Robust, accurate and stray field immune angle detection with Absolute Magnetics Encoder Technology

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Abstract: This paper investigates the performance of Absolute Magnetics' patented encoder technology in real-world scenarios, focusing on its ability to maintain reliable angle sensing despite misalignment and magnetic stray fields. Several tests were conducted to evaluate the system's robustness under these challenging conditions. The benefits of an integrated encoder solution compared to conventional external encoders are discussed. Finally, the paper examines the advantage of using the Absolute Magnetics Encoder without the need for calibration.

1. The Absolute Magnetics Encoder Technology

Absolute Magnetics invented a new technology for rotary position sensing.
The here described magnetic encoder system consists of two parts: A magnet with a unique, multi-periodic magnetization pattern and corresponding electronics for data processing.
Signal acquisition is done on only 1 single magnetic track (see figure 1). This differentiates the Absolute Magnetics Technology from the Nonius / vernier principle, which uses 2 magnetic tracks for data acquisition. Multiple magnetizations with different periods are intentionally superposed, which brings advantages in terms of robustness of the encoder. When it comes to air gap changes and eccentricity, there is no need to "avoid interference of different magnetic tracks" as with the Nonius / vernier principle.

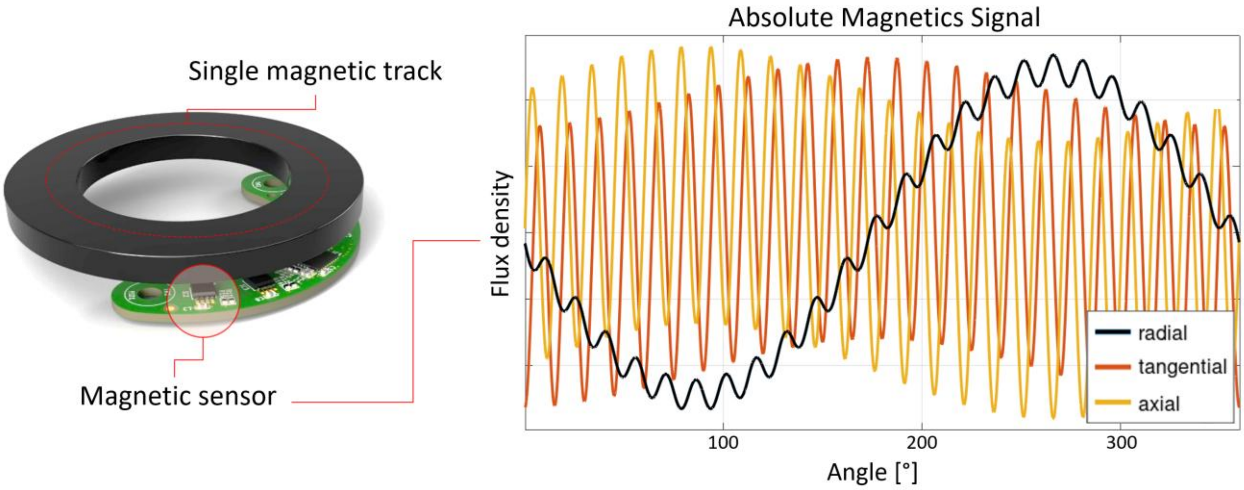

Figure 1: The multi-periodic magnetic signal in 3 axes: Radial (black), tangential (red) and axial (orange), acquired on only 1 single measurement track.

The processing algorithm allows to simultaneously calculate a "global position" on the complete mechanical turn, as well as a "local position" within each magnetic increment. The global position is responsible for making the encoder an absolute position sensor and the local position enables high accuracy.

2. Integrated Encoder Solution

Space is a valuable good in today's world. Almost every application is optimized for small installation space. This goes down to the component level and leads to the question: How to save space with the encoder solution?
Figure 2 on the right shows the concept of an integrated encoder solution in an electric motor. This concept can help to optimize installation space and use synergies in combination with the overall motor assembly.

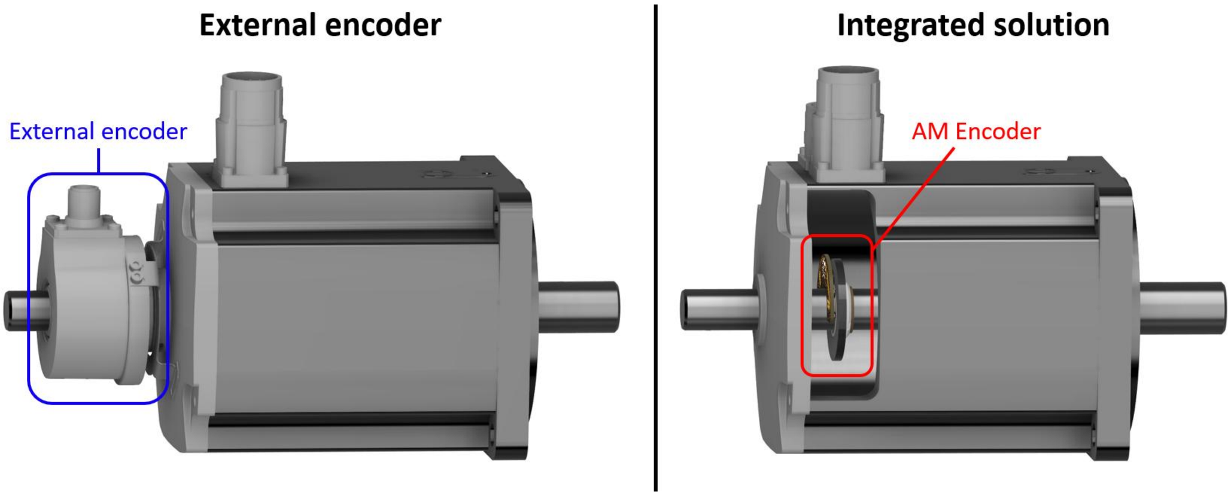

Figure 2: The concept of an external encoder (left) compared to an integrated encoder solution (right)

Benefits of an integrated encoder solution
The goal when designing an encoder solution is to bring added value to the overall system in which it is integrated. It is therefore necessary to consider the encoder in the context of e.g. the overall drive unit, and not as a stand-alone part. Some of the synergies that can be used with an integrated encoder solution are described in this section.

Bearing:
The rotating part of the Absolute Magnetics Encoder consists of a magnet, a metallic sleeve and an overmolding (see figure 3). Like this the magnet-assembly can be directly attached to motor-shaft by press-fit. There is no need for an additional encoder bearing, which leads to fewer components in the overall system and therefore decreased overall costs.

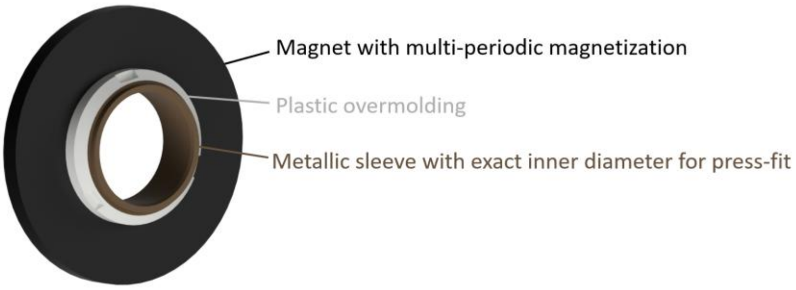

Figure 3: Magnet assembly of the Absolute Magnetics Encoder

Housing:
With an integrated solution, the encoder is encapsulated in the motor housing. There is no need for a separate encoder housing.

Space:
Fewer system parts do not only have an advantage in terms of price, also the installation space can be decreased. With the right design, the encoder will reduce the overall size of the drive unit.

Design:
Whereas an external encoder is a part which can be used for different applications without design change, an integrated encoder solution needs to be tailored to embed in the specific application.

An important prerequisite to enable an integrated encoder solution is the robustness in presence of magnetic stray-fields. This topic is discussed in chapter 4 of this paper.

3. General Performance

The Absolute Magnetics Encoder can be used in different settings (more details in section 6):

- Without any kind of calibration
- With optional factory calibration

The accuracy without any calibration is less than 0.5°. By factory calibration the accuracy can be decreased to less than 0.1°.

The current version of the Absolute Magnetics Encoder was tested with speeds up to 7’500 rpm. To reach higher speeds, the measurement of magnetic fields was changed from digital hall probes to analogue hall probes. This new electronics design with analogue hall probes ensures that there is no loss of performance at higher speeds. The limiting factor for high-speed applications is the mechanical stability of the magnet. Tests with speeds above 20’000 rpm in a real-world setup are planned soon.

The test setup for the measurements discussed in chapters 4 and 5 (stray field immunity and misalignment) is shown in figure 4. The Absolute Magnetics (AM) Encoder is placed on the same shaft as a precise reference encoder. The whole shaft is turned using a stepper motor and data is analyzed using a dedicated software tool.

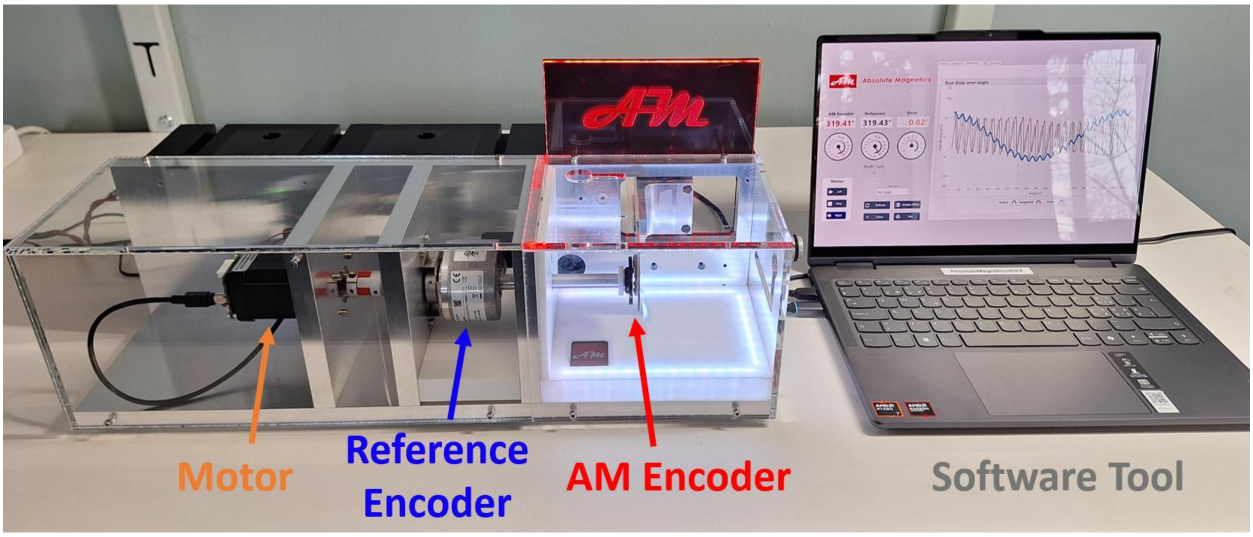

Figure 4: Test setup for stray-field and misalignment tests (chapter 4 and 5)

4. Stray field immunity

Magnetic stray fields are an important topic in a lot of applications where encoders are used. There are various sources of magnetic fields which can potentially influence magnetic encoders.
In an electric motor, there can be strong magnetic fields coming from rotating permanent magnets or from stator windings. With an integrated encoder solution as shown in figure 2, the position of the encoder is closer to the sources of magnetic stray fields. The encoder is therefore exposed to stronger stray fields compared to solutions with an external encoder. This means that robustness to magnetic stray fields is a key requirement for encoders used with an integrated solution.
Other common sources of magnetic stray fields can be high-current cables or magnetic clutches and brakes.

The Absolute Magnetics Technology is robust against static and dynamic stray fields.
The reason for this is the processing algorithm, which removes the influence of stray fields for the resulting angle value.

4.1 Robustness to dynamic stray fields

To simulate a dynamic external stray field, a test with two neodymium magnets as source of stray fields was set up. The magnets were placed in direct proximity to the encoder, so that the magnetic field measured by the hall probes of the encoder electronics was influenced (see test setup in figure 5).
The test was done without a rotating encoder magnet to see the influence of the stray field directly in the raw data of the encoder hall probes. For the few seconds in which the test was conducted, the magnets were moved around in order to have a dynamic stray field over time.

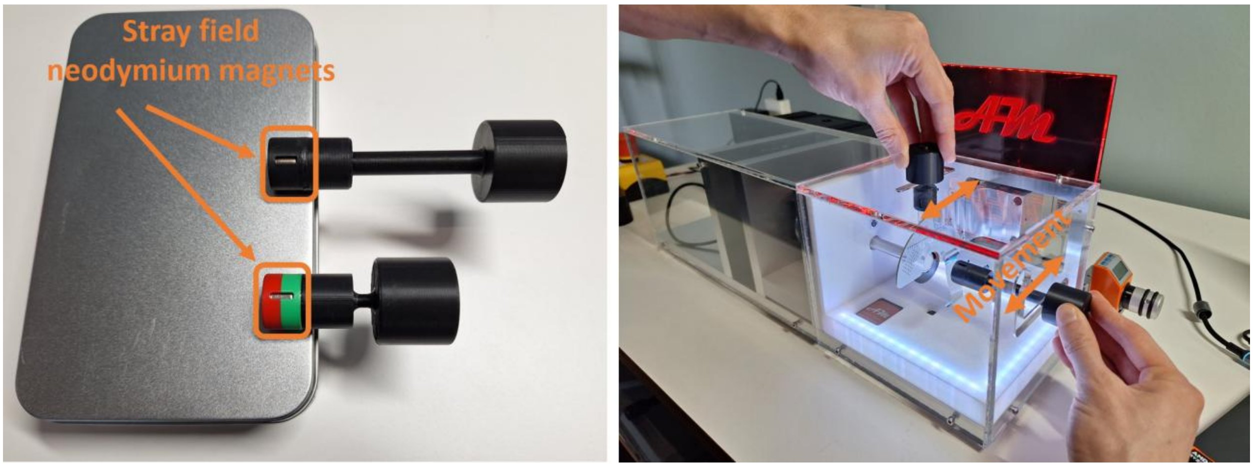

Figure 5: Stray field magnets (left) and dynamic stray field test (right)

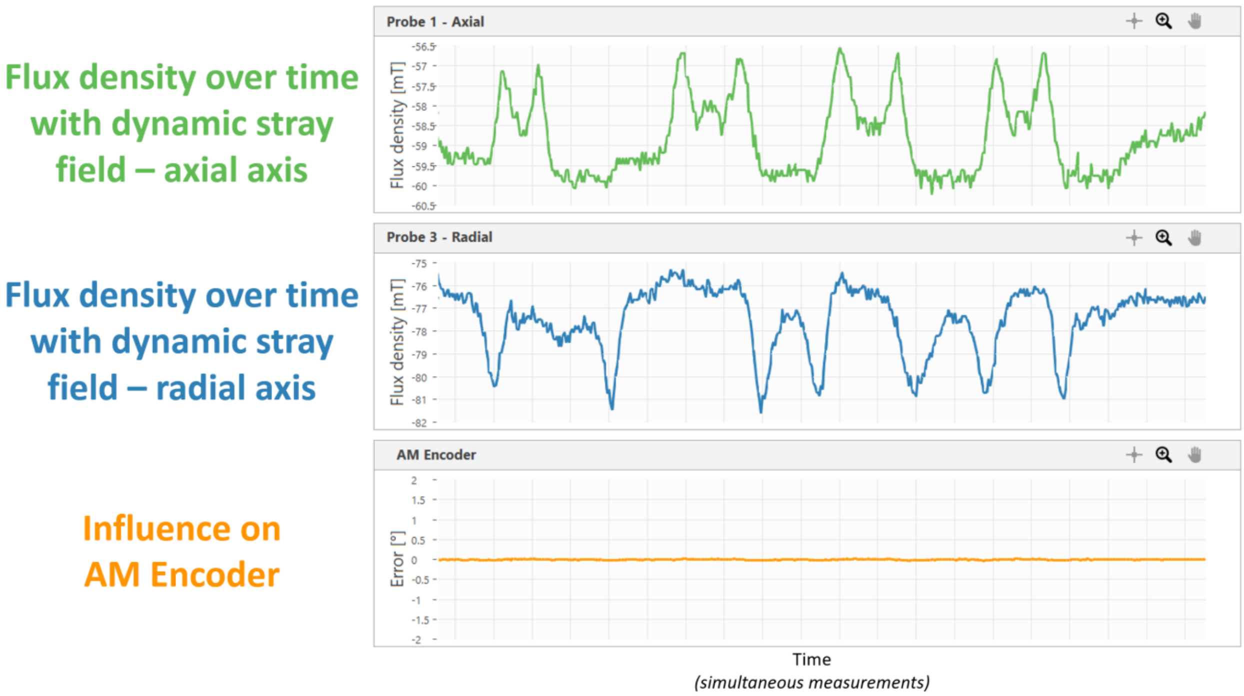

Figure 6: The result of the test with dynamic stray fields: The performance of the AM Encoder (orange line) was not influenced

The result of the stray field test is shown in figure 6. The green line on top visualizes the raw data of the hall probe measuring the axial axis. The blue line in the middle shows the flux density over time from the hall probe measuring the radial axis. In both graphs a clear influence of the stray field magnets is visible. In both axes, a stray field of about 5 mT can be seen in the raw data.
The orange line at the bottom of figure 6 shows the angle error of the Absolute Magnetics Encoder. It shows clearly that the angle error stays constant, which means it is not influenced by the big magnetic stray field applied during the test.
This test shows the robustness of the Absolute Magnetics Encoder to external magnetic stray fields.

5. Misalignment in real-world test setup

To test the robustness of the Absolute Magnetics Encoder against misalignment, several measurements in different misaligned positions were carried out.
Figure 7 describes the setup for the test. The electronics board was moved on the “sidewards” and the “up / down” axis in steps of 0.2 mm. In both axes misalignment of ±1 mm was tested in an uncalibrated setup.

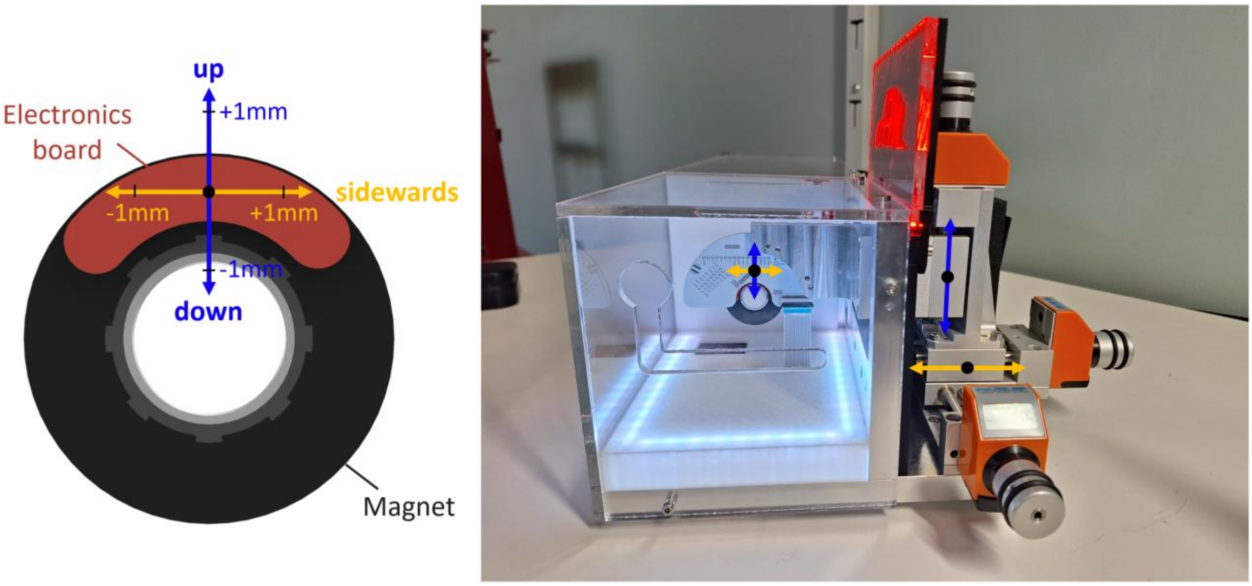

Figure 7: Test for misalignment. The electronics board was moved ±1 mm up / down and sidewards

Table 1 and figure 8 show the results for misalignment on the sidewards axis. Even big misalignments in both directions do not significantly increase the error of the Absolute Magnetics Encoder. For all misalignments of 1 mm or less on the sidewards axis, the increase of the error span is less than 0.2°.

Misalignment sidewards	-1.0 mm	-0.8 mm	-0.6 mm	-0.4 mm	-0.2 mm	0.0 mm	0.2 mm	0.4 mm	0.6 mm	0.8 mm	1.0 mm
Error increase (span)	0.17°	0.14°	0.09°	0.05°	0.03°	0.00°	0.03°	0.05°	0.10°	0.13°	0.17°

Table 1: Test results for misalignment on sidewards axis

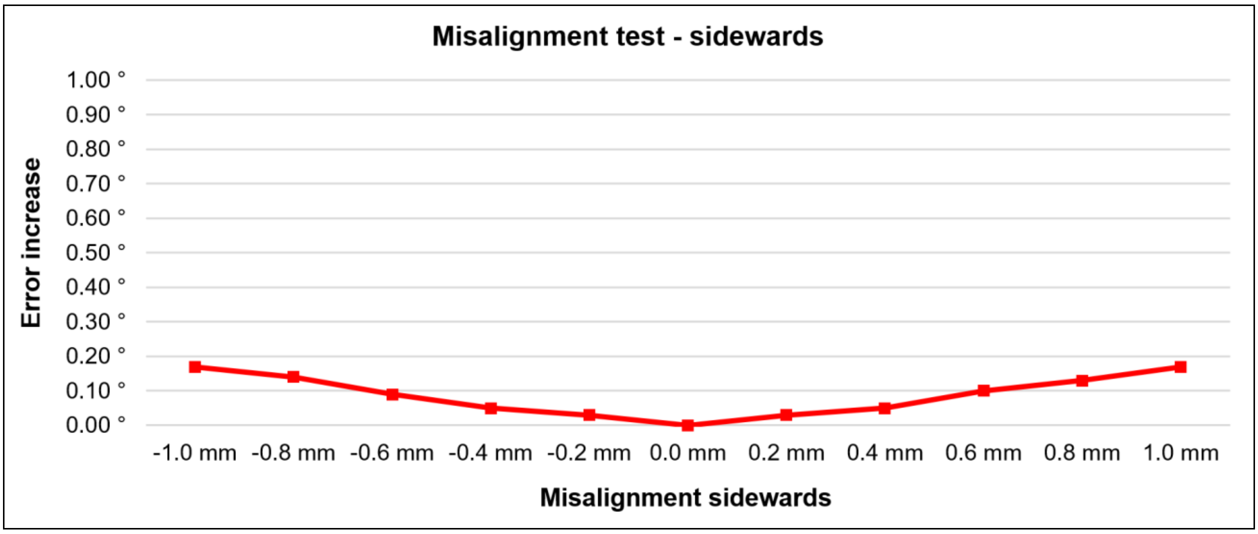

Figure 8: Test results for misalignment on sidewards axis

Table 2 and figure 9 show the results for misalignment on the up / down axis. For positions where the electronics board was moved up, i.e. towards a bigger measurement radius, the misalignment value is positive. For positions where the electronics board was moved down (see figure 7), the misalignment values are negative.
The results of misalignment in the up / down axis show the stability of the Absolute Magnetics Encoder in this axis. All the positions within this measurement range show an increase in error span of less than 0.2°. It could also be shown that the encoder is even more robust in the up direction compared to the down and sidewards directions.

Misalignment up (+) / down (-)	-1.0 mm	-0.8 mm	-0.6 mm	-0.4 mm	-0.2 mm	0.0 mm	0.2 mm	0.4 mm	0.6 mm	0.8 mm	1.0 mm
Error increase (span)	0.18°	0.13°	0.10°	0.07°	0.04°	0.00°	0.01°	0.03°	0.05°	0.07°	0.09°

Table 2: Test results for misalignment on up (+) / down (-) axis

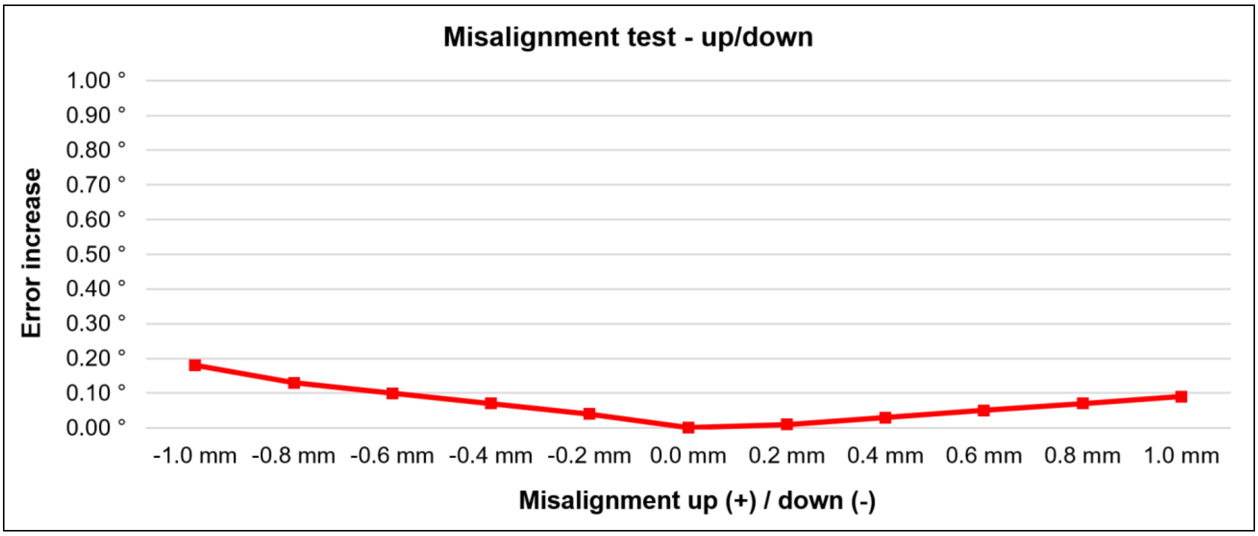

Figure 9: Test results for misalignment on up (+) / down (-) axis

6. No calibration needed

The Absolute Magnetics Encoder reaches an accuracy of less than 0.5° without any calibration. This means that for certain applications the requirements can already be met.
For applications which require a higher accuracy, an optional factory calibration can be made.

The possibility of using an encoder without a calibration process results in various advantages for the overall system:

Simplification of the assembly process:
There is 1 less step in the production line, which means less manufacturing time and cost savings. This is especially true for high-volume projects.

Interchangeable parts in production:
As no calibration is done, there is no specific encoder electronics that matches the encoder magnet.
For production it is not necessary to match the two encoder parts with the same serial number. This leads to a simpler and more cost-effective assembly process.

Interchangeable parts for replacement:
In case one of the two encoder parts gets damaged, only the damaged part can be exchanged.
E.g. if the electronics board gets damaged for an encoder in an electric motor, only the electronics part must be replaced. There is no need for additional effort to care about the magnet replacement on the motor shaft.