Residual magnetism of steel products:

Physical background, causes, existing field configurations, hard magnetic spots, recurrence of magnetism, concentration effects of magnetic fields
Quality criterion low residual magnetism

Modern production methods are increasingly based on complex and highly sensitive fabrication processes which are dependent on highest quality in intermediates. Examples like coating, molding or punching processes require lowest possible residual magnetism values on the produced parts as well as on tools to avoid disturbances due to magnetic sticking of particles.

Conventional welding methods work only reliably up to a certain residual magnetism level, otherwise disturbing magnetic arc blow may occur.

Assembly of state-of-the-art internal combustion engines, precision roller bearings, gearbox components, electronics parts or medical products are subject to strict cleanliness criteria. The trend to increased technical cleanliness of products calls for lowest possible residual magnetism on parts. This guarantees an efficient performing of industrial cleaning methods.

Manual or automated handling of microscopic ferromagnetic components such as injection needles for medical applications or miniaturized parts for the watchmaker industry is already disturbed or even impractical at low residual magnetism.

Non destructive testing methods based on eddy current for crack, grinding burn-, or material detection is only reliable if the tested products have lowest possible residual magnetism fluctuations. Otherwise the testing process will result in a high "pseudo" rejection rate.

Electron beam welding and hardening, transmission electron microscopy, photolithography and radiotherapy need for process stability a magnetically neutral environment in the region of the electron beam.

These are some reasons why the call for low residual magnetism has become a decisive quality criterion.
Sources and units of magnetism

• **Physical sources of magnetic fields**
  – Ferromagnetic elements, such as iron, nickel and cobalt
  – Electric currents, e.g. current carrying coil
  – Temporal change of an electric field (Maxwell equations)

• **Units of magnetic fields**
  – Magnetic field strength \( H \) (A/m or Oersted)
  – Magnetic flux density \( B \) (Tesla or Gauss, 1mT ^= 10Gauss)
  – Link between both units: \( B = \mu_0 \mu_r H \)
  – Air has a \( \mu_r \approx 1 \), transformation: 1mT ^= 7.96A/cm

• **Examples of H-fields near the surface of a part**
  – Neodymium permanent magnet ~ 3'500A/cm
  – Typical value of residual magnetism on a steel part ~ 1....100A/cm
Microscopic and macroscopic magnetism

- **Microscopic magnetism**
  - Magnetic moment of atoms

  Chaotic magnetic moments. (Field vectors cancel each other out).

  Sum of field vectors

  Aligned magnetic moments

- **Macroscopic magnetism in the ferromagnetic material**
  - Spontaneous orientation of the magnetic moments due to material and quantum mechanical effects.
  - Grouping of magnetic moments to the domain structure (domain = Weiss domains).
  - The increase of an external field $H$ polarizes the domains by Barkhausen jumps and the magnetization of the part increases in the direction of the external field.

  Oriented domains.

  Rectified (summed) field vectors lead to measurable magnetism at the surface.

Domains (~10µm…1mm)  Bloch wall

Graphic s: Wikipedia
Hysteresis loop describes the magnetic characteristics of a ferromagnetic material

- **Remanence** $B_r$:
  Magnetization that stays after removal of external field $H$ (closed magnetic loop).

- **Magnetic saturation** $B_s$:
  Complete alignment of magnetic domains. This equals the max. possible magnetization of a material.

- **Coercivity** $H_c$:
  Demagnetizing field that drives the magnetization back to zero.

- **Initial magnetization curve**
  Path of initial magnetization.
Factors influencing the residual magnetism of ferromagnetic materials

The coercive force essentially determines the amount of residual magnetism that stays in the material after a magnetization.

The table below describes the key influencing factors on the magnetization of steels.

<table>
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<th>Low alloy, low carbon steels (e.g. structural steel, mild steel, case hardening steel, etc.)</th>
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Residual magnetism inducing processes in production environments

- Crack testing (magnetic powder and flux leakage testing)
- Usage of lifting magnets or handling magnets (permanent and electric)
- Usage of chucking equipment (permanent and electric)
- Installation of magnetic bases (e.g. gauge bases)
- Welding processes (high DC or AC currents)
- Processing with magnetized tools, magnetic chucks etc.
- Handling with magnetic tools, claws etc.
- Galvanic- and electro discharge processes (chrome plating, ECM, EDM ...)
- Some PVD coating processes (e.g., magnetron sputtering)
- Forming processes (structural change in the material)

Typical limit values automotive: 2…5 A/cm, measuring distance to surface?

- Vibrations + magnetic field of earth
- Magnetic field of earth

[A/cm] - Values in the arrow apply to Hall effect zone distance to the surface of 0.5mm
Residual magnetism corresponding to magnetic dipole field configuration

The magnetization of a ferromagnetic part in a main direction causes a magnetic dipole. This magnetization corresponds for example to a bar magnet.
A magnetic dipole leads due to the high pole spacing in relation to the part size to relatively large volume stray fields.
At edges and corners the highest residual magnetism has to be expected.
In larger distance, the dipole field $H$ decreases with the third power of the distance $r$ ($H \sim 1/r^3$).
The 2D FEM representations were created with a magnetic field finite element analysis software.

Possible causes:
– Storage or transport of large parts with high slenderness ratio parallel to the magnetic field of earth
– "Freezing" of static field components (e.g., magnetic field of earth) during cooling of steel
– Crack detection with DC fields
– Conventional welding with DC current components
Residual magnetism according to superficial, fine pole field configuration

More frequently occurring and virtually "normal" state for ferromagnetic parts is a fine pole, superficial residual magnetism.
On parts made of hard steel (high Coercivity) the magnetic points on the surface show generally much higher residual magnetism and are more clearly demarcated than on soft steel. This superficial residual magnetism usually has a chaotic structure.
The residual magnetism maximum does not necessarily lie at corners or edges, but can occur anywhere on the surface. To discover the magnetic spots on a surface, the entire part surface must be scanned by a residual magnetism probe with small measurement distance to the surface (0.5mm).

Possible causes:
- Direct contact to tools, collets, tool holders etc. with increased residual magnetism
- Use of magnetic lifting or clamping systems
Hard magnetic spots

Hard magnetic spots are local spots in the material with high coercive fields due to impurities, inclusions or locally modified alloy composition. On hard magnetic spots increased residual magnetism is measured. These spots may cause a magnetization of the adjacent material under certain circumstances (for example vibration or shock).

To discover hard magnetic spots on a surface the entire part surface has to be scanned by the residual magnetism meter probe.

The demagnetization of these spots needs significantly more field strength than for other regions of the material, due to the high Coercivity.
Recurrence of residual magnetism on ferromagnetic parts

Residual magnetism occurs after machining, examples: Sawing, milling, drilling, turning, grinding etc.

Material is getting magnetized, reasons:
Vibration, shock and in some cases steels may re-magnetize after a relatively short time by itself

Possible situations

Ferromagnetic part
Exemplary illustration of a magnetized region or a hard magnetic spot in steel. In this situation no residual magnetism is measured from outside (e.g. Magnetic region trapped due to demagnetization with insufficient penetration depth)

Residual magnetism on the surface (emerging field lines)

Residual magnetism on the section

Residual magnetism occurs after machining, examples: Sawing, milling, drilling, turning, grinding etc.
Field concentration due to direct contact, narrowing, edges and corners

Narrowings, edges and corners on ferromagnetic parts lead due concentration effects to increased field strengths and field gradients.

Field concentration on an edge

Field concentration between a narrowing
If the field strength exceeds a critical value, the residual magnetism transfers from one surface to the other

Field concentration due to direct contact between the two rollers.
Residual magnetism transfers increasingly at the contact points

External field, e.g. magnetic field of earth
• Maurer Magnetic AG, the specialist for
  – Industrial demagnetizers
  – Magnetic field instruments
  – Demagnetization services
  – Troubleshooting in magnetism
  – Magnets and magnet systems