SENSITEC
KÖRBER SOLUTIONS

AA700 Family

AMR FreePitch Sensors for Angle and Length Measurement.

Content

1. Introduction

The AA700 sensor familiy is based on the Anisotropic MagnetoResistive (AMR) technology. The AMR effect occurs in ferromagnetic materials and causes a change of the reluctivity as a function of the magnetic field.

AMR sensors of the AA700 family only detect the angle of the applied magnetic field, mainly independant from field strength.

AMR sensors are made in thin layer technology on a wafer. The manufacturing equipment, the clean room ambience and the individual process steps are similar to the CMOS chip production.

By combining a magnetic measurement scale with a sensor of the AA700 family and an evaluation electronics linear and rotative motions can be measured (see Fig. 1.2 to 1.5). The sensors of the AA700 family are not linked to defined pole lengths that is why they are called FreePitch sensors. In this document you will find the description how to configure the measuring system with AA700 sensors for linear and rotational position sensing to obtain high-precision results of measurement.
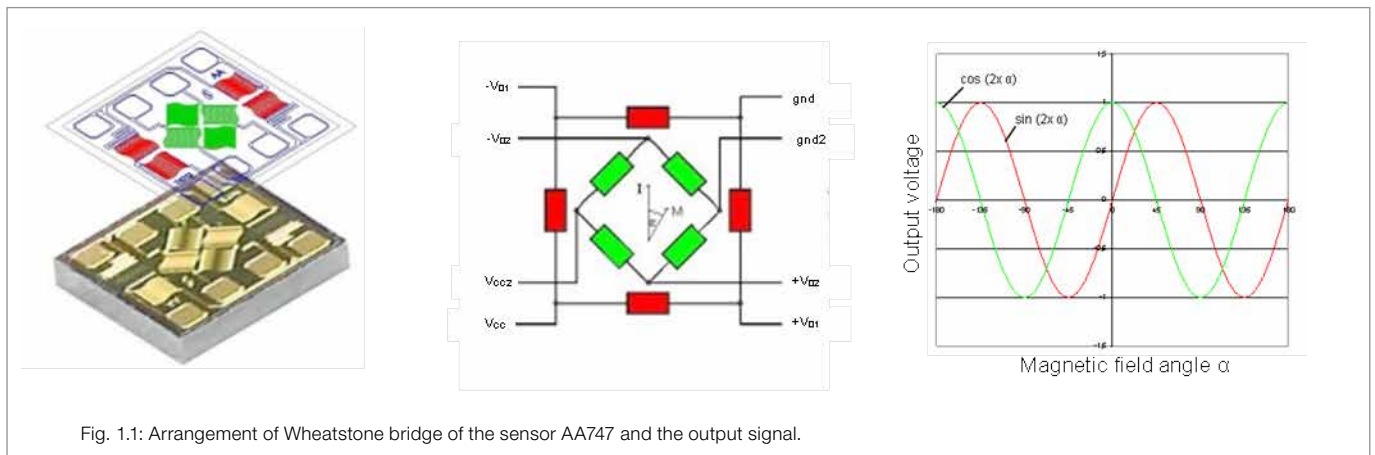

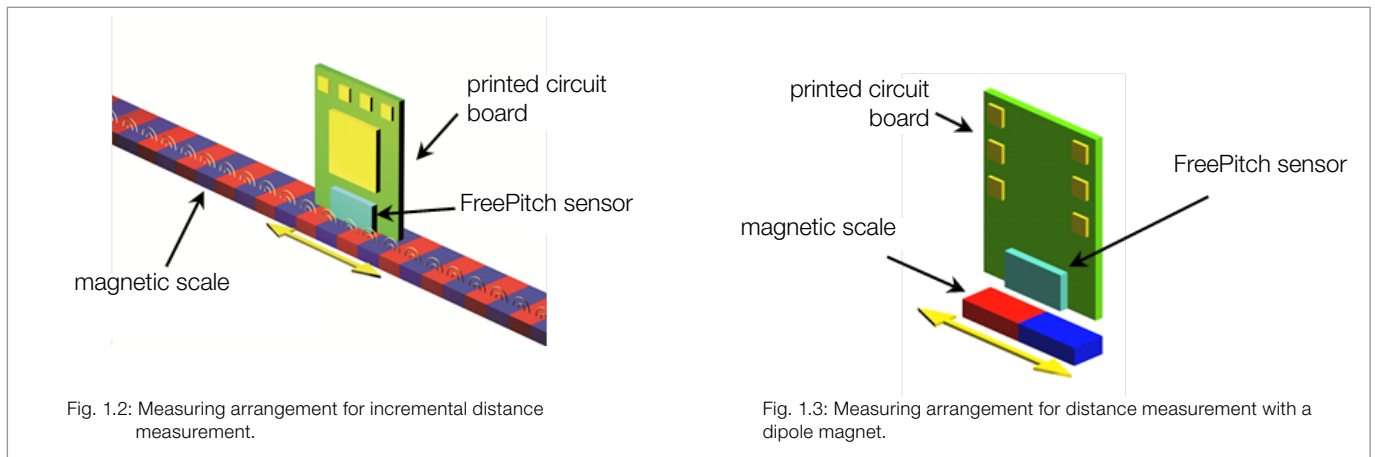Fig. 1.1: Arrangement of Wheatstone bridge of the sensor AA747 and the output signal.

Fig. 1.2: Measuring arrangement for incremental distance measurement.

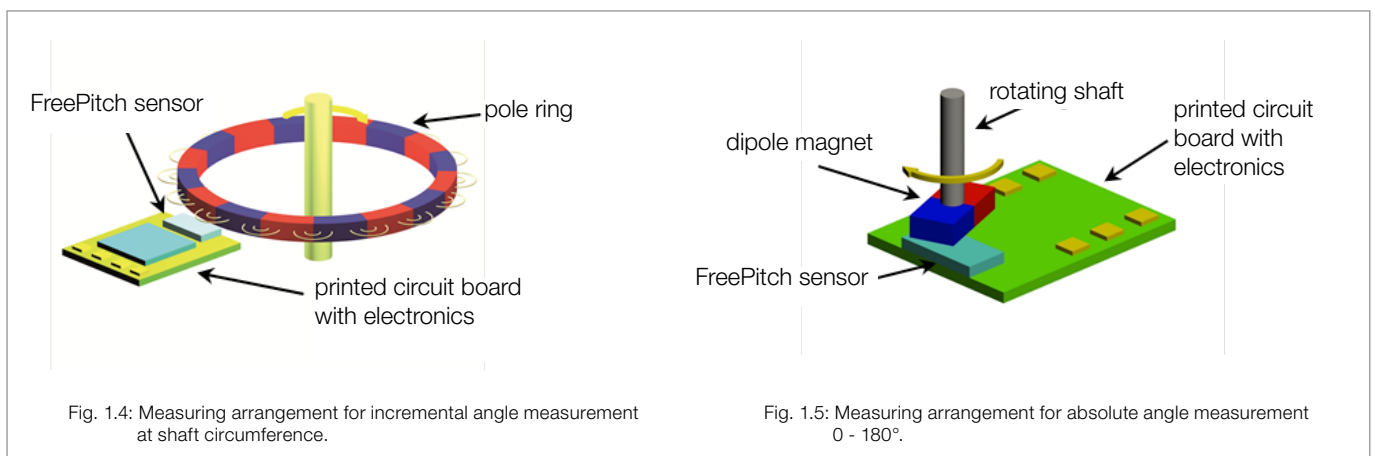Fig. 1.3: Measuring arrangement for distance measurement with a dipole magnet.

Fig. 1.4: Measuring arrangement for incremental angle measurement at shaft circumference.

Fig. 1.5: Measuring arrangement for absolute angle measurement 0 - 180°.

1.1   Advantages of the AMR Technology

Sensitec's AMR technology has significant advantages:

– High resolution

– Small, therefore easy to integrate

– Contact-free and wear-free

– Insensitive to dust, water, oil or other dirt

– Resistant to hits and vibrations

– Low noise, very good signal to noise ratio

– Low power consumption

– High band width

– Resistant to radiation

1.2   Advantages of the AA700 Sensors

The design of the AA700 family is patented and the result of years of experience. The application advantages of that sensor family are:

– Easy system integration and increased reliability due to large air gap

– The high accuracy and resolution allows precise positioning or sensitive rev regulation

– Increased precision of measurements even with simple evaluation circuits due to minimal offset voltage

– Increased system accuracy due to negligible hysteresis

– The low offset temperature coefficient allows the use in a wide temperature range without significant loss of accuracy

– AA700 sensors are qualified for the use within a temperature range of -40 °C to +150 °C and can be so used in many automotive applications

1.3   Applications

– In automotive industry

– Position capture of a throttle body in a combustion motor

– Distance measurement for pedal and wiper

– Angle measurement at steering

– Automatic headlamp levelling

– General position capture at doors, windows, seats, sunroofs a. o.

In industrial sector

– Incremental and absolute angle encoder

– Motor feedback systems

– Industrial robotics

– Mountings and valves

– Power tools

A concrete example for the reliability of Sensitec's AMR sensors is their use as position sensors in Mars robotics drives (Fig. 1.6). The Mars rovers Spirit and Opportunity are driving at the Mars surface since 2003. Thereby they are exposed to radiation and extreme differences in temperature.

Another example is the torque measurement for steering (Fig. 1.7). The sensor of the AA700 family gauges a pole ring. A customized ASIC, which is easy to adjust, is used for the data transfer from sensor to on-board computer (ECU). No additional adjustment is necessary in the end system. There is no mechanical abrasion as the sensor gauges contactless and it is insensitive to dust and oil.

Fig. 1.6: Mars Lander Opportunity: for more than 6 years on mission with MR technology.

Fig. 1.7: Torque measurement for active steering with AA745 sensor.

2. Functional Principle

2.1 The AMR Effect

When electricity runs through a magnetizable conductor the electrical resistance depends on the angle between electricity direction and magnetic field direction. To get the highest electrical resistance the magnetic field and the electricity direction have to be parallel to each other (in the same direction or opponent, see Fig. 2.1).
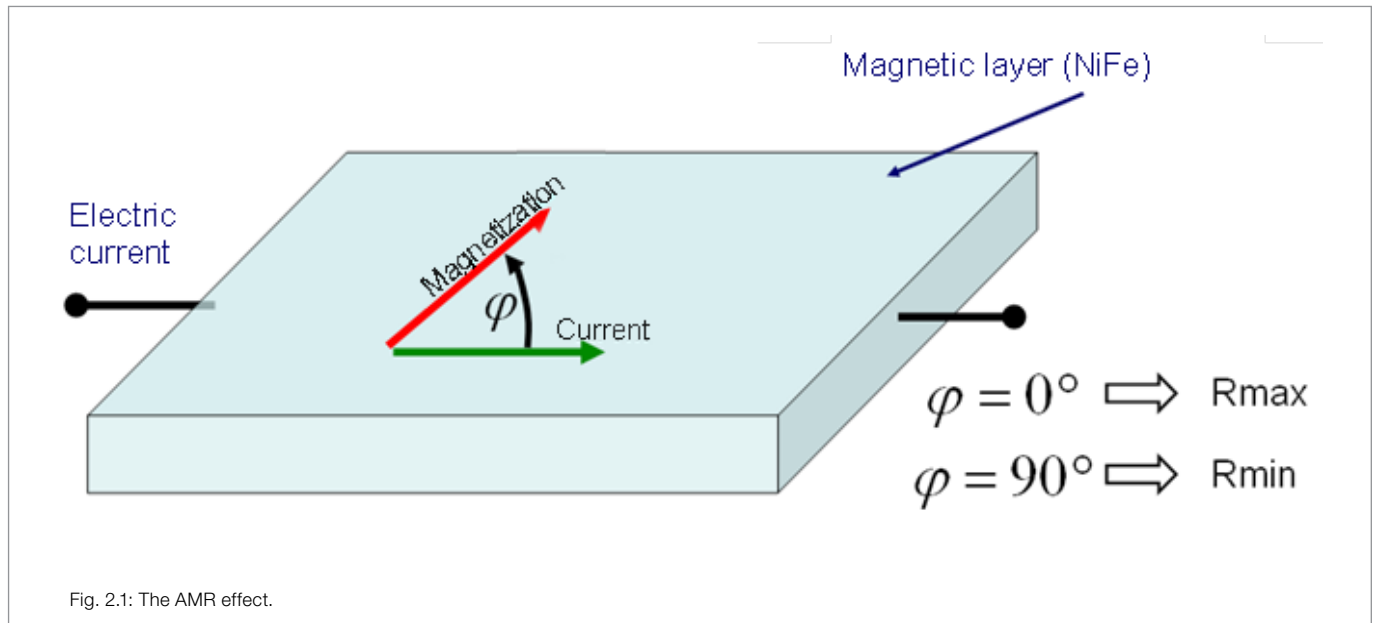

Fig. 2.1: The AMR effect.

This effect is called anisotropic magnetoresistive (AMR) effect and was discovered by William Thomson (Lord Kelvin) in 1857.

The electrical resistance can be specified with the formula (1):

$$R = \frac{R_{max} - R_{min}}{2} + \frac{R_{max} - R_{min}}{2} \times \cos (2\varphi) \dots [2.1]$$

R_{max} and R_{min} are the maximum and minimum resistance of the conductor in the magnetic field (Fig. 2.1). The angle   is the angle between electricity direction and magnetic field. The AMR effect is 2-periodic as a complete sine (or cosine) is run through after a magnetic field rotation of 180° (π rad).

The direction of the magnetization follows in thin layers the magnetization of the external applied magnetic field already at field strengths of a few mT.
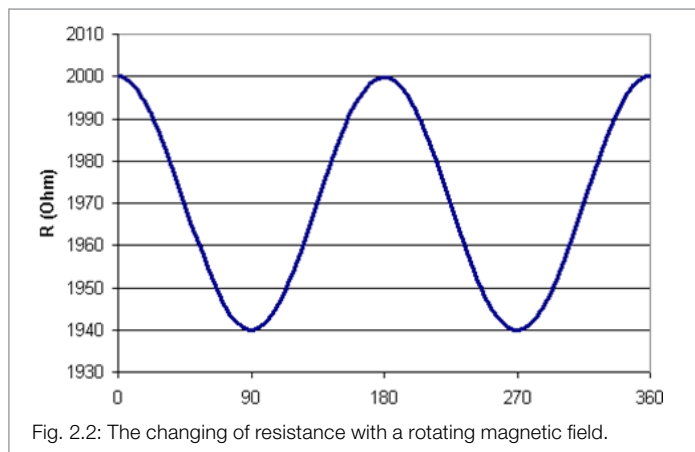

Fig. 2.2: The changing of resistance with a rotating magnetic field.

The changing of resistance with AMR sensors is normally 3 %.

To minimize modifications in test results due to temperature influences the AMR sensors are built as Wheatstone bridges. This configuration is described in the following section.

2.2 The AMR FreePitch Sensors for Length and Angle Measurement

Sensors of the AA700 family detect the angle of a magnetic field via two Wheatstone bridges. At first we consider a single AMR bridge in a magnetic field.
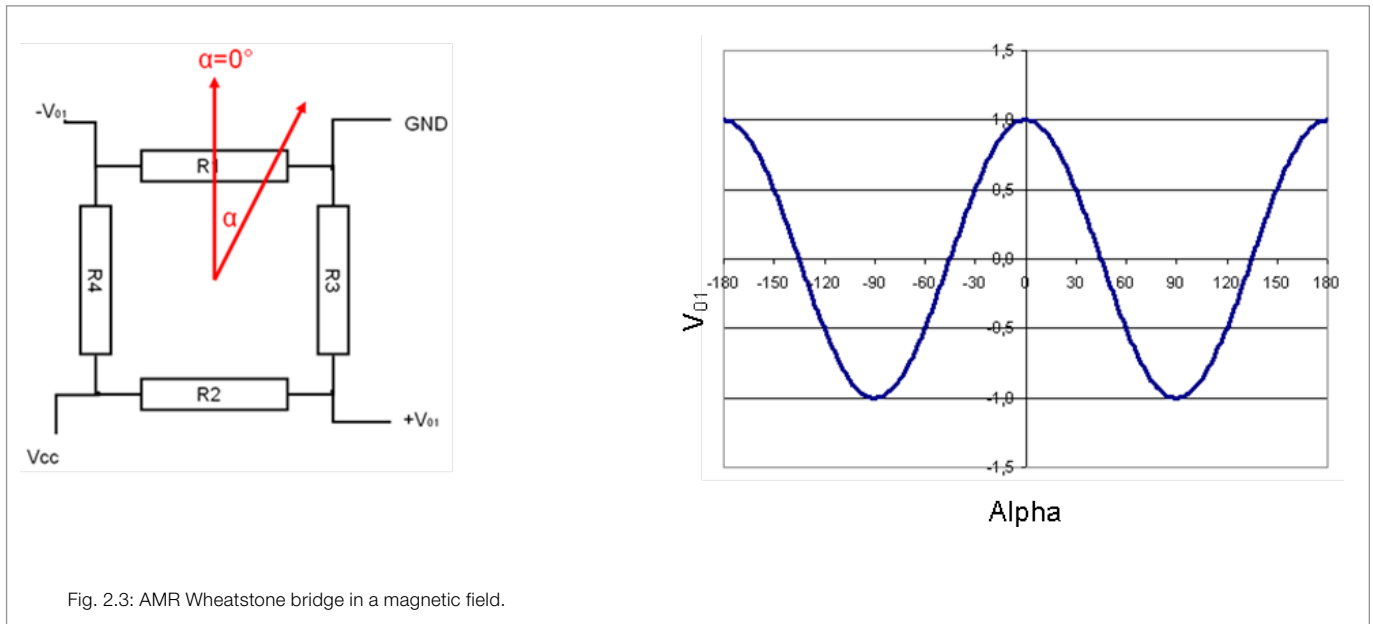

Fig. 2.3: AMR Wheatstone bridge in a magnetic field.

In Fig. 2.3 the angle between the sensor main axle and the external applied magnetic field is defined as α. When the magnetic field is applied in an angle $\alpha = 0°$ (see Fig. 2.3), two resistances of the bridge are magnetized in longitudinal direction (R3, R4) and have so a higher resistance than the two magnetized resistances in cross direction (R1, R2).

If the magnetic field turns around the angle α, the signal trace arises as diagrammed in Fig. 2.3 on the right. This bridge supplies a cosine-shaped signal up to 180° (maximum at 0°). At a value up to 360° an MR-Wheatstone bridge is „2-periodic". The second MR-Wheatstone bridge in the sensor is turned by 45° compared to the first one. So, the output phase is shifted by a quarter period compared to the first bridge. For this reason the signal arises from Fig. 2.4.
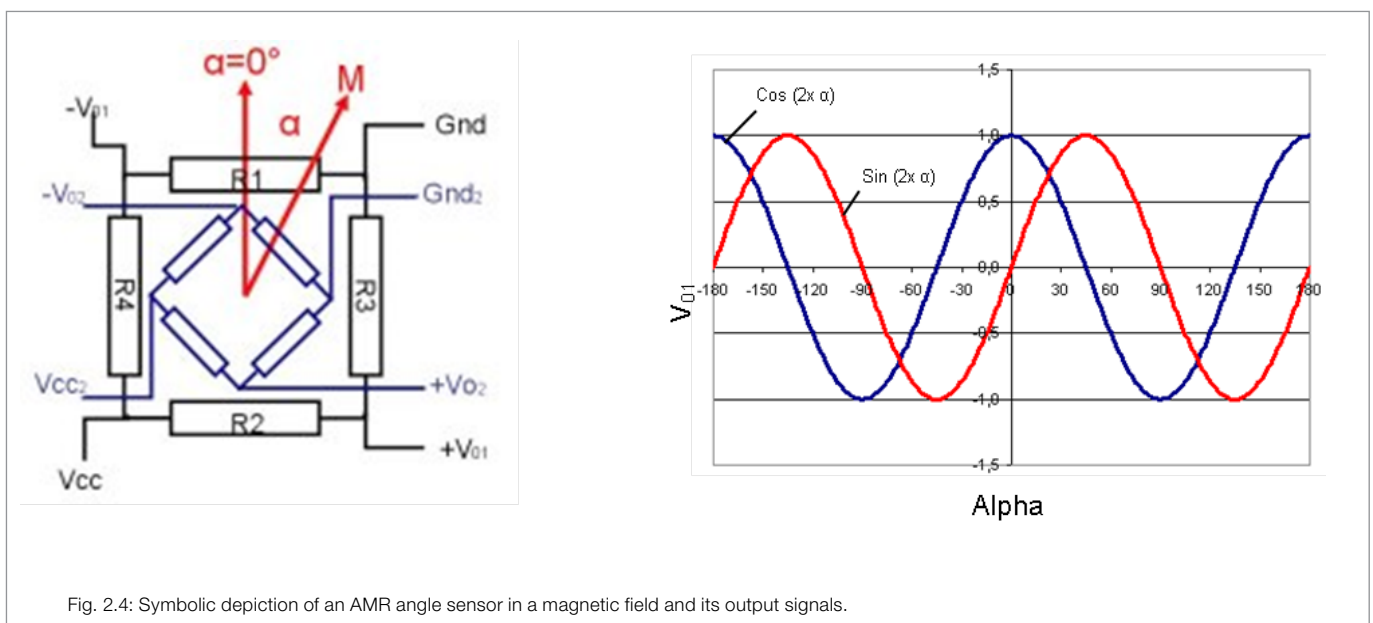
Fig. 2.4: Symbolic depiction of an AMR angle sensor in a magnetic field and its output signals.

The two bridges supply the sine and cosine signals. The magnetic field angle is calculated from the quotient (tangent) of the two signals. If the signs of the sine and cosine signals are followed on an arc tangent calculation, the magnetic field angle up to 180° can be defined. The Arctan2 function follows these signs.

Fig. 2.5: Sine and cosine signals as well as the calculated Arctan2 function.

Fig. 2.5 shows the sine and cosine signals and the calculated Arctan2 function. This allows an explicit determination of an angle up to 180°.

3. Design Advantages of the AA700 Family
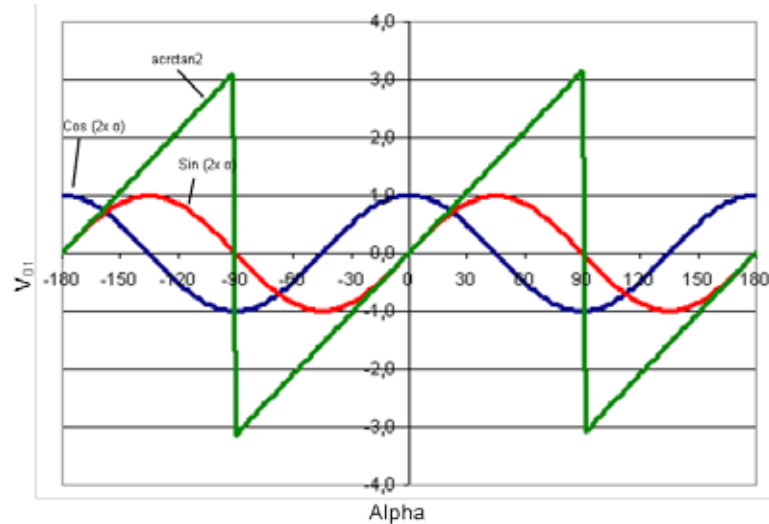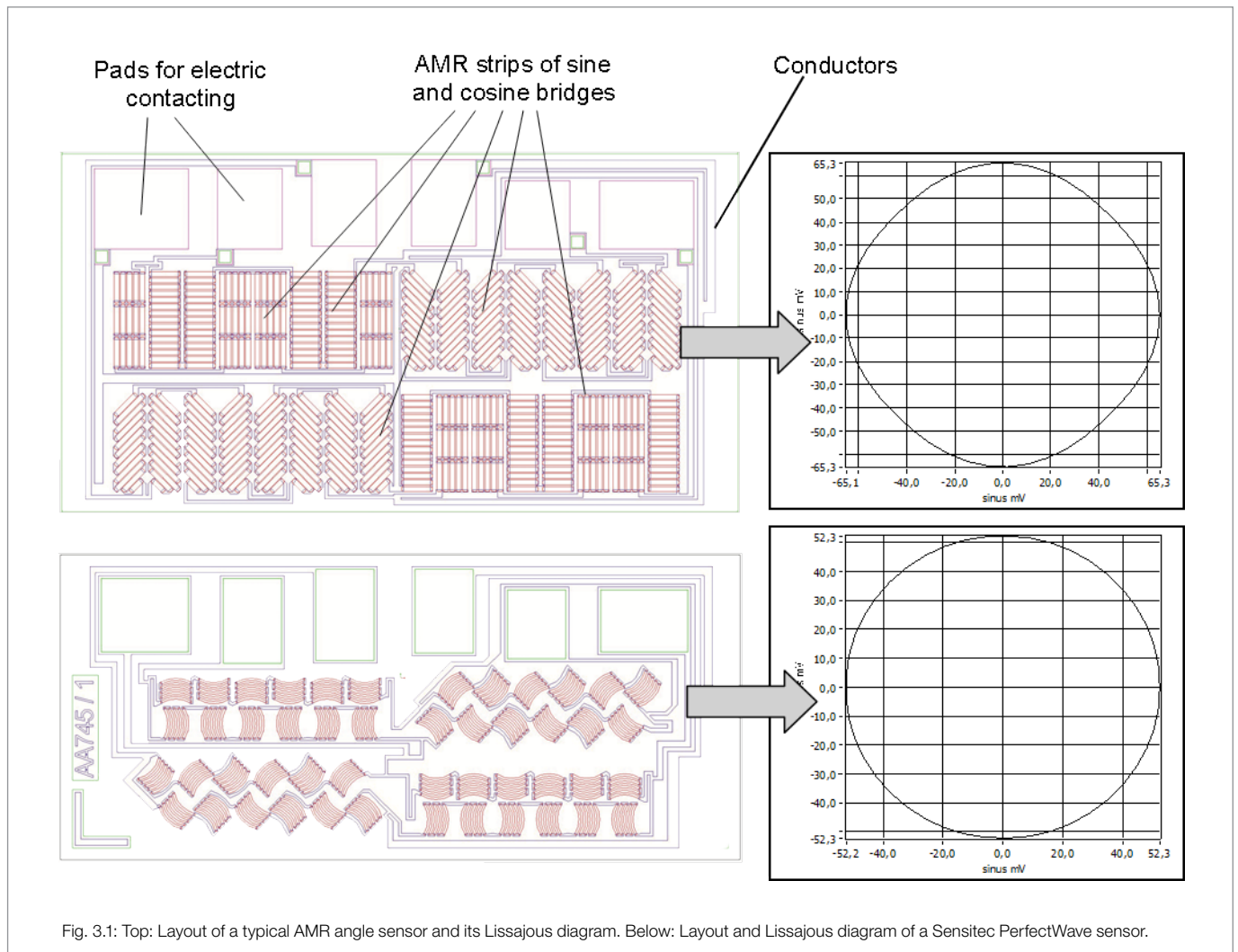
The FreePitch angle sensors of the AA700 family stand out from other MR sensors due to a multitude of patented design features. For example, harmonic faults in the sensor signal, which arise due to the shape anisotropy, are reduced via PerfectWave technology. Shape anisotropy is the phenomenon of the magnetic preferred direction in longitudinal direction at bodies, which are much longer than wide.

The shape anisotropy also appears in the elements of an AMR sensor. Fig 3.1 shows on top the layout of a typical AMR sensor.

Fig. 3.1: Top: Layout of a typical AMR angle sensor and its Lissajous diagram. Below: Layout and Lissajous diagram of a Sensitec PerfectWave sensor.

The individual AMR strips, which form together the resistances of the two Wheatstone bridges, are highly visible. Due to this shape anisotropy (preferred direction) the magnetic field in the strips of the sensor does not follow for 100 % the external applied magnetic field. The magnetic field strength, necessary to get over the shape anisotropy, is defined by the strip thickness - strip width ratio. Short, wide strips have less shape anisotropy than long, small strips.

The strips in Fig. 3.1 point into 4 directions, which leads to a 4 periodic error as a result of the shape anisotropy. In the right part of Fig. 3.1 the Lissajous diagram of the sine and cosine signals are shown. Harmonics on the sine and cosine signals cause the deviation from perfect circularity. Therefore the error caused by shape anisotropy is also called „harmonic error".
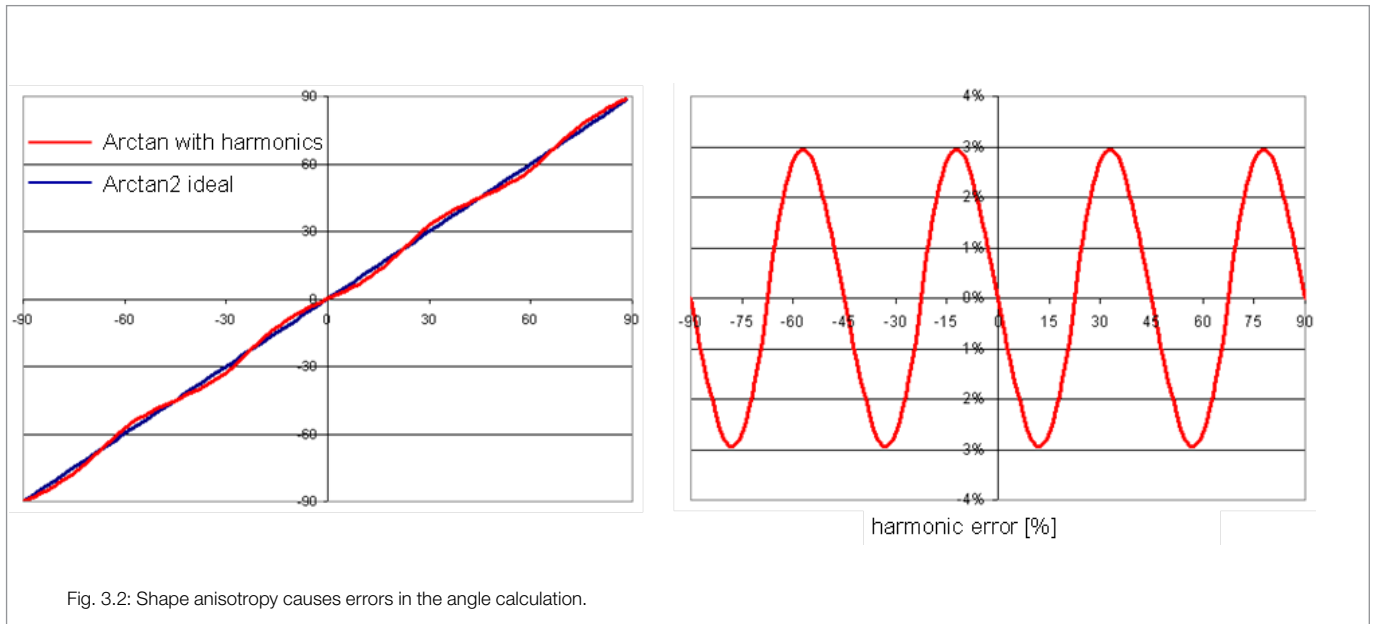
Fig. 3.2: Shape anisotropy causes errors in the angle calculation.

Fig. 3.2 shows the ideal Arctan2 curve of a sensor without harmonic error as well as the curve of a sensor with harmonic error. During a magnetic field revolution by 180° the sensor passes through a full period and the error passes through four periods. The error is called 4-periodic.

There are three possibilities to reduce the effect of the shape anisotropy in the AMR sensor:

1. Operation with strong magnetic field
2. A sensor design with wide AMR strips
3. Reduced AMR layers
4. A sensor design with curved AMR strips

3.1 Operation with strong Magnetic Field

The shape anisotropy is particularly noticeable at weak magnetic fields. The effect of the shape anisotropy is negligible, if the sensor is used in corresponding strong magnetic fields. The magnetic field strength decreases with increasing air gap. The request to work always with adequate strong magnetic fields is only rarely to implement and stronger, mostly bigger, magnets involve higher costs.

3.2 A Sensor Design with wide AMR Strips

The second possibility to reduce the effect of shape anisotropy is to use wider strips in the sensor design. The shape anisotropy is defined by the layer thickness - sensor strip width ratio. It is smaller in wide strips. To get a sufficient bridge resistance even so, more strips have to be connected in series and so the sensor surface is enlarged. For this reason the AA700 sensors were not designed in this way.

3.3 Reduced AMR Layers

Another possiblity to reduce the effect of the shape anisotropy is to reduce the AMR layers. But this causes a reduced signal amplitude, too. The AMR effect will be reduced when reducing the layers.

3.4 A Sensor Design with curved AMR Strips

Sensitec's patented, curved MR strips minimize the effect of shape anisotropy to the sensor signal. AMR sensors with curved strips are PerfectWave sensors. PerfectWave sensors of the AA700 family combine lowest dimensions and minimal measurement errors caused by shape anisotropy.

4. Reference Values of the AA700 Family

It is recommended to use AA700 angle sensors always in „strong field operation". This means that sensors should be operated in a sufficient strong magnetic field so that the effects of the shape anisotropy in the sensor is negligible. Therefore a magnetic field of 25 kA/m is sufficient. Instead of strong field you can also say operation „in satiation". This has the same meaning.

The AA700 angle sensors detect only the direction of the magnetic field. The strength only has an effect on the accuracy but not on the strength of the output signal.

The following values refer to operation in satiation (25 kA/m) at room temperature and are characteristic values. Data sheets with complete technical specifications can be found at: www.sensitec.com

Symbol	Parameter	AA745	AA747	Unit
$\Delta\alpha$	Angle error	Typ. 0.05 [1]		Deg.
V_{CC}	Supply voltage	Typ. 5		V
V_{off}	Offset voltage per V_{CC}	±2		mV/V
V_{peak}	Signal amplitude per V_{CC}	Typ. 13		mV/V
RS/RB	Sensor resistance / bridge resistance	R_S = typ. 1.6	R_B = typ. 3.2	kΩ
T_{amb}	Ambient temperature range	- 40 to + 150		°C
H_{ext}	Magnetic field strength [2]	Typ. 25		kA/m

[1] For larger production volume can be resticted to target value +/-2 (µV/V)/K.

[2] External applied magnetic field in sensor level to realize a. m angle error.

Table 4.1: Reference values of the AA700 sensors.

5. Measurement Configurations

After having described in detail the basics of the AMR technology and the AA700 family the following section explaines how to detect a position rotative or linear with magnetic angle sensors.

5.1 Rotative at Shaft End

The easiest way to detect a position (absolute up to 180°) with an AMR angle sensor of the AA700 family is to represent a rotation angle of a shaft to the magnetic field in the sensor. So, the dipole magnet is mounted centrical at shaft end opposite to the angle sensor (Fig. 5.1).

Fig. 5.1: Symbolic diagram of configuration for rotational position sensing at shaft end.
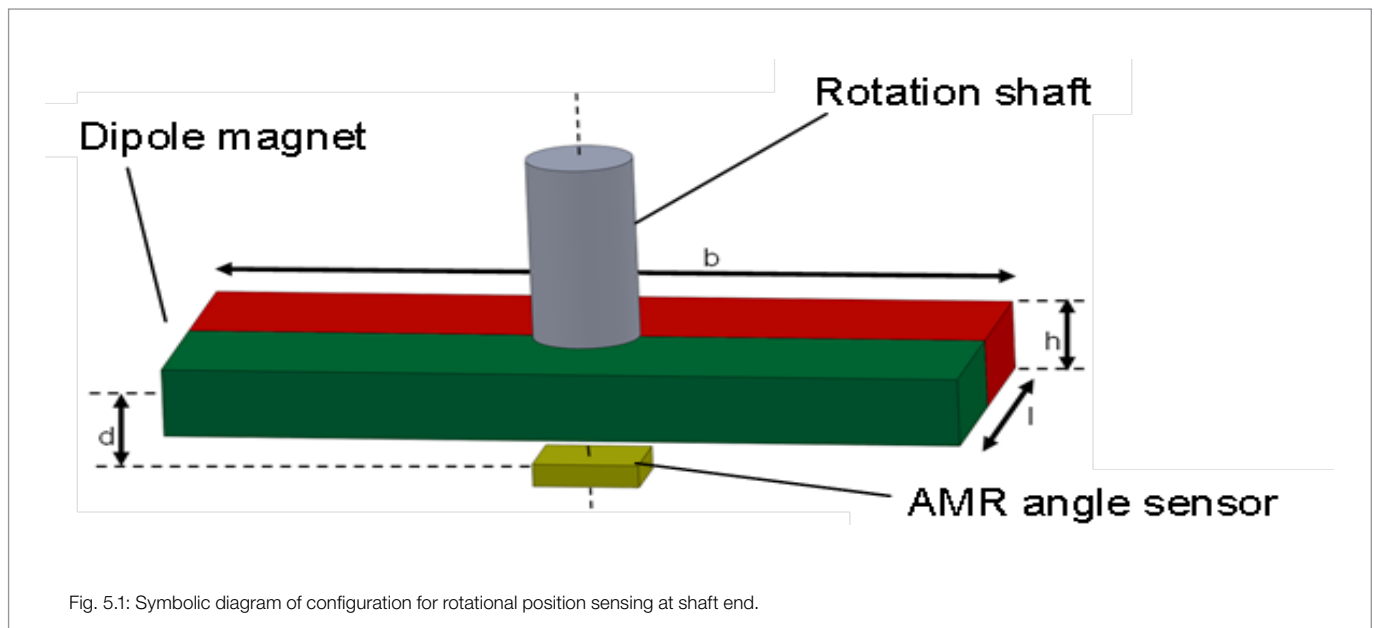
The accuracy of the position sensing depends on the accuracy ot the geometrical configuration. This interrelationship is described in chapter 8.

In an ideal geometrical configuration:

– the sensor is positioned in the center line of the shaft
– the sensor is mounted near the magnet
– the shaft does not run out radially
– the magnet geometry is chosen optimal

With the AA747 an absolute angle accuracy of typical 0.05° at room temperature is possible.

5.2 Linear Position Sensing with a Dipole Magnet

A simple and cost-saving kind to make an absolute length measurement is to measure alongside the 2-pole magnet. The maximal absolute measured distance is longer than the dipole magnet.
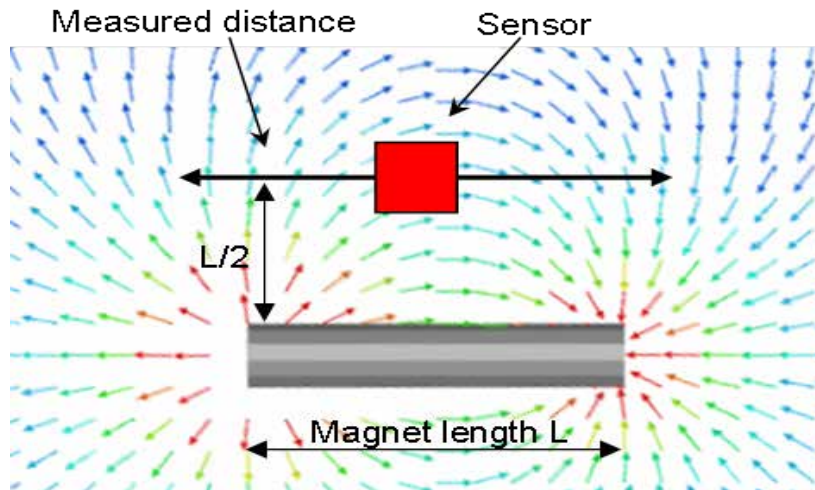

Fig. 5.2: Sensor configuration for linear position sensing at a 2-pole magnet.

Fig. 5.2 shows the field profile of a 2-pole magnet. The arrows correspond to the magnetic field direction detected by the sensor. The rotation of the magnetic field by 180° causes a complete sine period. The measurement depends on the distance between sensor and magnet as the field direction changes depending on the distance.

AA745 or AA747 angle sensors are typically used in this configuration with measuring lengths of 3 to 30°. The optimal sensor distance is approx. half a magnet length (depending on magnet geometry). With this configuration a linearity of 1 % can be achieved.

5.3   Linear at Magnetic Scale

A linear scale consists of a series of north and south poles. An AA745 sensor is moving in a constant distance linear alongside the bar magnet and detects a magnetic field, which is rotating via a pole length by 180°. This causes a complete sine or cosine period at the angle sensor. See Fig. 5.3.
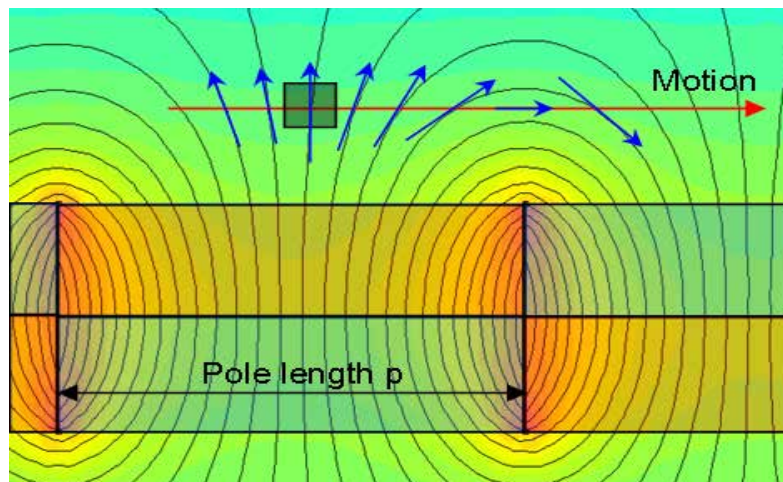

Fig. 5.3: Turnaround of magnetic field at a linear motion alongsinde a magnetic scale.

The output signal of the angle sensor is periodic via a pole length of the scale. So, an absolute position sensing is only possible within a pole length. The designer can chose any pole length (keeping a min. lenght of 2 mm). Therefore the sensors of the AA700 family are called FreePitch sensors.

Amongst others, the accuracy Δx on length measurement depends on the angle accuracy Δα of the sensor and the pole length p.

$$\Delta X = p \times \frac{\Delta\alpha}{180} \quad ... [5.1]$$

If the angle accuracy Δα of the AA745 sensor is = 0.05° and the pole length p is = 2 mm, the theoretic measuring accuracy is valid: **Δx = 0.55 µm**.

The optimal distance between sensor and scale is 1/2 pole length. The effect of air gap and chosen magnet on the measurement accuracy is described in chapter 8. If the traverse path is longer than a pole length the poles have to be counted by the evaluation electronics. In that case it is called an incremental system. Incremental systems get a reference via a dedicated sensor. This reference position has to be detected once so that the position is counted relatively to the reference point as increment. The reference point can be realized as an individual pole on the second scale track or it can be outside the scale in a mechanical or optical manner.

5.4   The Multi Track Nonius Process

With sensors of the AA700 familiy the absolute position within a pole length can be defined. For long traverse paths a second magnet track is necessary to define at which sensor the pair of pole stands. An often used principle is the nonius process.
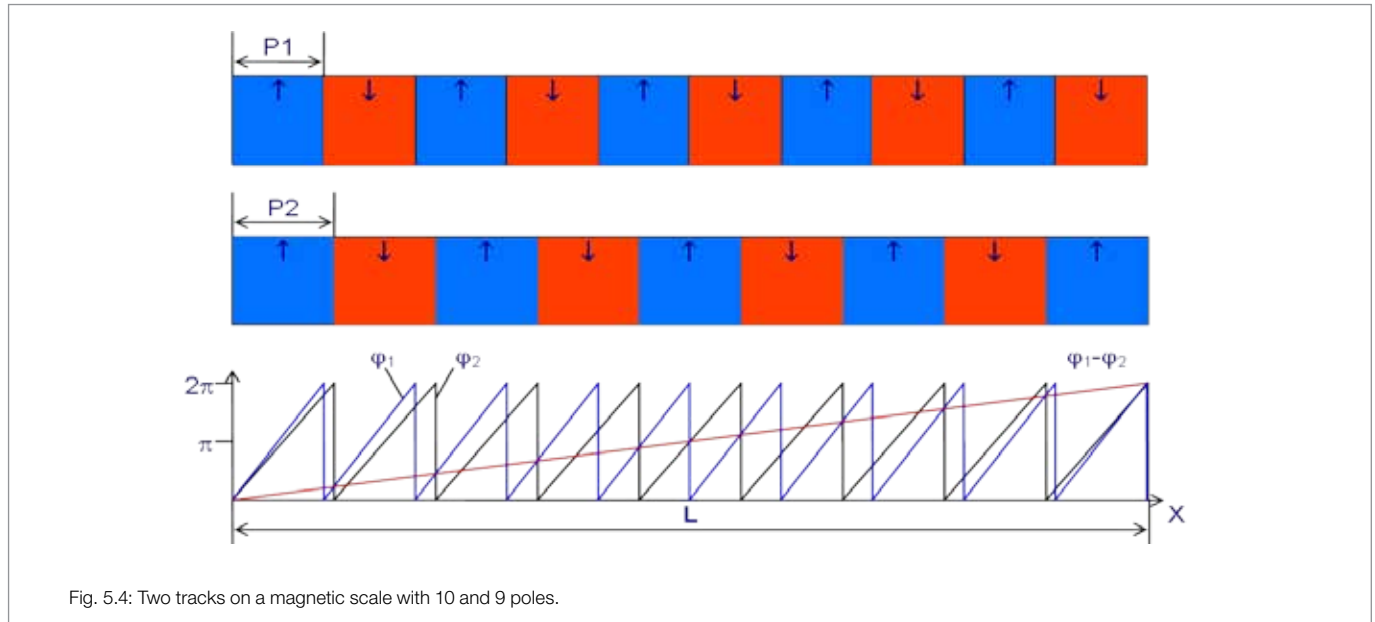

Fig. 5.4: Two tracks on a magnetic scale with 10 and 9 poles.

Fig. 5.4 shows two scales with the same length but a different number of poles (scale 1: 10 poles, scale 2: 9 poles). The measuring head includes two sensors of the AA700 family and moves them along the two scales. From both sensors the position is defined relatively to the magnet pole via the Arctan2 process. The difference supplies the information above at which pole the sensor head stands.

With a basic period length of P1 = 10 mm and P2 = 11,1 mm an absolute length measurement of 100 mm can be realized.

5.5   Rotative at Shaft Circumference

Rotative measurement processes at the shaft circumference are similar to linear measurement processes, because mathematical speaking a linear measurement scale is a pole ring with an infinite diameter.

Both single track incremental and multi track absolute configuration can be used rotative as described above.

5.6   360° Absolute at Shaft End

For each mechanical turn of a shaft the sensor AA74x generates two periods of an electrical output signal. As a result it is necessary to use an additional indicator for determining the absolute shaft position. This can be realized with a sensor that is capable to distinguish between north- and south pole. This sensor does not need separate magnetic track.

6. Sensor Range

Both AA745 and AA747 are qualified for automotive applications acc. to AEC-Q100. They are also applicable in industrial applications.

At the AA745 the elements of the Wheatstone bridge are positioned on one side of the sensor. If the sensor is on the edge of a PCB the sensor elements can be fixed very close to the magnetic scale. So, this sensor is especially suitable for linear position sensing at a scale or rotative position sensing at shaft circumference.

At the AA747 the sensor elements are positioned so that a very small quadrate sensor form arises. The AA747 is especially suitable for angle measurement at shaft end.
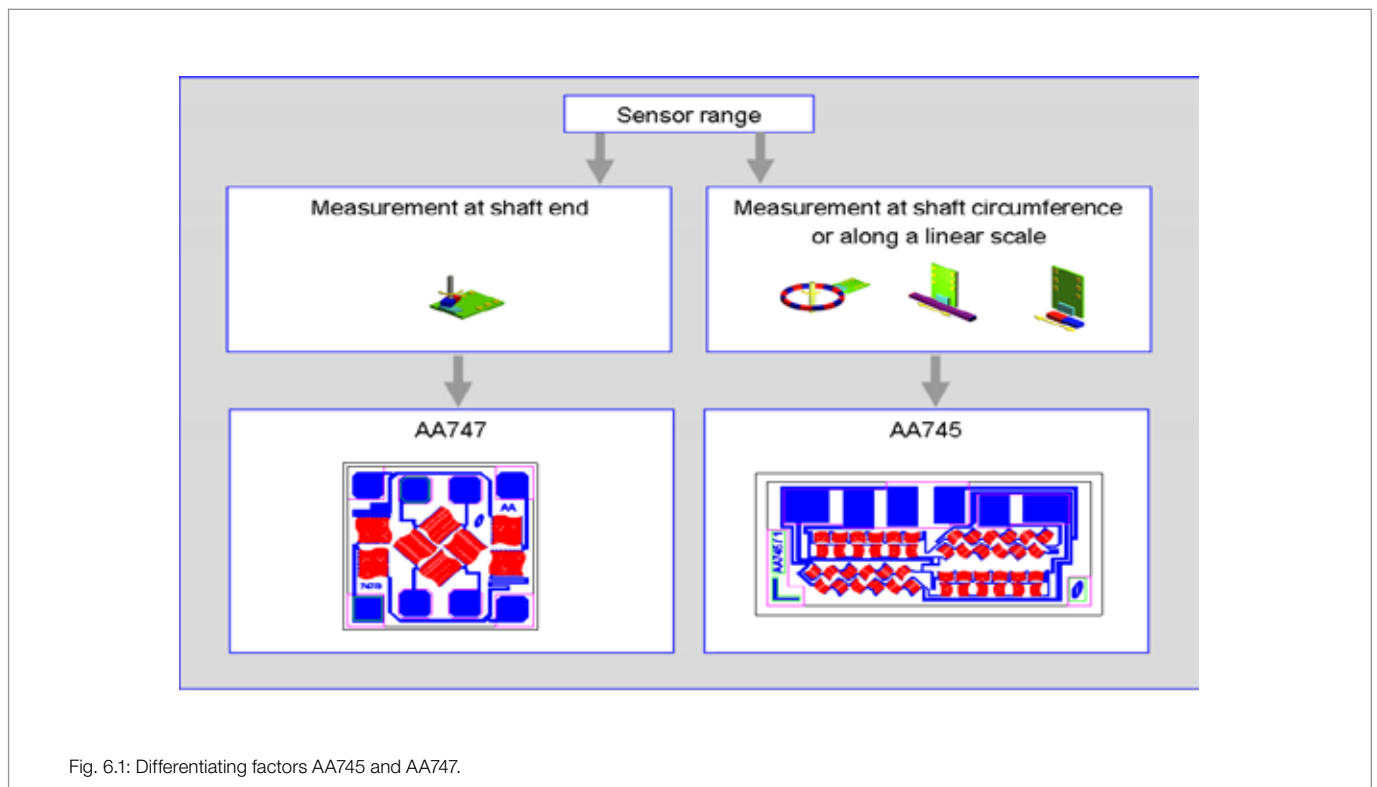
Please see diagram below for differentiating factors.

Fig. 6.1: Differentiating factors AA745 and AA747.

6.1 Product Overview

The AA745 is dimensioned for a position sensing at a linear scale or pole wheel, the AA747 for angle detection at shaft end. For this reason the delivery forms are different. The AA745 is available as „Bare Die" and is processed per COB (Chip On Board). The AA747 is available in an SMD-compatible SO8 housing. Further delivery forms available on request.

Product Overview AA745

Product Codes	Package	Delivery Form
AA745ABA-LL	Bare Die (Wafer - undiced)	Wafer box
AA745ACA-LK	Bare Die (Wafer - diced)	Foil

Table 6.1: Product overview AA745.

Product Overview AA747

Product Codes	Package	Delivery Form
AA747AHA-LB	SO8 housed	Tape on reel

Table 6.2: Product overview AA747.

7. Magnetic Materials

As described in chapter 4 the sensors AA745 and AA747 shall be operated at a mangetic field strength of at least 25 kA/m. For each application it is reasonable to configure the magnet to the highest possible magnetic field strength. This minimizes the errors in the sensor as well as the errors caused by interference fields. The sensor cannot be marred either by very strong magnetic fields. The strength of the magnetic field is defined by the distance to the magnet, the magnet dimensions and the magnet remanence Br.

The remanence Br specifies the strength of a magnetic field of a magnet, that persists after magnetization. The maximal achievable magnetic flux at the surface of a magnet is 1/2 x Br. The coercive field strength Hc describes the magnetic field strength, that is necessary to change the stored magnetization. If the Hc is too low the magnetization can change unrequested due to external magnetic fields.

Both characteristics Br and Hc are material characteristics.

	Coercive field strength Hc (kA/m)	Remanence Br (mT)	Drift (/ K)	Temperature stability (°C)	Corrosion stability	Remark
SmCo (Samarium-Cobalt)		1000	-0,03 %	>200°	very good	
Hard ferrite (Polymer bound)	150 - 190	120 - 290	-0,2 bis -0,4 %	Up to 160°	very good	Injection-molds around inserts possible
Hard ferrite (sintered)	130 - 250	210 - 400	-0,2 bis -0,4 %	Up to 250°	very good	
AlNiCo (cast metal)	50 - 120	800 - 1300	-0,2 %	Up to 450°	very good	
NdFeB (Polymer bound)	250 - 400	400 - 650	-0,8 %	Up to 150°	very good	Injection-molds around inserts possible
NdFeB (Neodymium-iron-bo-ron)	870 to 2750	800 - 1300	-0,1 %	80 to 200°	bad	

Table 7.1: Often used magnetic materials and their typical data.

Synthetic material bound (polymer bound) magnets are often used. These magnet materials are composed of hard ferrite or rare earth element magnetic powder and synthetic materials. Due to the use in injection-molding machines user-defined shapes of measurement scale can be realized. In some applications the injection-mold around inserts is interesting.

Criteria for material choice are cost, temperature range, mechanical geometry and mechanical stress. In addition to the material the magnet geometry has also an effect to the measurement. Details to this can be found in chapter 8 „system accuracy".

As an active measurement scale Sensitec offers pole rings, linear scales and 2-pole magnets.

8. System Accuracy

The signal quality and the accuracy of an angle sensor depend on several parameter. Basically they can be divided in environmental effect, magnet characteristics, sensor characteristics and adjustment. See the following diagram for an overview of the complex relationships in a measurment system.
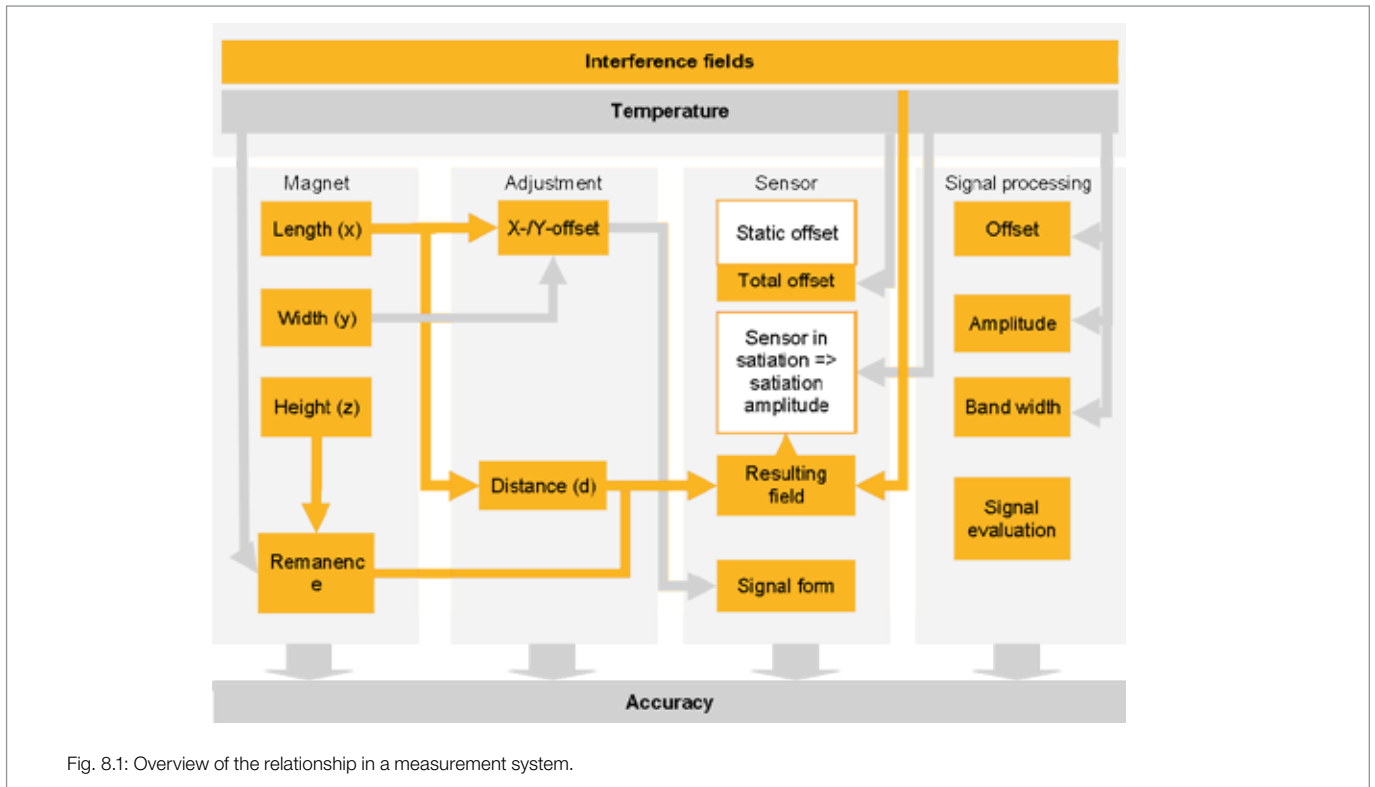

Fig. 8.1: Overview of the relationship in a measurement system.

8.1 Magnet Dimensioning for Optimization of Field Strength and Accuracy

Two factors have to be considered when dimensioning the magnet for the rotative position detection at shaft end:

1) The required magnetic field strength at the position of the sensor has to be observed. It is determinated by the magnet geometry, the magnet material and the sensor position relative to the magnet.

2) The permitted sensor offset from centerline. The error dimension arising by the offset is highly defined by the magnet geometry.

The magnet has to be dimensioned so that it generates a magnetic field at the sensor as strong and homogeneous as possible at a volume (price) as small as possible. A strong magnetic field allows a big gap and reduces the effect of interference fields. The homogeneity of the magnetic field allows maximized mechanical tolerances when installing the sensor.
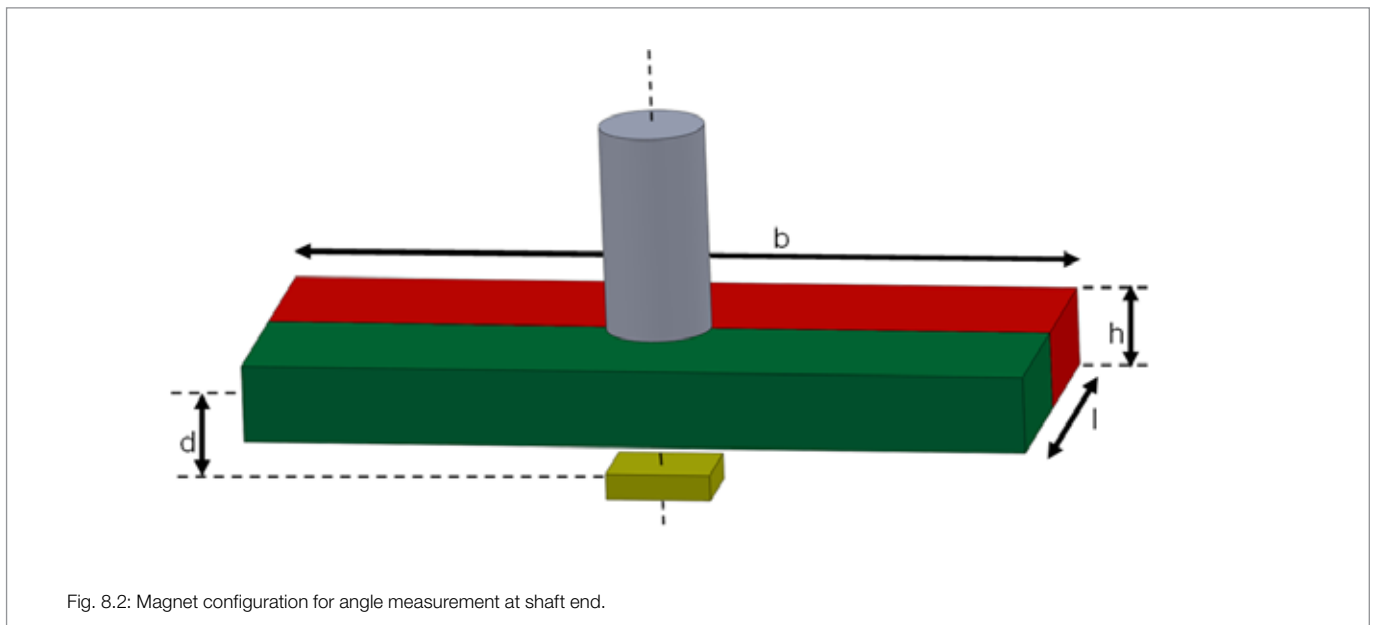

Fig. 8.2: Magnet configuration for angle measurement at shaft end.

Fig. 8.2 shows the cofiguration of a rotating magnet opposite to an angle sensor chip.

Fig. 8.3 at next page shows the relation between the lenght of a magnet (ponting from north to south pole) and the resulting field strenghth within different distances to the sensor. The magnet used is made of ferrite with Br = 300 mT. When using other materials a simple linear conversion is possible acc. to other material remanences. There is an optimal magnet length for each gap. Small gaps increase the field strength when reducing the magnet volume.
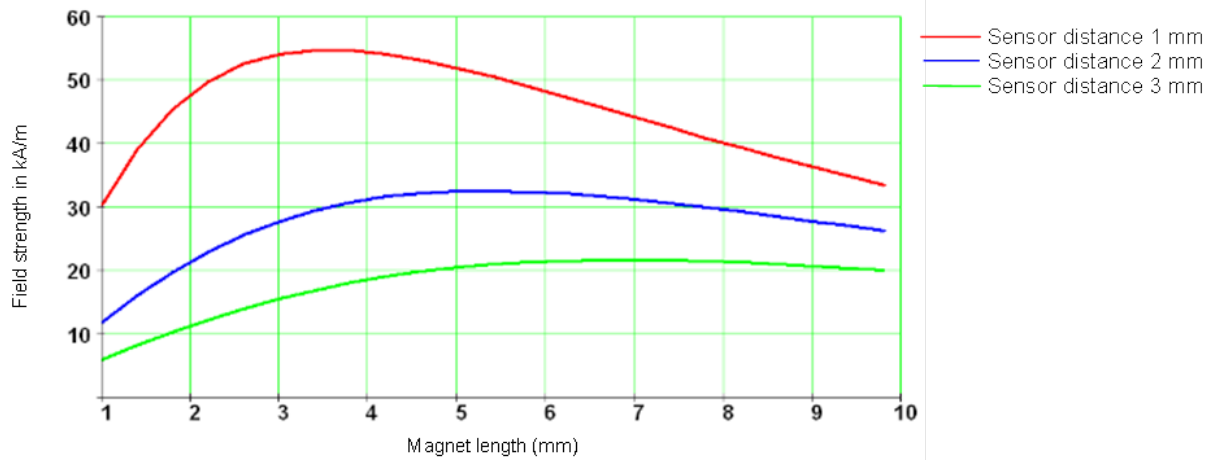
![SENSITEC KÖRBER SOLUTIONS]

Fig. 8.3: Magnetic field strength as function of magnet length with three different magnet distances. Br = 300 mT, b = 7 mm, h = 5 mm.

The sensor should be mounted as centrical as possible opposite the centerline. Offset or wobbling causes errors in measurement. The factor of these error contributions can be reduced by a good dimensioning of the magnet.

Fig. 8.4 shows the effect of the magnet width on the maximal angle error in different gaps caused by the offset. The offset is assumed with 1 mm.
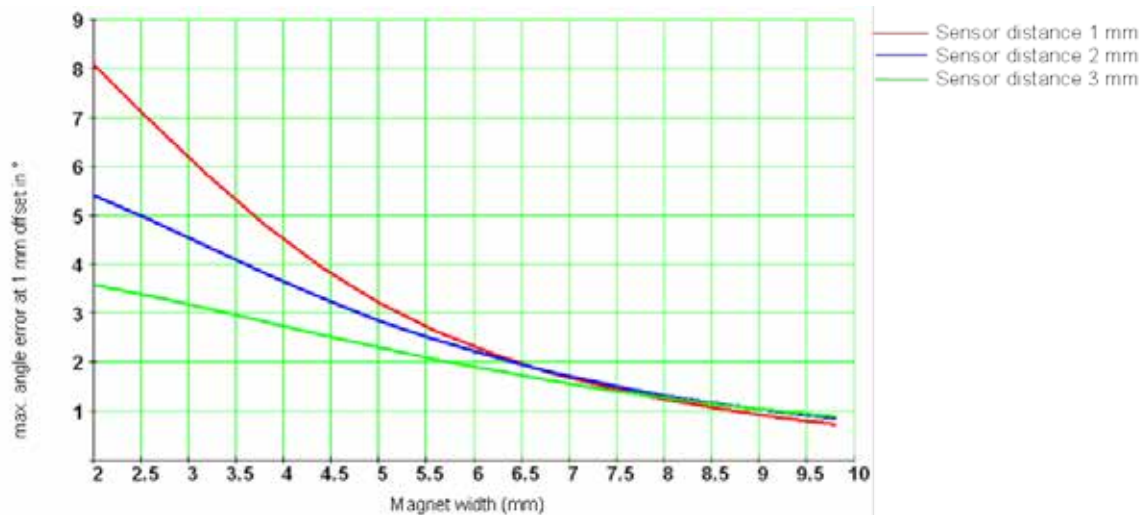

Fig. 8.4: Angle error with 1 mm center offset. Br = 300 mT, l = 2 mm, h = 5 mm.

The offset results in a quadruple error. If the offset is only 0.5 mm instead of 1 mm the error contribution in Fig. 8.4 has to be divided by 4.

8.2 Dimensioning of Pole Rings and Linear Scales

For the dimensioning of the pole rings and linear scales the same rules are valid.

For the dimensioning of the scale the following has to be considered:

1. The magnetic field strength at the position of the sensor.
2. Error contributions caused by the gap.
3. Error contributions caused by the end of the linear scale.

Just like the dipole magnet the field strength at the position of the sensor is defined by three factors:

– Magnet geometry

– Magnet material

– Sensor position relative to magnet

With thicker scales the depth of magnetization is only a few millimeter. With full strength magnetized thin scales the field strength can be doubled by back iron.

A linear magnetic scale is made of many magnets in a row. The field strength as a function of the pole length, distance and thickness of strip is described by the following approximation formula:

$$H_{max} \approx 0.4 \cdot Br \cdot \left(1 - e^{-2.5 \cdot \frac{D}{P}} \right) \cdot e^{-2\pi \cdot \frac{A}{2 \cdot P}} \quad ...[8.1]$$
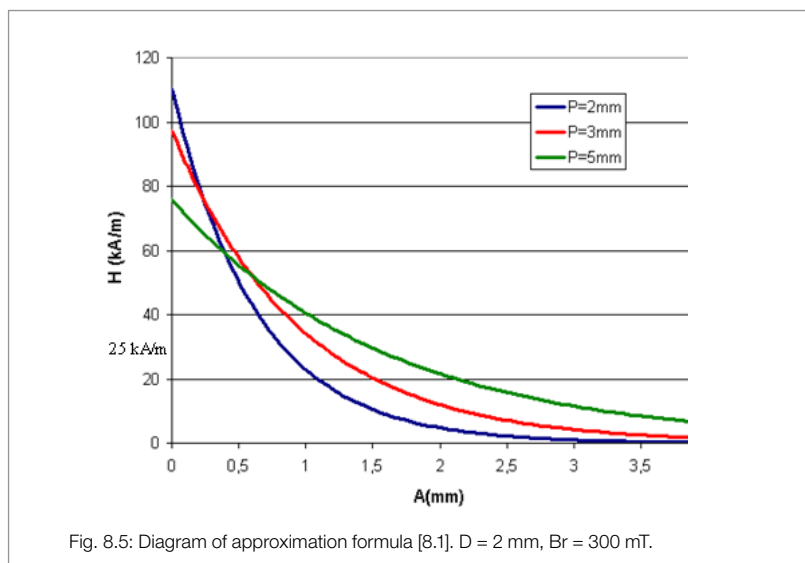
Br = Magnetic remanence (mT)

D = Strength of scale and magnetization depth (mm), respectively

P = Pole pitch (mm)

A = Distance to scale (mm)

H_{max} = Maximal magnetic field strength (kA/m)

Fig. 8.5: Diagram of approximation formula [8.1]. D = 2 mm, Br = 300 mT.

As illustrated here the maximal field strength was measured via approximation formula as function of the distance with three different pole pitches. The strength of the measuring strip was assumed with 2 mm and 1 mm with back iron, respectively. Br was applied with 300 mT.

A stronger scale is only contributing the magnetic field if it is magnetized at the full strength.

It is visible that the gap has to be chosen conformable small for small pole pitches. The following equation is valid for the gap:

$$A \leq \frac{P}{2} \ ... \ [8.2]$$

Below the effect of the gap to the accuracy is examined. Fig. 8.6 shows each horizontal and vertical component (X and Y) of the magnetic field, if the measuring point moves parallel to the scale at a length of 4 mm. As parameter the distance to the scale was chosen 0.5 to 2 mm. The pole length of the scale is 2 mm.
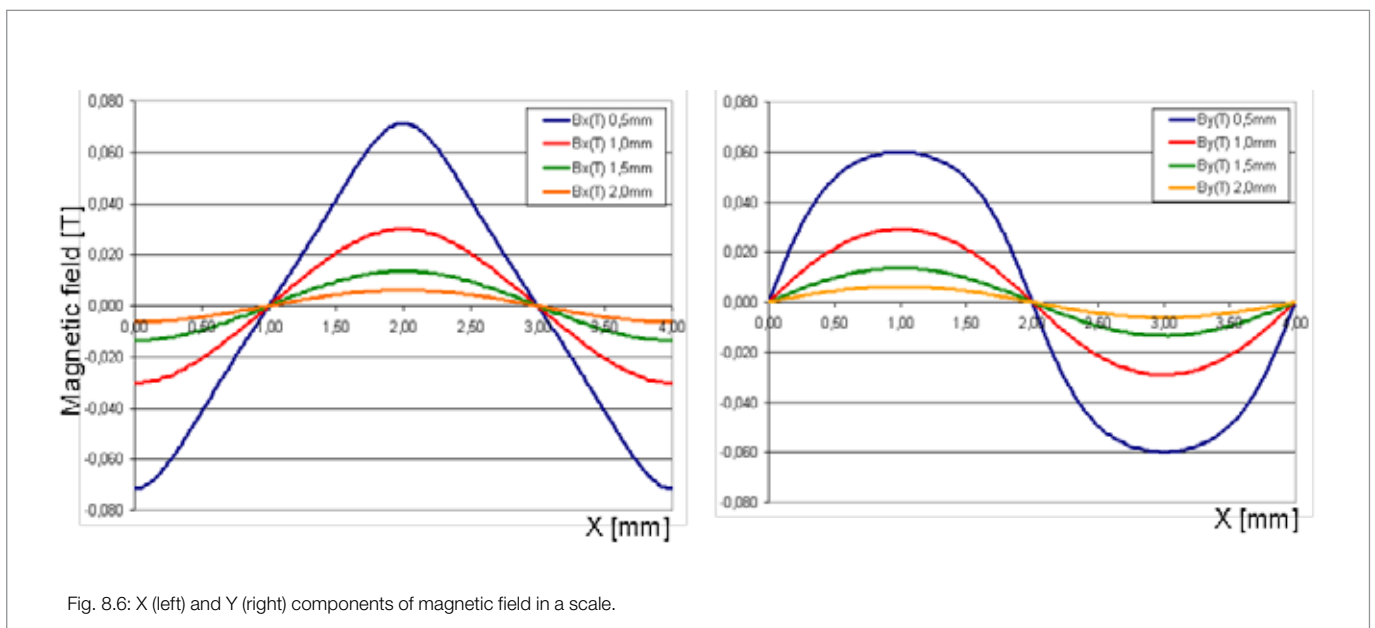

Fig. 8.6: X (left) and Y (right) components of magnetic field in a scale.

When moving across two magnetic poles the magnetic field rotates by 360°. If the two field components are sinusoidal in X and Y direction, the angle is a linear function.

Fig. 8.6 reveals:

– With increasing distance the field components decreases.

– With an average distance (1 or 1.5 mm) the shape of the field component is similar to a sine or cosine curve.

– With a small distance the shape is not anymore similar to a sine or cosine curve.

The AA700 angle sensor supplies a complete signal period when moving across a magnetic pole. For the detection of the sensor position within a pole, the Arctan2 function is used. Fig. 8.7 on the next page shows the deviation from the ideal position for the different gaps.
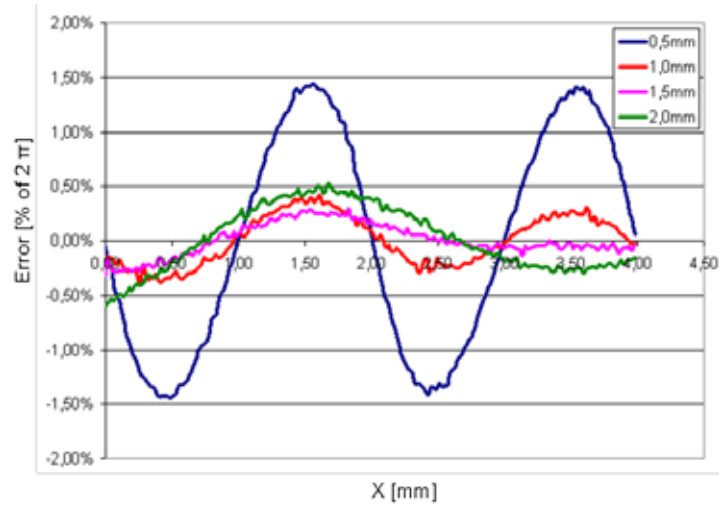
Fig. 8.7: Deviation in position caused by nonlinearity of magnetic field developing.

The noise ratio in Fig. 8.7 is caused by the resolution of simulation. On the basis of this diagram we determine:

– A too small distance leads to a maximum error.

– A distance of 1 mm and 1.5 mm is the optimum.

– Further enlarging the distance does not lead to a significant increase of the error.

These results confirm the equation for the gap from the previous page and it can be supplemented to:

$$\frac{P}{4} \ A \leq \frac{P}{2} \ ... \ [8.3]$$

With a larger gap the magnetic field decreases and the effect of external interference fields increases and maybe the effect of shape anisotropy, too.

Another mesasuring error can occur at the end of the scale. Fig. 8.8 shows a magnetic field simulated around the end of a scale.
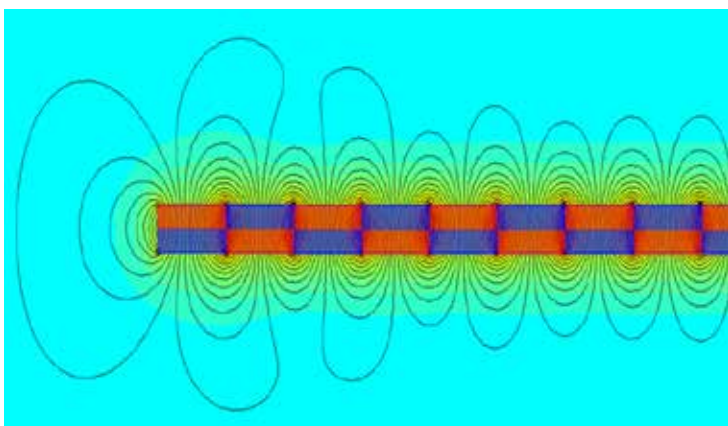

Fig. 8.8: Magnetic field simulation at a scale.

It is visible clearly how the magnetic field is affected on five poles at the end of the scale. The number five is a reference value: on the first five poles the linearity is affected negative due to the end of the scale.

In an application the scale is mostly mounted on a magnetically soft metal carrier and there are possibly further metallic parts around. If the accuracy at the end of the scale is important a simulation can bring clarity. Sensitec offers linear pole rings and scales on the basis of polymer-bonded hard-ferrite. Details can be found in our catalogue.

8.3 Sensor and Measurement Error Parts

Before the measurement signals of the AMR bridges are integrated in the calculation of the Arctan2 function the following has to be considered:

Is the distance too large it leads to the maximum error.

– Offset voltage of Wheatstone bridge

– Amplitude differences between the two Wheatstone bridges

– Phase error

8.3.1 Offset Voltage

Exemplification of the offset voltage effect.
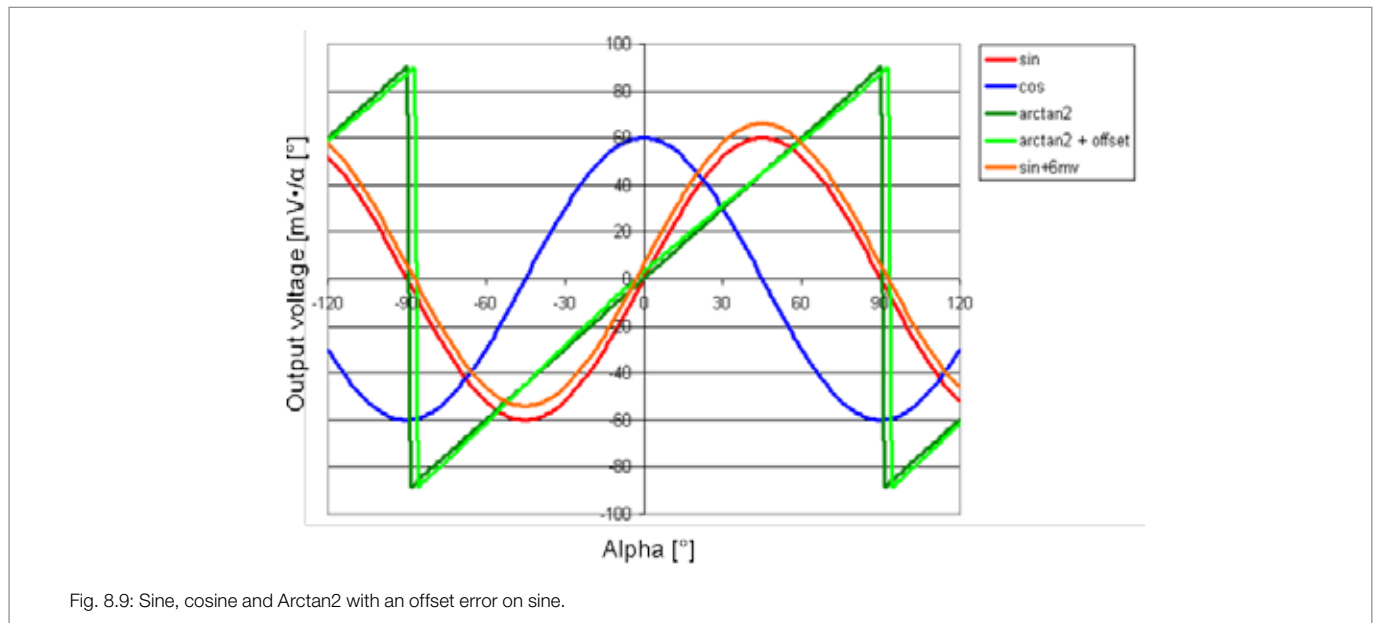
8.3.2 Offset Error on Sine

Fig. 8.9: Sine, cosine and Arctan2 with an offset error on sine.

Fig. 8.9 shows the ideal sine and cosine signal as well as their Arctan2 and how the curves and the Arctan2 change, if the sine signal is generated with an offset error. The error used here is highly exaggerated to visualize the modification in the diagram. With an offset error of 6 mV on an amplitude of 60 mV (= offset error 10 %) the angle error is maximal 2.9° acc. to Arctan2 calculation. These 2.9° on 180° correspond to 1.6 %.

Equation for the calculation of an angle error as a result of an offset error:

$$\Delta \varphi \approx \frac{\Delta U_0}{2\pi} \dots [8.4]$$

The offset error ΔU_0 is to be used in % of the amplitude and the angle error $\Delta\varphi$ in % of 180°.

To avoid offset caused errors the evaluation electronics has to be able to define the average value (DC component) for a complete sine at least. This means that this offset has always to be deducted from the measurement. In the majority of cases it is sufficient to determine the offset once.

8.3.3 Amplitude Difference

Fig. 8.10 shows the progress of the signals, if the sine signal has an amplitude error of 6 mV (= 10 % of 60 mV).

Fig. 8.10: Sine, cosine and Arctan2 with an amplitude error on sine.
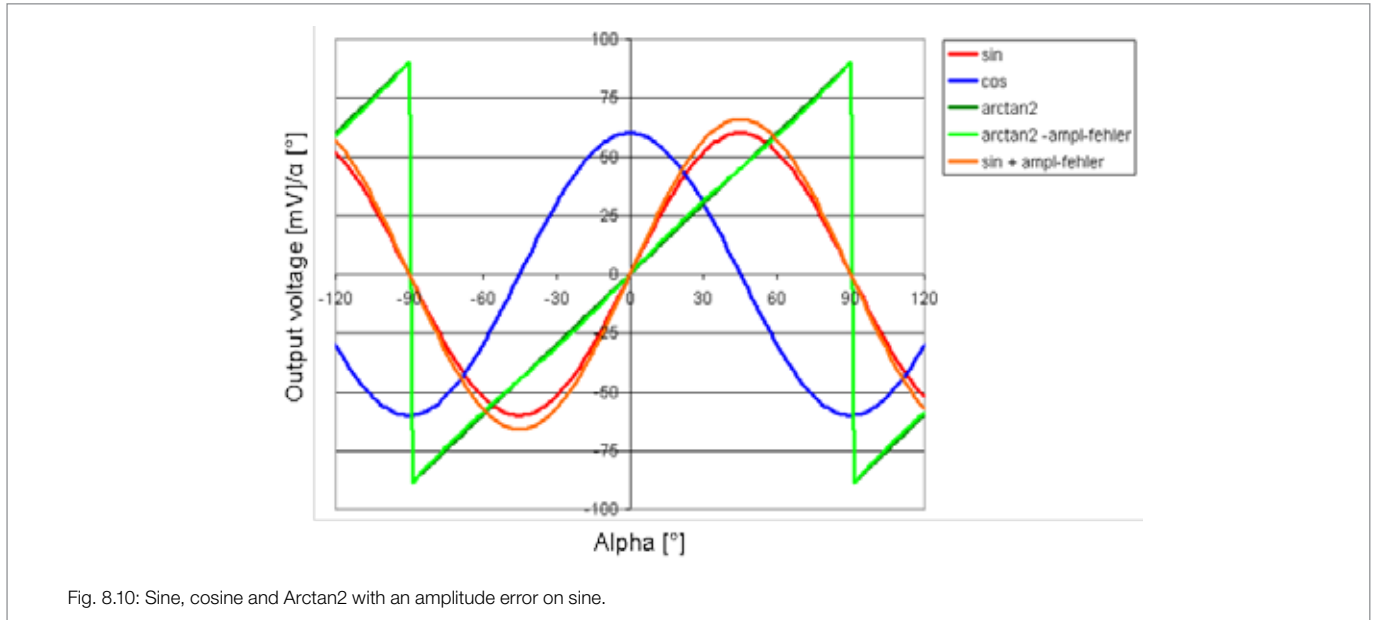
With an amplitude error of 6 mV (= 10 % of 60 mV) on the sine an angle error of round about 1.4° can be calculated.

Equation for the calculation of an angle error as a result of an amplitude error in one of the signals:

$$\Delta \varphi \approx \frac{\Delta U}{4\pi} \quad \dots [8.5]$$

In doing so amplitude errors ΔU are to be used in % of the amplitude and angle errors Δφ in %of 180°

As the tangens function is the quotient of sine and cosine any amplitude error appearing in parallel on both sine and cosine will be compensated automatically. If both Wheatstone bridges are at the same supply voltage the changes of the supply voltage will be eliminated automatically, too. At the AA747 however, both wheatstone bridges have their own connection for the supply voltage and a difference in the supply voltage is possible.

8.3.4 Phase Error

The phase error in the sensor is defined by lithography in production and is negligible small. However, the effect of a phase error is described because it can arise on the digital signal processing due to asynchronous sampling.

8.3.5 Phase Error on Sine
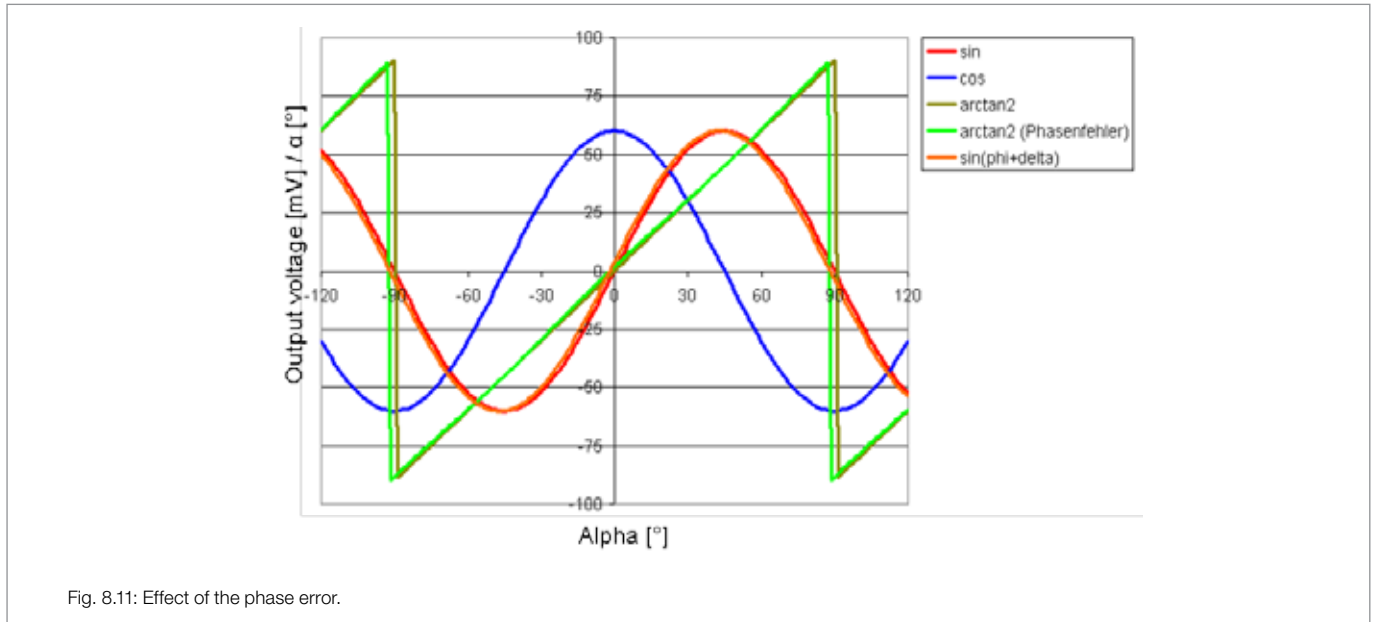
Fig. 8.11: Effect of the phase error.

Fig. 8.11 shows the ideal sine, cosine and Arctan2 signals and the corresponding signals in case of a phase error of 1.8°. If so, the output signal has a phase error of 3.6°. Acc. to Arctan2 this leads to an error of 1.8°. Phase errors have a direct effect on the result.

$$\text{phase error = angle error} \quad \dots\dots \text{[8.6]}$$

Phase errors have the same periodicity as the sine and cosine signals.

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9.   Signal Processing

The sensor signal has to be adjusted to an application suited signal. This can be realized for example by amplifier, comparators, interpolators, micro controller, CPLD or FPGA. Below you will find an example of a block diagram for incremental position measuring with reference point, interpolation and line driver.

Fig. 2.3: AMR Wheatstone bridge in a magnetic field.
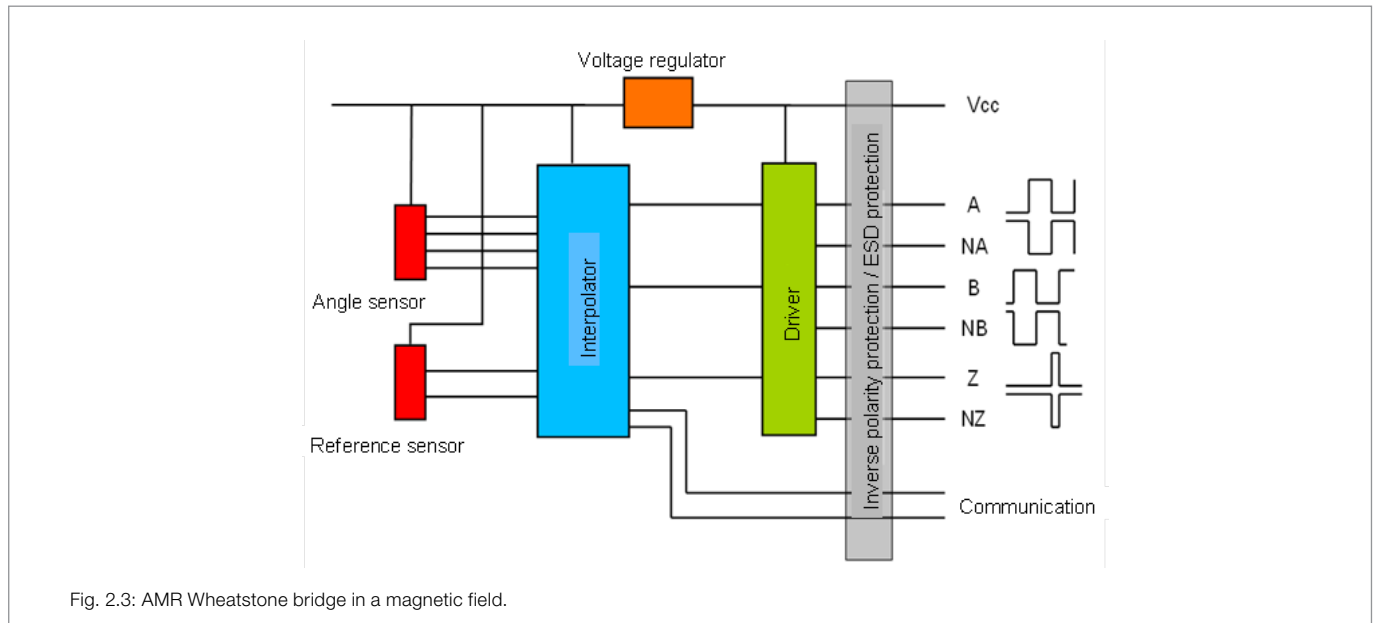
In Fig. 9.1 the angle sensor and a reference sensor are connected to the interpolator. This interpolator amplifies the input signals, adjusts offset voltages and defines via Arctan2 procedure the position within a pair of poles. A change in position leads to pulses on the A and B lines. The driver amplifies these signals for transmission. The protective circuit has to dissipate the energy which is coupled from external into the line.

The output signals as incremental impulses in Fig. 9.1 are just one of many possibilities. In most of the applications the sensor signal has to be amplified first either as an analog circuit from the operational amplifier or as integrated input amplifier in the interpolator. Below you will find the description for the input amplification.

9.1   Block Schematic of a typical Sensor System

The easiest execution of a pre-amplifier keeps the sensor mid voltage at 1/2 x Ub and generates amplified sine and cosine signals. So the sensor signals can be adopted to the input circuit of the analog digital converter of the micro controller.

Fig. 9.2: Simple pre-amplifier circuit.
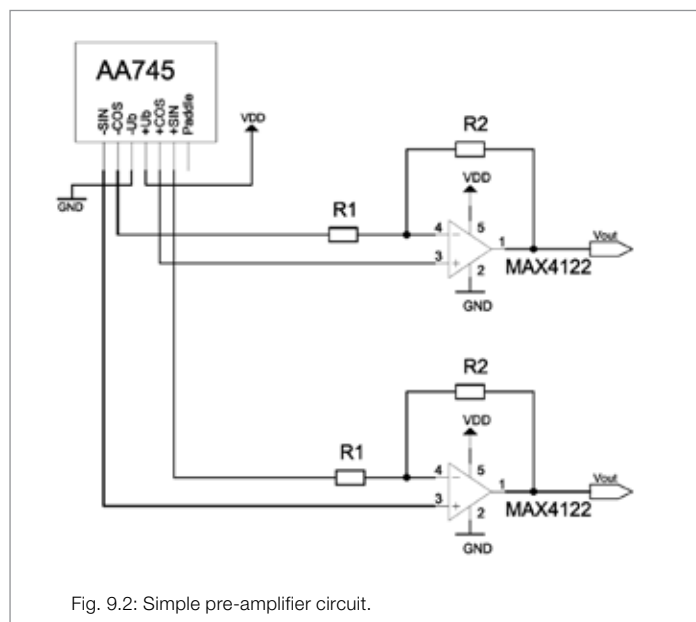
$$V = \frac{R_2}{R_1 + R_2} \ \dots \ [9.1]$$

RB = Sensor bridge resistance R1 > RB

The digital preparing of signals (e.g. the elimination of static offset) is made in the micro controller. For the simple pre-amplification in Fig. 9.2 an amplifier and two resistors are required for sine and cosine. This however could cause a detuning of the bridge circuit because of asymmetrical load. Another disadvantage is a too small input resistance.

To achieve the almost infinite input resistance of the used operational amplifier an impedance converter has to be connected upstream of each of both inputs. In the circuit specified here the differential gain is defined via the resistances R1 and R2.
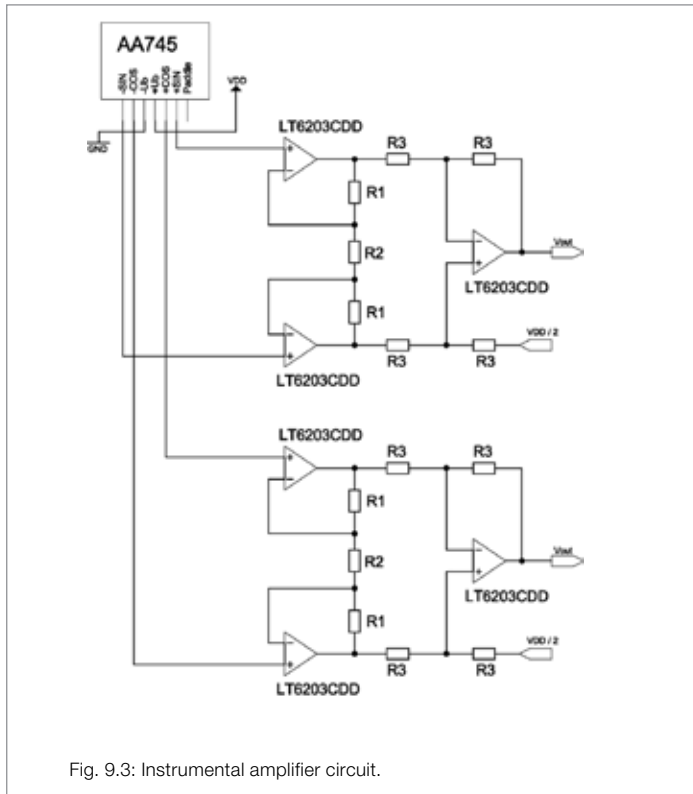
$$V = 1 + \frac{2 \cdot R_1}{R_2} \quad \dots [9.2]$$

Fig. 9.3: Instrumental amplifier circuit.

Instrumental amplifier are built more complex and stress the measuring bridges only minimal. Some of the semiconductor manufacturer offer instrumental amplifier in a housing.

Programmable amplifier can be used, too, as they can also program the offset of the sine and cosine signals. Several programmable amplifier offer the possibility to adjust the amplitude and the offset dynamically during operation via temperature.

9.2 Applications with Interpolation ASIC

For the digitalization to a quadrature signal A/B it is recommended to use an interpolation module. The built in frontend of the interpolator allows to connect the sensor chip directly. These modules offer considerably, partially programmable functions. For example resolution, hysteresis, rotational direction or the like can be adjusted.
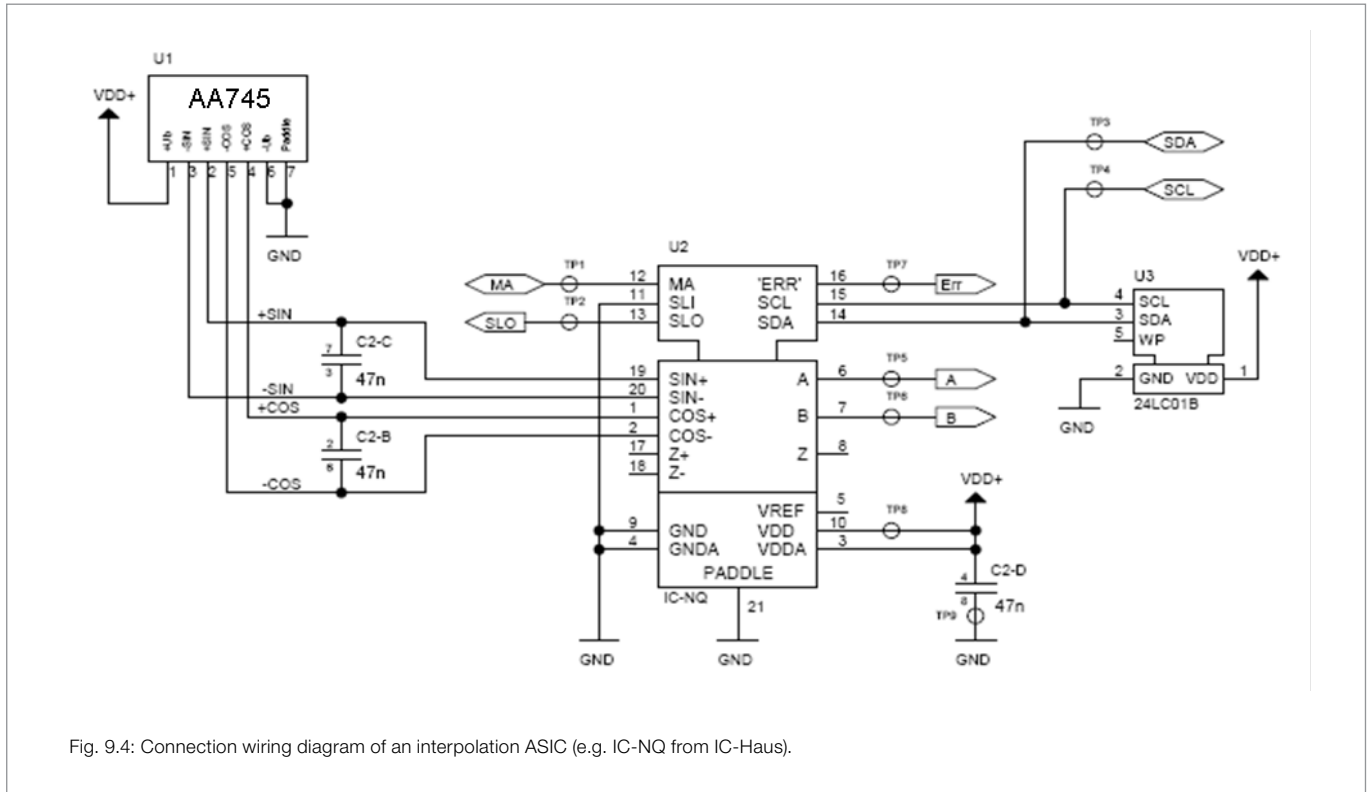

Fig. 9.4: Connection wiring diagram of an interpolation ASIC (e.g. IC-NQ from IC-Haus).

There are several suppliers for AA700 sensor suited signal conditioning ASICs. Find a small overview in the following table. Sensitec has a profound application knowledge and our application engineers would willingly advise you.

ASIC Suppliers (a choice)

Company Name	Postal Address	Internet Address
GEMAC MBH	Zwickauer Str. 227, 09116 Chemnitz	www.gemac-chemnitz.de
IC-Haus GmbH	Am Kümmerling 18, D-55294 Bodenheim	www.ichaus.de
NXP Semiconductors	Stresemannallee 101, 22529 Hamburg	www.nxp.com
RLS d.o.o.	C II Grupe Odredov 25, SI –1261 Ljubljana-Dobrunje	www.rls.si
Sensitec* GmbH	Georg-Ohm Straße 11, 35633 Lahnau	www.sensitec.com
Sensor Dynamics AG	Schloss Eybesfeld 1e A-8403 Graz-Lebring, Austria	www.sensordynamics.cc
ZMD AG	Grenzstrasse 28, 01109 Dresden	www.zmd.de

[1] The Sensitec ASICs are delivered exclusively as part of a complete solution.

Table 9.1: Choice of ASIC suppliers.

10. Magnetic Conversion Factors

In literature you will often find units from the Gaussian system. Below you will find the factors for the conversion in SI units.

Parameter	Symbol	CGS Unit	Conversion	MKSA Unit
Magnetic flux density	B	Gauss	$1 \text{ Gauss} = 10^{-4} \text{ Tesla}$	Tesla ($T = Wbm^{-2}$)
Magnetic field strength	H	Øersted (Øe)	$1 \emptyset e = \dfrac{1000}{4\pi} \text{ A / m} \approx 79.577 \text{ A / m}$	Ampere / Meter

Conversion of flux density in field strength

$$B = \mu \cdot H$$
$$\mu = \mu_0 \cdot \mu_r$$
$$\mu_r \approx 4\pi \cdot 10^{-7} \text{ Vs/Am in air}$$
$$B \approx 12{,}5 \cdot 10^{-3} \text{ H}$$

Tip: Find more concerning the magnetic field strength: http://en.wikipedia.org/wiki/Magnetic_field

11. Equations

The following equations are specified in this document.

Chapter	Equation	No./Page
Chapter 2	$R = \dfrac{R_{max} + R_{min}}{2} + \dfrac{R_{max} - R_{min}}{2} \cdot \cos(2\varphi)$	2.1 / page 6
Chapter 5	$\Delta X \approx p \cdot \dfrac{\Delta\alpha}{180}$	5.1 / page 14
Chapter 8	$H_{max} \approx 0.4 \cdot Br \cdot \left(1 - e^{-2.5 \cdot \frac{D}{P}} \right) \cdot e^{-2\pi \cdot \frac{A}{2 \cdot P}}$	8.1 / page 22
Chapter 8	$A \leq \dfrac{P}{2}$	8.2 / page 23
Chapter 8	$\dfrac{P}{4} < A \leq \dfrac{P}{2}$	8.3 / page 24
Chapter 8	$\Delta\varphi \approx \dfrac{\Delta U_0}{2\pi}$	8.4 / page 25
Chapter 8	$\Delta\varphi \approx \dfrac{\Delta U}{4\pi}$	8.5 / page 26
Chapter 8	Phase error = angle error	8.6 / page 27
Chapter 9	$V = \dfrac{R_2}{R_1 + R_B}$	9.1 / page 28
Chapter 9	$V = 1 + \dfrac{2 \cdot R_1}{R_2}$	9.2 / page 29

12. Glossary

Term	Explanation
Anisotropy	Exhibiting properties with different values when measured in different directions.
Chip layout	The geometrical design of the MR structures and interface connections of the chip.
Coercivity Hc	Necessary magnetic field strength to change a stored magnetization.
Component	Single components that are intended for integration into a module or a system.
FixPitch	FixPitch sensors are adapted to the pole length (pitch) of the measurement scale. The linearity of the sensor is optimized and the influence of interference fields is minimized.
FreePitch	FreePitch sensors are optimized so as to be independent of the pole length (pitch) of the measurement scale. FreePitch sensors are therefore particularly compact and come close to an idealized point-sensor.
Kit	This term describes a construction set of individual, unassembled components and modules that are intended for easy customer-side assembly and integration into a machine or device.
Module	A module from Sensitec comprises several components. The module itself is not yet functional and requires other components - such as a measurement scale - to form a kit or a system.
PerfectWave	Sensors with PerfectWave design provide the best signal quality, highest accuracy and optimal sensor linearity by filtering out higher harmonics in the signal. The linearity of the sensor is assured, even for weak magnetic field measurement.
PurePitch	In PurePitch sensors the FixPitch principle is extended over several poles in order to increase accuracy still further. This arrangement reduces the influence of errors in the measurement scale an improves the immunity to interference fields.
Remanence Br	Strength of magnetization that remains in material after magnetization.
Shape anisotropy	Magnetic anisotropy caused by the geometrical dimensioning of a current-carrying element.
System	A system is a fully functional combination of Sensitec components or modules in a single package. The advantage of the complete system is a minimization of design and assembly effort.
Thin film technology	In this technology thin material layers, typically under 1 µm, are deposited on a substrate.

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