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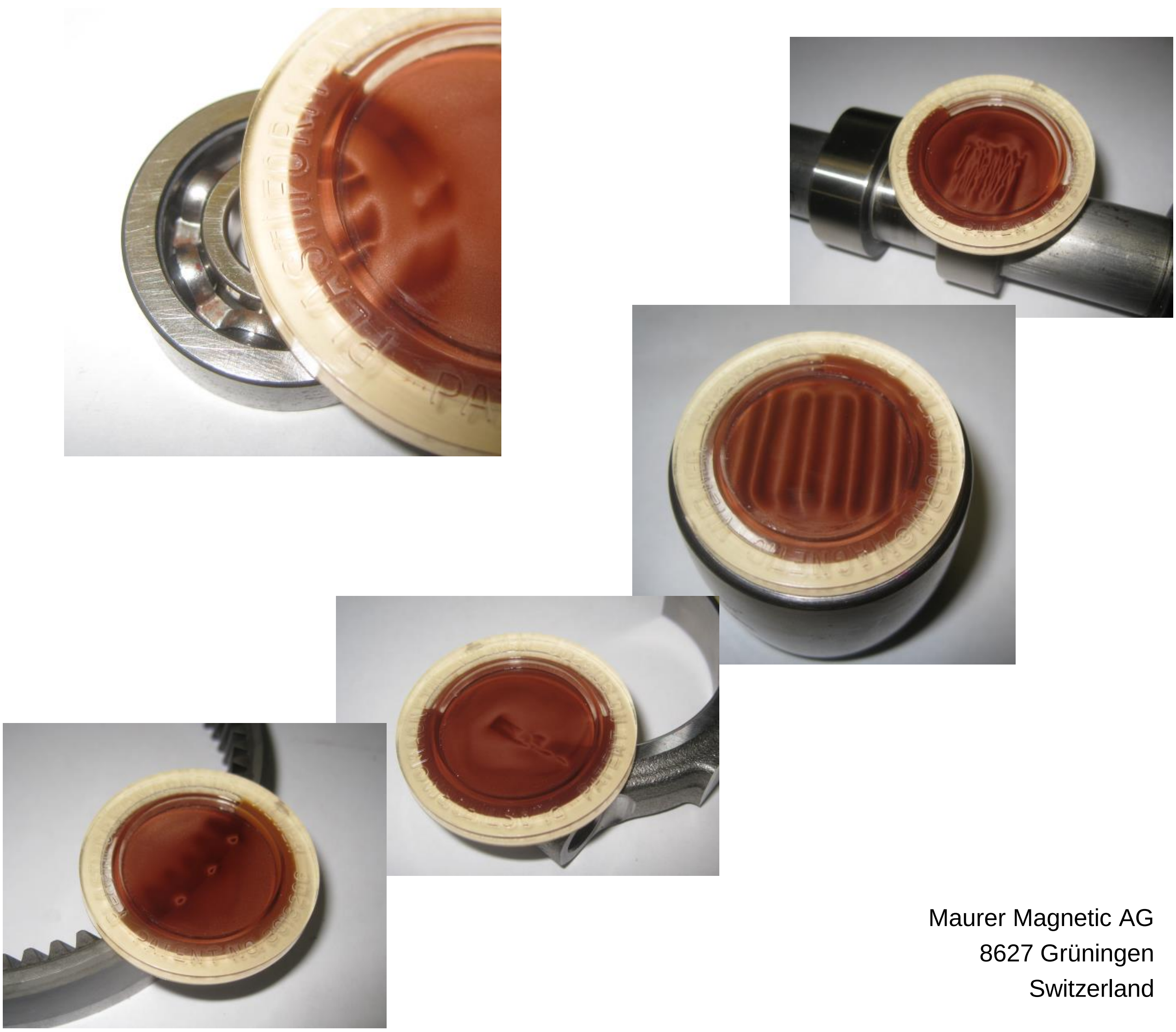
Measuring Residual Magnetism of Ferromagnetic Parts



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- Industrial demagnetizing devices and systems
- Instruments for measuring magnetic fields
- Degaussing services
- Troubleshooting in residual magnetism
- Permanent magnets and magnetic systems


Abstract

Modern manufacturing processes use increasingly complex and sensitive manufacturing processes, which are dependent of a very high quality of the intermediate products. Manufacturing processes, e.g. coating, welding, shaping or stamping processes depend on a minimum possible residual magnetism on materials, parts, tool, and machinery. The assembly of modern internal combustion engines, precise ball bearings, gear parts, electronic components, and medical injection systems, affords a strictly clean manufacturing environment. To meet the more and more demanding requirements on residual particles, cleaning processes rely on the absence of an residual magnetism. For these reasons, the demand for low residual magnetism has become a decisive quality criterion.

The accurate measurement of residual magnetism on ferromagnetic parts is therefore an upcoming and growing requirement. At the time of publication of this document, no standards for the measurement of residual magnetism on ferromagnetic parts have yet been issued.

Residual magnetism of components is usually measured using hand-held magnetic field strength meters. Other common terms for field strength meters are Gaussmeter or Teslameter. By its nature, residual magnetism can be measured only on the surface of a part. The value indicated depends on the construction and design of the probe, its location referring to the surface, and the configuration of the magnetic field.

Typical production parts made of ferromagnetic steel show a highly inhomogeneous pattern of residual magnetism. Distinct magnetic poles show up, creating stray fields escaping from the surface that protrude into the open space only on a short distance. Beside adequate instrumentation, this calls for an adequate search method for finding the maximum residual magnetism on the surface.

The strength of the residual magnetic field on the surface of the material has a crucial impact on the quality of the following industrial processes :

- Industrial cleaning (removal of sticking of ferromagnetic particles)
- Galvanic coating processes (e.g. nickel or chrome coatings)
- Welding processes using electric current (e.g. electron beam welding)

Another important impact is given by ambient magnetism, such as the magnetic field of earth. These fields create an induced magnetism in ferromagnetic materials, which adds up vectorially to the residual magnetism inherent in the material. Induced magnetism depends on the location and the position of the part within its ambient surrounding.

The mostly inhomogeneous residual magnetism of parts and the impact of the ambient magnetic field on the measured values afford appropriate measuring methods and equipment. Without taking care of this, measurements of residual magnetism are imprecise and poorly reproducible. In the range of 0...4A/cm, deviations of over 100% in subsequent readings are not uncommon. The target limits for residual magnetism, as derived from risk assessments, are just in this critical range between 2...4A/cm (2.5...5 Gauss).

This paper introduces appropriate procedures and instruments for measuring residual magnetism, that improve the accuracy and reproducibility in order to achieve this target.

The following three factors play a crucial role:

- The magnetization of the part (dipole or fine pole magnetism)
- The influence of the magnetic field of earth and other ambient magnetic fields
- The search method for finding the maximum residual magnetism on surfaces.

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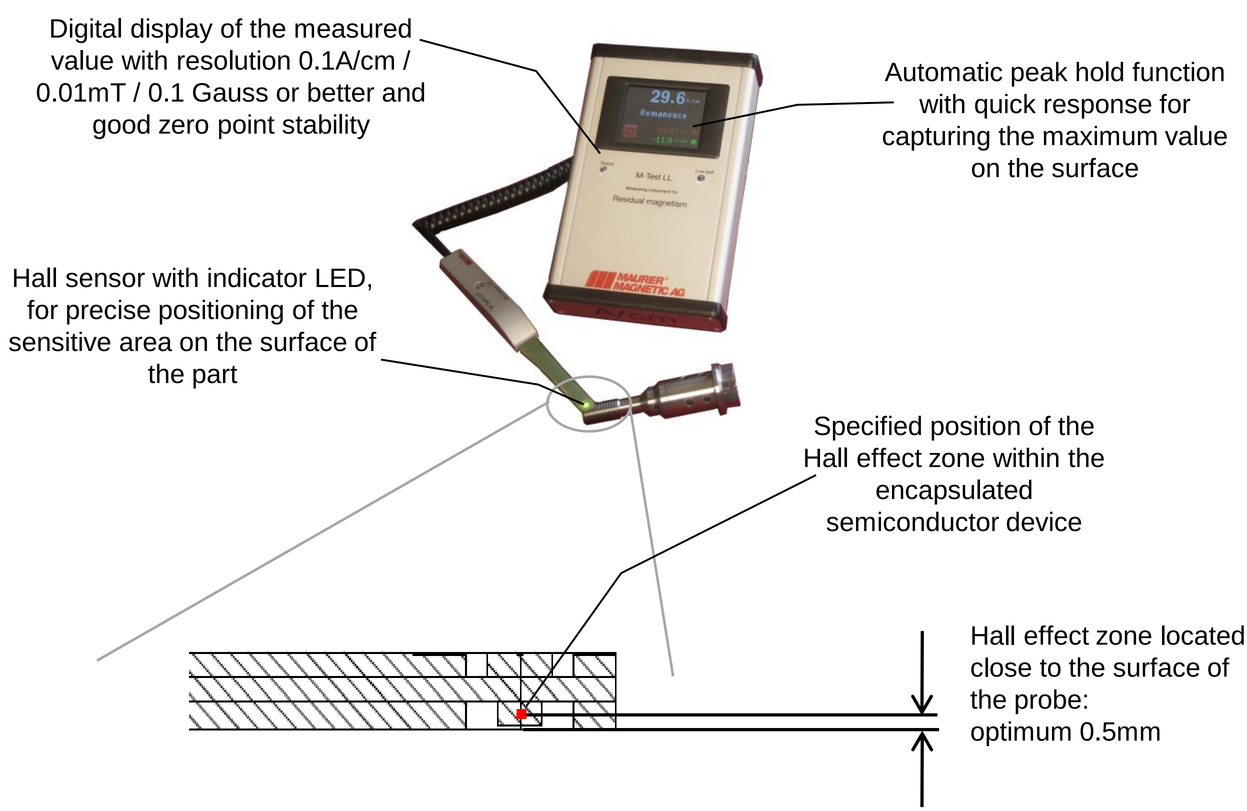
Configuration and strength of magnetic fields

The density of field lines decreases disproportionately with increasing distance from the magnetic pole. The rate of this decrease depends essentially on the size and configuration of these poles. Between these poles, we find magnetically neutral zones acting as pole separations. In the most simple case, two opposite poles may be theoretically treated as a dipole. The field strength H of a magnetic dipole decreases with the distance r according to the law $H \sim 1/r^3$.

The field strength close to the surface of a part showing inhomogeneously distributed magnetism may be evaluated only by measurements. According to the rule given above, the field strength decreases on a distance of a few millimeters from the surface to very low values, below 1A/cm. Close to the surface, the field strength is many times higher and depends mainly of the material properties. It is this value that is significant for the effects of residual magnetism.

The differences of residual magnetism values by measuring with different instruments are mostly due to the construction of the probe and its suitability for accessing and getting close to small area fields located on the surface of part.

Properties of an instrument suitable for measuring residual magnetism



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Residual magnetism of ferromagnetic parts

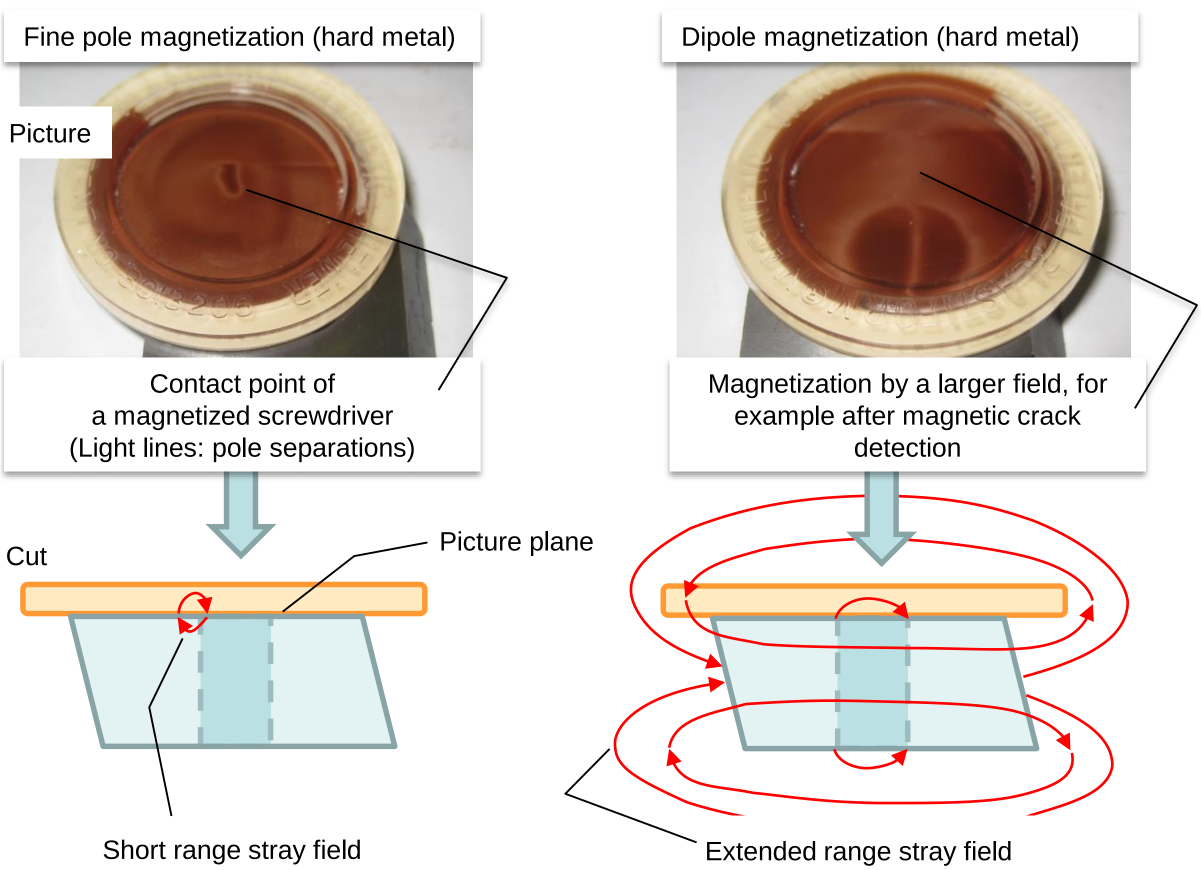
The residual magnetism of a part is largely dependent on the previous production and handling processes.

The first magnetic influence of the part is already happening in the steel mill. Under the influence of the magnetic field of earth, annealing, rolling, and transport processes may magnetize the steel with great depth up to values of 10...40A/cm on the surface. After these processes, the residual magnetism of the crude steel tends to a dipole magnetization. The same kind of dipole magnetization is created by magnetic crack detection equipment, as it is frequently used in industry.

Many times in the course of manufacturing, a part comes in contact with more or less strong magnetic fields of random polarity. Magnetic handling equipment, tools, collets, cutting tools, clamping devices, or induced magnetic fields etc. continue to magnetize or to change locally the polarity of the part. These magnetic effects tend to imprint fine poles on the part surface (see pictures on the front page of this paper).

For better understanding the effects, the residual magnetism on ferromagnetic parts is split up here in the following categories:

- Dipole-magnetization of the part with one main pole separation
- Magnetization with short stray field range (fine pole magnetization)
- Combinations of the two magnetizations on different locations of the part

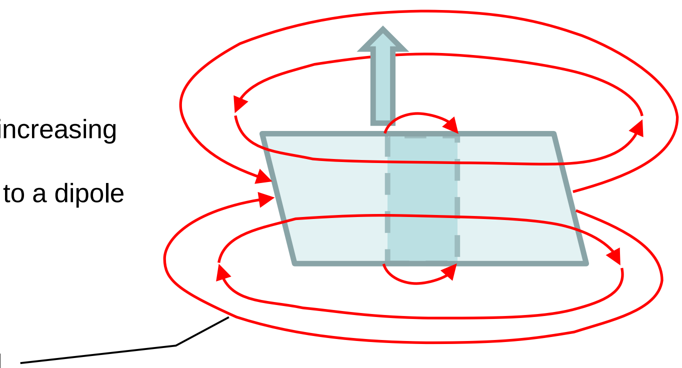


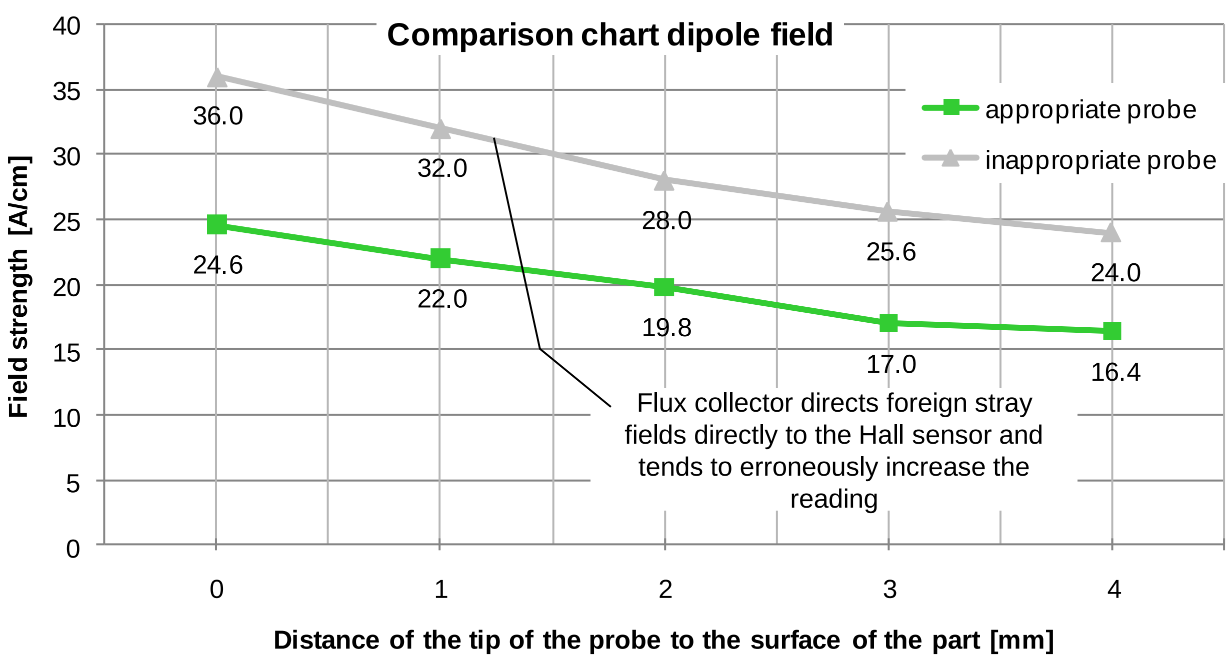
Field strength at increasing distance from the part surface

Suitable probe:
- distance of the Hall effect zone to the part surface ~0.5mm
- Probe without flux collector
- Accurate positioning

Inappropriate probe:
- Distance of the Hall effect zone to the part surface unknown
- Probe with flux collector
- Inaccurate positioning

Comparison between both probes:
Residual magnetism measurement at increasing distance from the part surface.
The stray field of the part corresponds to a dipole field.





Field strength at increasing distance from the part surface

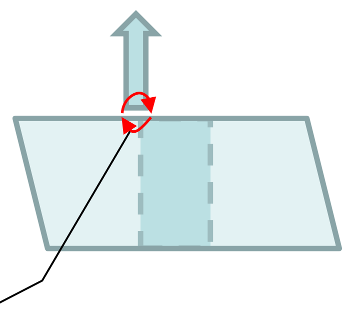
On parts with wide range stray field (dipole magnetization), probes of different design show little difference in readout of residual magnetism.

Small pole fields are detected and correctly measured only with probes of which the Hall effect zone is closer to the tip than 1 mm.

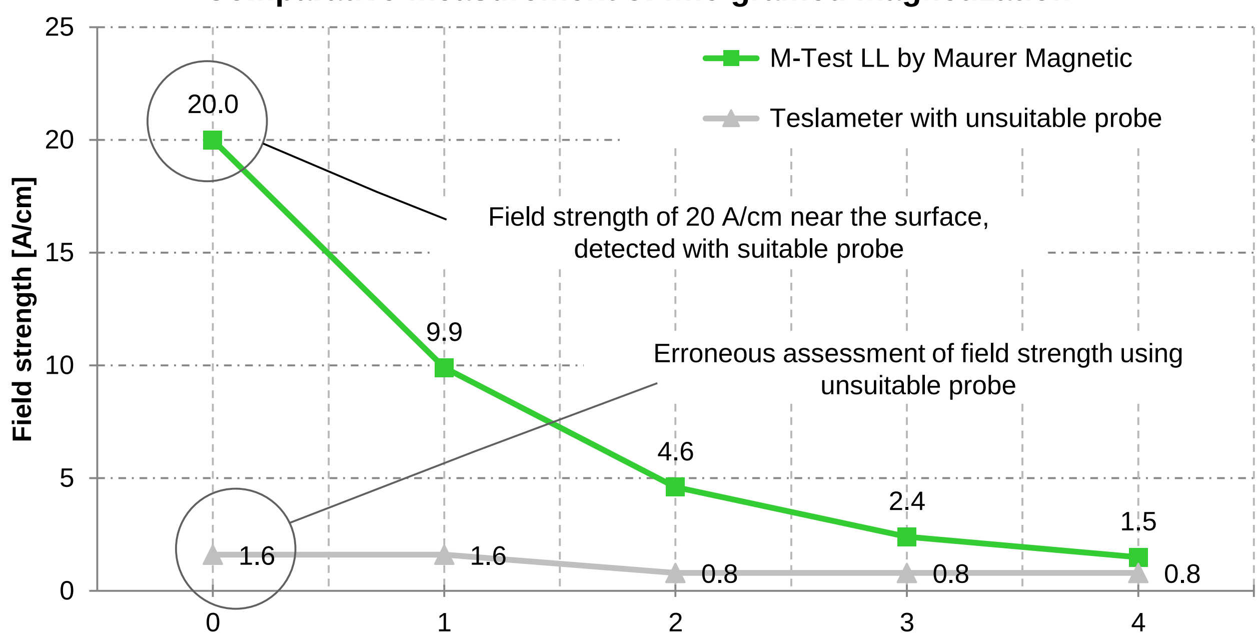
Hall probes equipped with a flux collector on the Hall element smoothen and suppress the stray fields of fine pole residual magnetism, which leads to erroneous readings.

The use of magnetic field measuring instruments with inappropriate probes leads to an incorrect assessment of residual magnetism. With inappropriate instruments, even strong fine pole magnetic fields remain undetected.

Comparison between probes of different design:
Residual magnetism measurement at increasing distance from the part surface.
The residual magnetism of the part corresponds to a fine pole field.



Comparative measurement of fine-grained magnetization



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Induced magnetic fields

The magnetic field of earth has an average value of ~ 0.03 ... 0.06mT. The direction of the field lines running in the open air is substantially parallel to the N-S axis, with an inclination of about 45° to the Earth's surface. Inside buildings, the magnetic field of earth is further distorted in direction and strength by surrounding ferromagnetic structures, e.g. beams of steel or reinforced concrete.

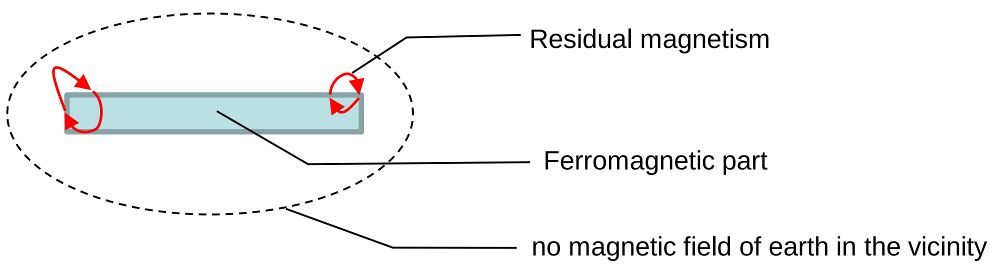
Ferromagnetic materials collect and conduct magnetic fields due to their high permeability. A ferromagnetic part attracts the lines of surrounding magnetic fields (e.g. magnetic field of earth). An induced dipole magnetic field appears around the part. The strength of the induced magnetic field depends on the permeability, geometry, size, and orientation of the part in the magnetic field of earth.

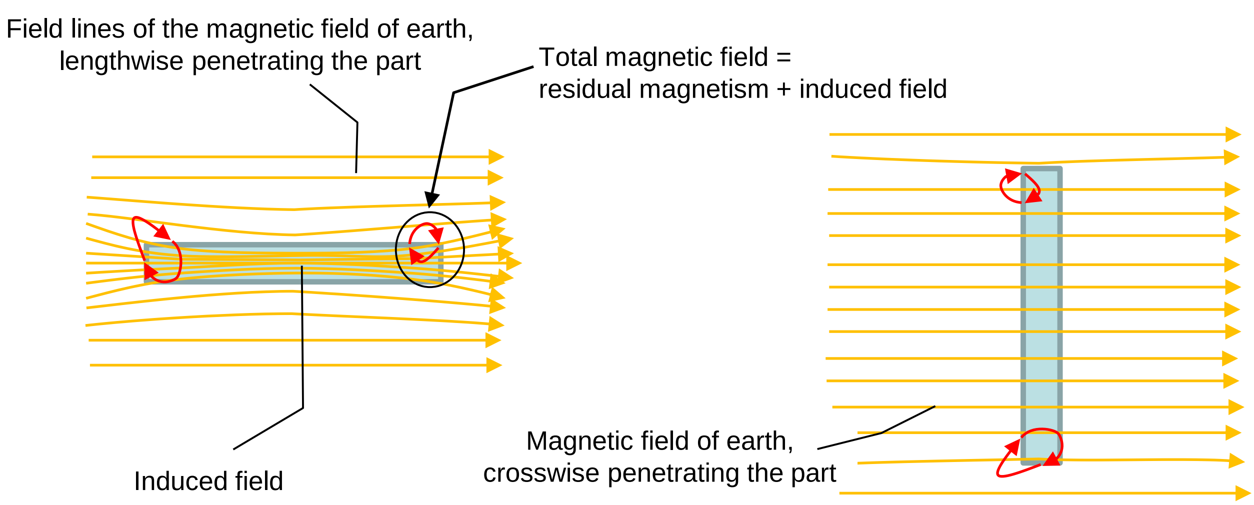
The magnetic field of earth induces magnetic poles on both ends of any elongated ferromagnetic part. This induced magnetism superimposes residual magnetism. Depending on orientation in space, variations of about +-1...4A/cm may occur when residual magnetism is measured within the magnetic field of earth. For a elongation ratio L/D of more than 4, the influence of the geomagnetic field and the orientation of the body have to be taken into account.

Orienting the part perpendicular to the ambient magnetic field weakens the induced magnetism.

Under the influence of the magnetic field of earth, the magnetic field measured is composed of the vectorial components of residual magnetism and the induced magnetism.

Since measured values of ferromagnetic parts cannot be reproduced at different ambient conditions, measuring results of magnetic field instruments are only comparable in identical, homogeneous magnetic fields.





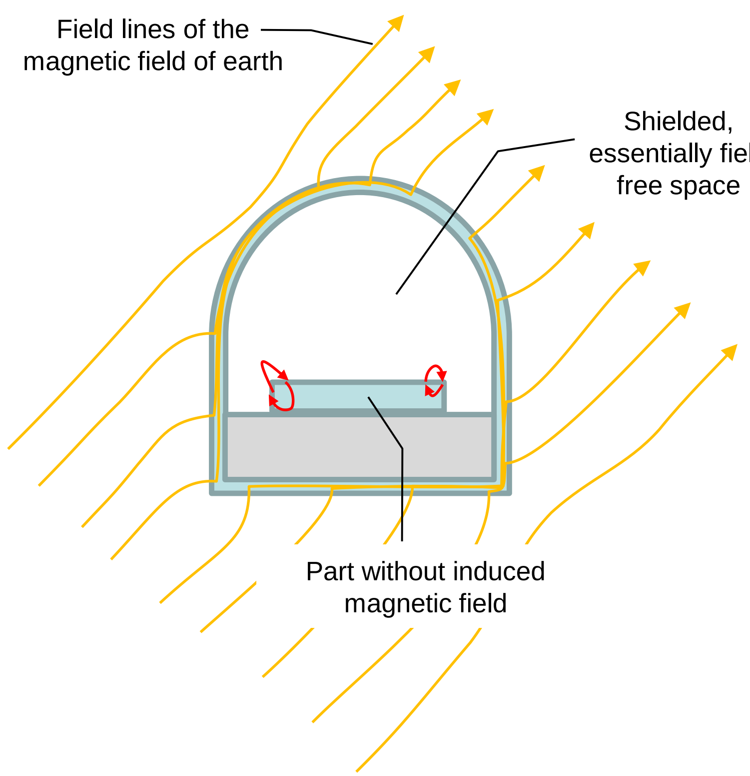
Measurement inside magnetic field shielding

Residual magnetism measurement is not affected anymore by induced magnetic fields when the measurement is conducted inside a magnetically shielded environment. The effect of the magnetic field of earth can be avoided in two different ways.

The passive shielding chamber consists of walls made of highly permeable material. The magnetic field of earth is diverted into the wall of the shield, and the influence of the magnetic field inside the chamber decreases approximately by a factor of 3.5...4 (total shielding factor for all three spatial dimensions). This is sufficient for reproducible measurements of residual magnetism. Passive shields are well suited for measurements of parts up to a size of approximately 300x300x300mm (chamber >> part).

The second solution consists of a 3-dimensional Helmholtz coil. The sides of the shielded space consist of coils, which compensate the magnetic field of earth by opposing fields. Helmholtz coils are also suitable for measurement of parts with larger dimensions.

Operation of a passive shielding chamber (Zero Gauss Chamber)



Zero Gauss Chamber
for parts up to ~250x250x250mm

3D Helmholtz Coil
for parts up to ~1500x1500x1500mm

Typical values of induced magnetic fields

-Hall probe attached on contact at the end of the part
-Magnetic field of earth ~0.05mT

Part	**Magnetic field of earth shielded;** Orientation of the part inessential **[A/cm]**	**Part oriented along the magnetic field of earth [A/cm]**	**Part perpen-dicular to the magnetic field of earth [A/cm]**	**Maximum induced field [A/cm]**
Ball bearing steel Cylinder roll LxD = 40x50mm L/D = 0.8	0.2	-0.3	0.6	0.5
Chrome steel Rod LxD = 100x4mm L/D = 25	1.9	1.7	2.9	1.0
Free cutting steel Rod LxD = 1500x15mm L/D = 100	7.2	5.8	8.9	1.7

The influence of the measuring method

The detection of the technically critical maximum value of residual magnetism on ferromagnetic parts requires a suitable method. The following cases represent the greatest challenge to the methodology:

- Parts measured while being exposed to the magnetic field of earth
- Parts with short range of the stray field (fine pole residual magnetism)

Reproducible measurements of parts exposed to the magnetic field of earth

In this case, the measured values depend strongly on the direction and strength of the geomagnetic field. Reinforced concrete, steel structures, machines, or neighboring power lines with high electrical currents etc. distort the magnetic field of earth. Field strength fluctuations between 0…600% of the value of the open-air geomagnetic field (0.03...0.06mT) are common in industrial buildings. The strength of the induced magnetic field in ferromagnetic parts is directly connected with the ambient field strength present in the measuring environment. Strong ambient fields may prevent measurement of residual magnetism.

Reproducible measurements can only be achieved by measuring in a field-free environment. If a screening is not possible, a reproducible result may be obtained by measuring the part in three different orthogonal orientations in space, averaging the six values obtained.

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Searching for maximum values on surfaces with fine pole magnetism

Because of the limited range of fine pole stray fields, the interesting surfaces of the part must be scanned with the probe extensively to detect the maximum values. For this task, a "peak hold“ function on the meter is recommended, which automatically retains the highest reading. The operator can concentrate on the accurate guidance of the probe on the part during the measurement. This ensures that maximum values can be reliably detected even for fine multi-pole residual magnetism.

The specification and implementation of the search method for the maximum values of residual magnetism is the key to get reproducible results.

Specifying limits for residual magnetism

A residual magnetism limit defines the maximum value acceptable on the entire surface or on a specific functional area of the part. The N-S polarity is irrelevant for the most common applications (preparation for cleaning, welding, coating).

Reliable verification of parts regarding limits of residual magnetism requires the following conditions:

- Minimum distance of the Hall effect zone to the part surface (appropriate measuring instrument)
- Measurement without influence of ambient fields (shielding of the magnetic field of earth)
- Measurement by qualified personnel (appropriate search method)
- Specified method for searching the peak value of residual magnetism.

Magnetism units conversion table

Unit Reading direction ->	**A/cm**	**A/m**	**mT**	**Gauss or Oerstedt**
1 A/cm =	-	100	0.1256	1.256
1 A/m =	0.01	-	0.001256	0.01256
1 mT =	7.96	796	-	10
1 Gauss or 1 Oerstedt =	0.796	79.6	0.1	-

Relationship between field strength H [A/m] and flux density B [mT]:
$B = \mu_r \times \mu_0 \times H$, in air $\mu_r \sim 1$; permeability of vacuum $\mu_0 = 1.256 \times 10^{-6}$ [Vs / Am]

