6.4 Application Notes: Magnetics

Measurement Configurations

Two separate methods for the detection of position or rotational motion using magnetic sensors can be distinguished. In the first case, the magnetic flux is varied by approaching or removing a magnet to/from the sensor or vice versa. This mechanism is suitable for position measurement or for non-contact switching. In rotational applications a rotating ring magnet or a ferromagnetic gear wheel modulate the flux through the sensor. This mechanism is applied when angular position or velocity has to be detected. In **figure 34** the possible measurement configurations are shown in detail.

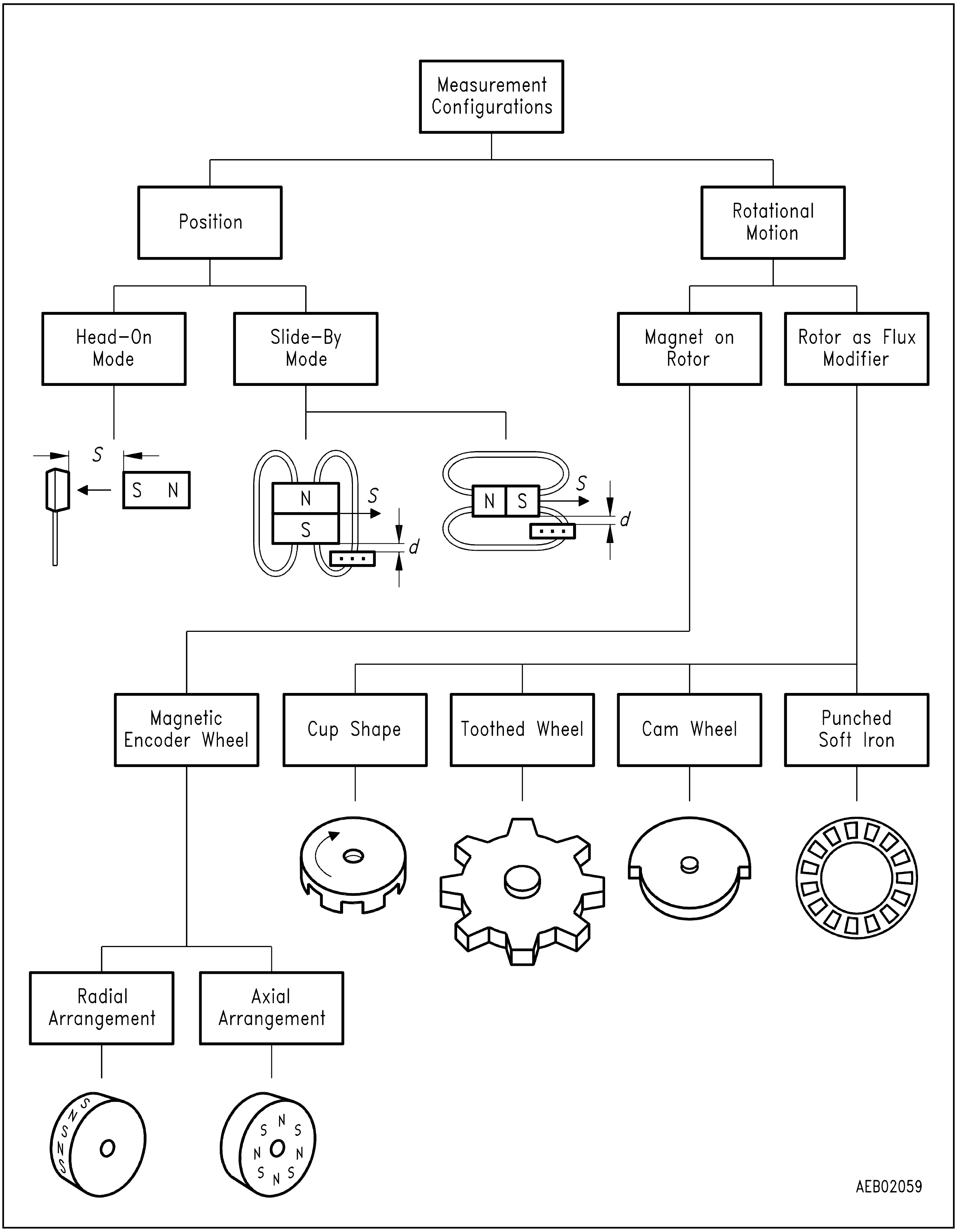

Figure 34
Measurement Configurations

Translational applications consist of two alternative functions, the Head-On Mode and the Slide-By Mode.

Head-On Mode

This is the simplest method with the magnet approaching from the front. Advantages of this mode are the simple mechanical design and the low sensitivity to lateral motion of the magnet. The flux density plot in **figure 35** shows that the displacement characteristics are nonlinear, for position detection the switching points of the sensor therefore have to be very precise. Also, a zero flux state cannot be achieved. Additionally the head-on mode bears the risk of damage to the sensor when the measurement range is exceeded (direct physical contact with the magnet). Unipolar switches, i.e. the TLE 4905 L, are suitable for head-on mode operation.

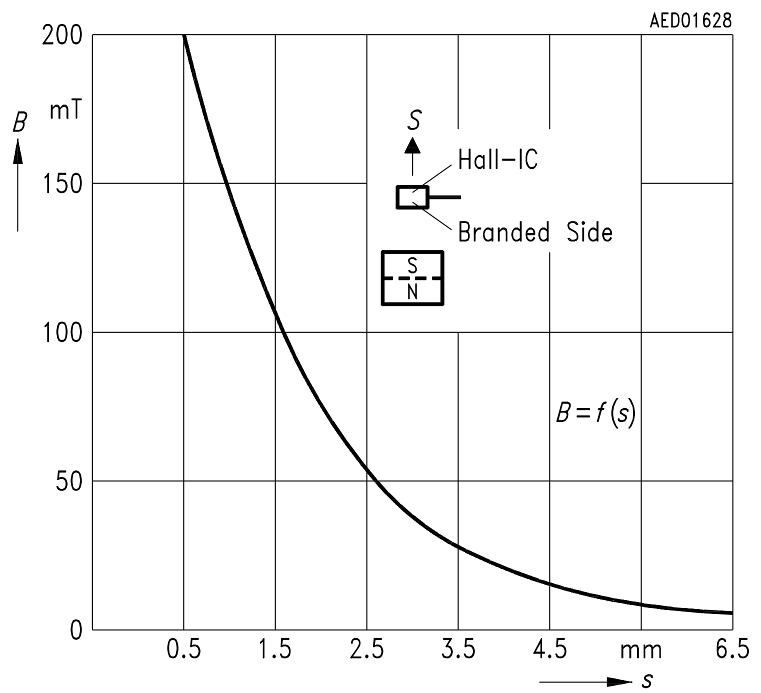

Figure 35
Magnetic Flux Density as a Function of the Distance *S* between Sensor and Magnet (Magnet: VX 145, Vacuumschmelze)

Slide-By Mode A

The magnet is led past the IC with one magnetic pole facing towards the chip surface. With this arrangement steep slopes and a zero or even negative fields are reached (in the case of a passing southpole). This allows for wider switching tolerances of the sensor. Sensor damgage due to overtravel of the magnet is excluded. This mode is, however, very sensitive to the lateral tolerances of the magnet, as the drastic variation of flux density versus air gap in **figure 36** shows. As for the head-on mode, the slide-by mode A is suitable for unipolar switches, i.e. the TLE 4905 L.

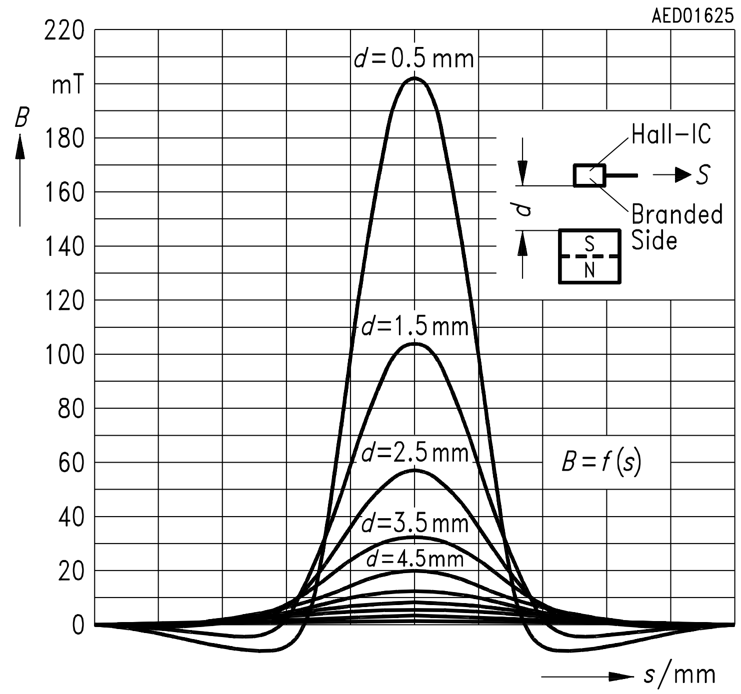

Figure 36
Magnetic Flux Density versus Displacement *S* in the Slide-by Mode A, Distance *d* as Parameter (Magnet: VX 145, Vacuumschmelze)

Slide-By Mode B

The magnet is led past the IC sidewards with both poles perpendicular to the chip surface, as shown in **figure 37**.

Both magnetic poles are used in this application. With this arrangement the highest flux density swing, which is very important for operational reliability, is achieved. Bipolar switches with different hysteresis as well as unipolar switches, i.e. the complete TLE 49x5 family, can operate in this mode.

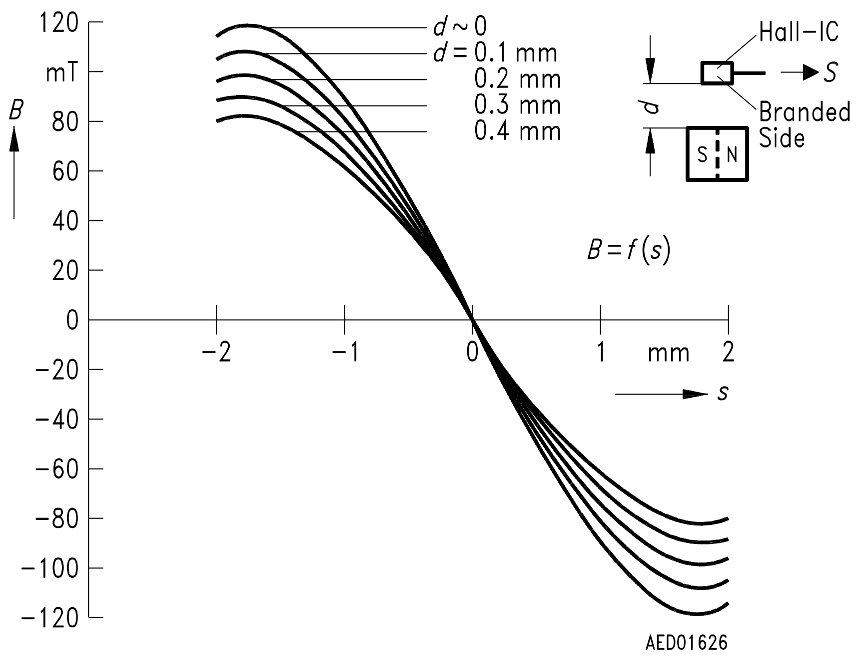

Figure 37
Magnetic Flux Density in the Slide-by Mode B, Distance *d* as Parameter (Magnet: VX 145, Vacuumschmelze)

Rotational applications serve to detect angular position, displacement or velocity. The first decision that must be made is whether the rotor is used as a generator for the magnetic field or as a modulator of the magnetic field strength.

Rotor as Magnetic Field Generator

A magnetic encoder wheel may be used in a radial or axial configuration, as in **figure 34**.

Ferromagnetic Rotor as Flux Modulator

For high precision angular position and speed measurements, rotors that modify the flux through the sensors have several advantages over magnetic rotors. When operating a sensor with a ferromagnetic rotor, a constant magnetic field must be provided by a back biasing permanent magnet attached to the rear side of the sensor. The turning rotor modulates the magnetic field, i.e. a ferromagnetic material in front of the sensor acts as a concentrator and increases the flux density of the magnet through the sensor.

Axial mounting of the sensor requires toothed wheels, whereas radial mounting is performed with vanes or punched soft iron rings. The application with a toothed wheel has the advantage that already existing wheels can be used. Especially for high precision toothed wheel applications, differential sensors based on two Hall cells give best results together with the lowest assembly requirements

Vane applications are very sensitive to radial bearing play, there is, however, only little sensitivity to axial play. Toothed wheels are used in automotive industry for ignition systems. ACPS systems (Active Crankshaft Position Sensing) that require a very precise angular position readout are based on a toothed crankshaft wheel in combination with a differential sensor. Also for speed sensing in gearbox applications, toothed wheels are the obvious solution.

For AWSS systems (Active Wheel Speed Sensing) the rotor wheel can be directly molded into the bearing, requiring therefore a flat punched soft iron wheel. Since the flux density change of a molded punched iron is very small (in the range of a few mT), the sensor must be able to switch very small field changes. Also for this application, differential sensors yield optimum results.

Magnet Choice

The described Hall IC applications always use one or more permanent magnets. Either the magnet itself moves, or its magnetic field is modulated by a ferromagnetic part. For the right choice of the magnet for a specific application, several factors must be taken into consideration.

Mechanical Factors

– Dimensions and tolerances
– Thermal expansion coefficients
– Is there a shaft hole required for the rotating part and what is its maximum eccentricity

Magnetic Factors

– Quantity, alignment and fitting accuracy of the magnetic poles
– Flux density at the specified airgap
– Magnetic temperature coefficient

Environmental Factors

– Resistance of the materials to the environment with regard to temperature, chemical composition and electrical potential

Of special importance are the characteristics and properties of the different permanent magnet materials. The three most important characteristics are the remanence B_R, the coercive force H_C and the density product $B_{H\,max}$:

- The remanence B_R [Tesla or Gauss] is a measure of how high the remaining magentic flux is after full magnetization in a closed circuit.
- The coercive force H_C is the field strength which must be applied in order to bring the flux density B or the magentization J back to zero (${}_BH_C$, ${}_JH_C$).
- The absolute maximum energy product $B_{H\,max}$ [kJ/m^3] is of great significance for the performance of the permanent magnet. It is calculated from the B-H values obtained during the demagnetization of a permanent magnet, see **figure 38**.

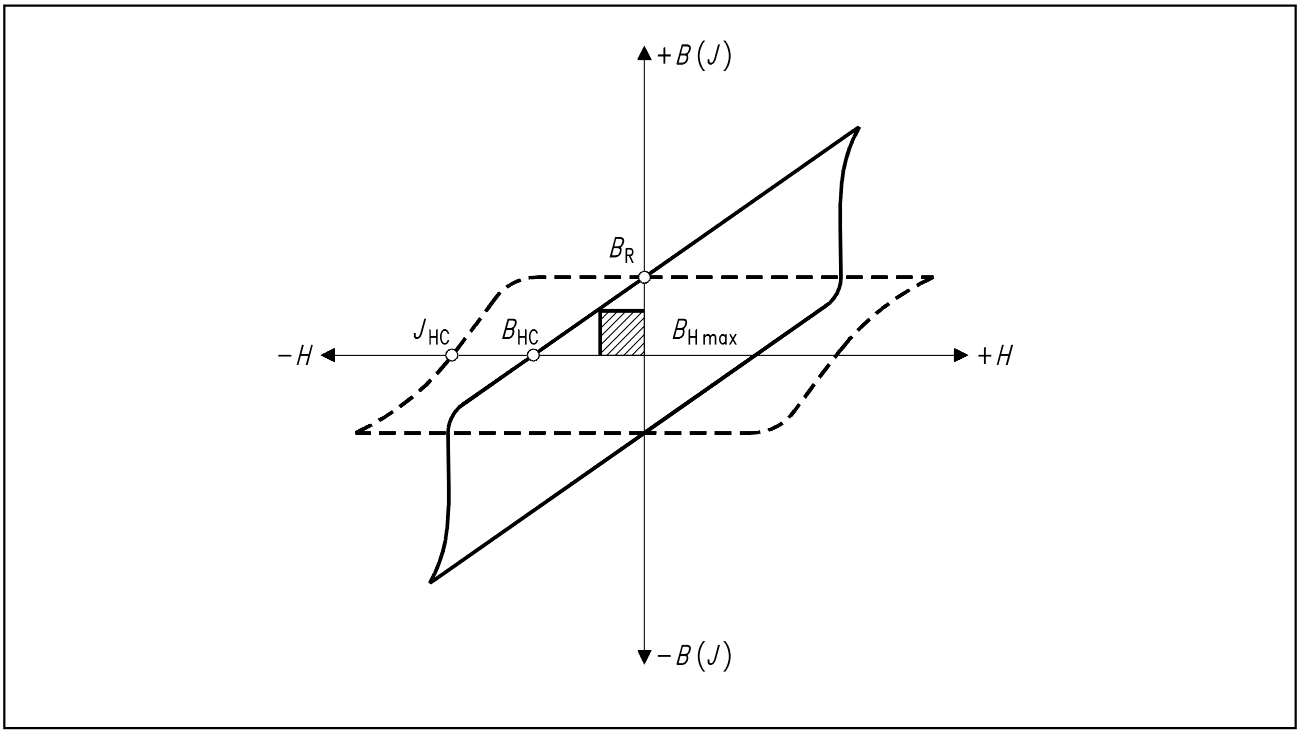

Figure 38
Magnetic Hysteresis Loops

In the following some common permanent magnets and their properties are discussed.

Rare-Earth Cobalt Sinter Material

This material is an alloy of a rare-earth material and Cobalt. Rare-earth materials are for example Samarium or Selen with the corresponding magnet materials Sm_2CO_{17} and $SeCO_5$, respectively. Rare-earth Cobalt magnets have the highest performances of all magnet types, however they are also the most expensive ones. They allow for high temperature ranges, up to about 250 °C for Selen Cobalt and up to 300 °C for Samaraium Cobalt. Also their maximum energy product is by far higher than the ones of other magnets. The long term stability of rare-earth based magnets is very good. Due to the hardness and brittleness, these materials cannot be shaped other than by grinding.

AlNiCo Alloys

As the name implies, AlNiCo magnets are alloys containing Aluminium, Nickel, Cobalt, Iron and additives which are offered in a wide range of properties. Among all magnets, AlNiCo magnets have the best thermal properties, i.e. the lowest temperature coefficient of expansion. The material is easily formed, it can be cast or sintered to any shape from metal powders.

Also the mechanical stability is good. This, and the above properties, make AlNiCo a suitable magnet material for mass production. However, the coercive force of AlNiCo is low and its longterm stability is rather moderate. AlNiCo is too hard and brittle to be shaped.

Sintered Compund Material from Neodymium, Iron and Boron (NdFeB)

As the name says, an alloy of Neodymium, Iron and Boron. This material has a high maximum energy value and a very high field strength. The drawbacks are the low temperature range and the susceptibility to corrosion. Also the relatively high reversible temperature coefficient of remanence must be mentioned.

Barium and Strontium Ferrites

These types belong to the group of ceramic magnets. The ferrites, typically Barium or Strontium, and the base ceramic material are compacted and sintered. A high coercive force and a low price are characteristic for ceramic magnets. As disadvantages the low remanence and the very high reversible temperature coefficient can be mentioned.