outer Diameter Φ: 8 mm, Height: 4 mm)	(0, 0, 1.1)

* Recommended Magnet

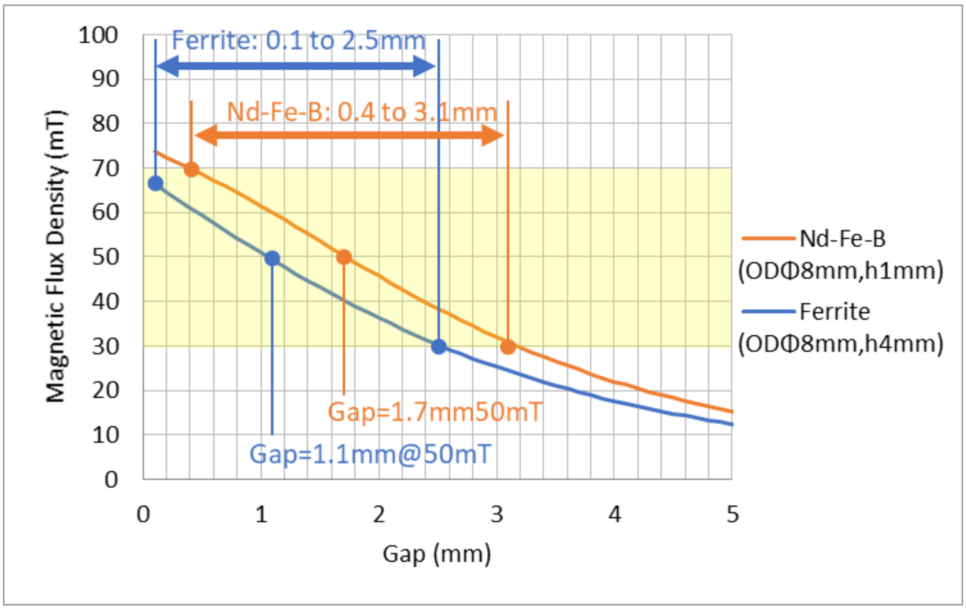

Figure 22. Gap vs Maximum Magnet Flux Density (Sintered ferrite magnet and recommended magnet)

Misalighment vs Angle Error

The angle error with respect to the misalignment when MAG is 50 mT is plotted below.

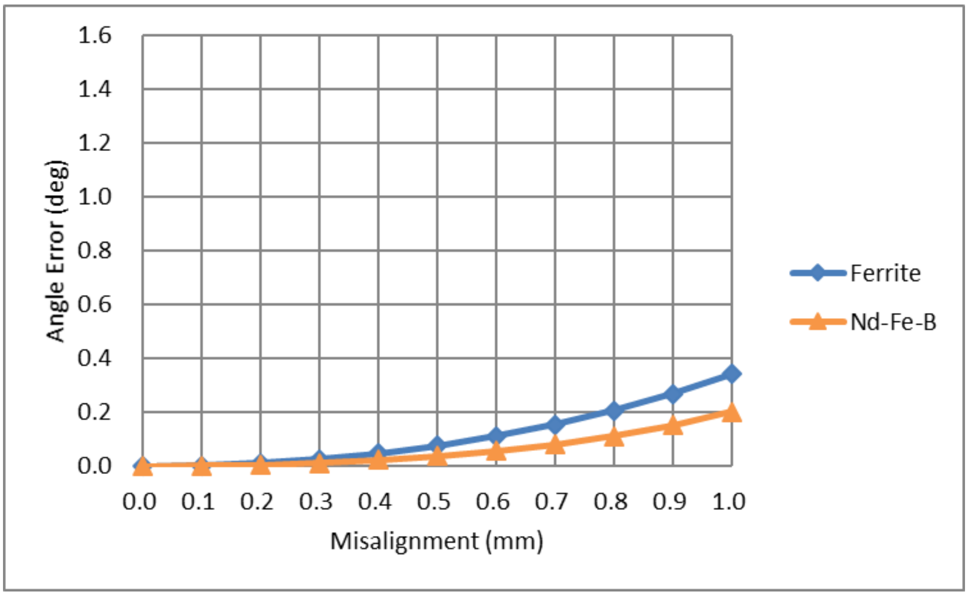

Figure 23. Misalignment vs Angle Error (Sintered ferrite magnet and recommended magnet)

8. Summary

Verified results in the previous chapters are summarized below.

Magnet Conditions				Possible range of sensor installation position (Gap*1)	Recommended Position *2	Angle Error *3 Unit: deg	Page Number
Shape	Outer Diameter / Inner Diameter	Height	Material				
Disk	8 / -	1	Neodymium	0.4 ~ 3.1	(0, 0, 1.7)	0.04	5
	6 / -	1		1.1 ~ 2.8	(0, 0, 1.8)	0.31	8
	10 / -	1		0.1 ~ 3.3	(0, 0, 1.3)	0.08	8
	8 / -	2		2.3 ~ 4.5	(0, 0, 3.2)	0.25	10
	8 / -	3		3.0 ~ 5.3	(0, 0, 3.8)	0.26	10
Ring	20 / 12	3		-4.2 ~ 1.2*4	(0, 0, -2.5) (0, 0, -0.5)	0.23	14
Disk	8 / -	4	Ferrite	0.1 ~ 2.5	(0, 0, 1.1)	0.08	15

*1. It refers to the distance from the magnet surface to the sensor.
*2. The center point of the magnet which is on the magnet surface of sensor side is defined as (0, 0, 0) position.
*3. Angle error caused by axis misalignment when the misalignment is 0.5 mm and the sensor is located at the recommended position.
*4. This is a configuration that the sensor IC is located inside the ring magnet.
*5. Ambient temperature is assuming room temperature.

9. APPENDIX

This chapter introduces the sensor position which is applied 50 mT recommended value in the case that the outer diameter and height is changed (Outer Diameter:Φ3 to 10 mm, Height: 1 to 5 mm).

[Conditions]
Magnet Shape: Disk, Outer Diameter Φ: 8 mm; Height: 4 mm
Magnetization Direction: Diametral
Number of Pole: 2 Poles
Material Characteristics: Sintered Ferrite Magnet (N35)
(Residual magnetic flux density “Br” = 1.21 T, Coercive force “Hcb” = 859 kA/m)
Ambient Temperature: Room temperature
++

Recommended position (Gap) of each magnet is shown below. The sensor position differs for each product. Please refer to the datasheet of each product about the sensor position.

		Outer diameter (mm)							
		3	4	5	6	7	8	9	10
Height (mm)	1	1.4	1.6	1.7	1.8	1.8	1.7	1.6	1.3
	2	1.7	2.1	2.5	2.7	3.0	3.2	3.3	3.5
	3	1.9	2.4	2.8	3.2	3.5	3.8	4.1	4.4
	4	2.0	2.5	3.0	3.5	3.9	4.3	4.6	4.9
	5	2.0	2.6	3.1	3.6	4.1	4.5	4.9	5.3

unit: mm

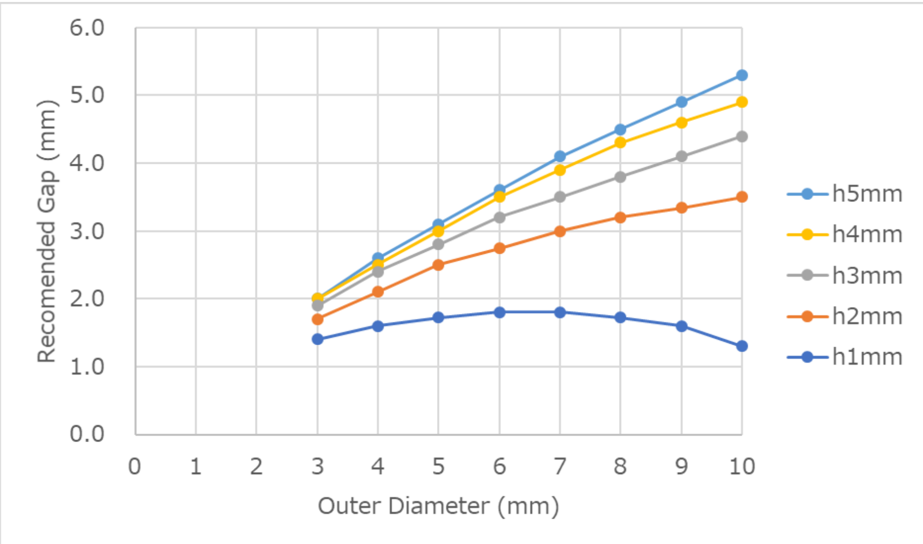

Figure 24. Outer diameter of magnet vs Recommended Gap

10. Revision History

Date (Y/M/D)	Revision	Reason	Page	Contents
2019/01/07	00	First Edition	17	
2019/03/14	01		19	Added definition of MAG. Added table data of magnet size and recommended arrangement.
2019/06/16	02		19	Modification of graph legend
2019/10/16	03		2~19	Change the term from “*Maximum magnetic flux density”* to “*MAG”*

Important Notice:

The data in this document is based on simulation, and there is no guarantee of reproducibility with actual magnets. Please use them as reference data for magnet selection.

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