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MATERION

TECHNICALTIDBITS

MATERION PERFORMANCE ALLOYS

MAGNETIC FIELDS AND UNIT SYSTEMS

Alphabet Soup. – Learn about the different, not always interchangeable units used in the science of magnetism.

- Gaussian / cgs / emu Units
- SI Units
- Magnetic Induction ($\vec{B}$)
- Magnetic Moment ($\vec{M}$)
- Volume Units
- Mass Units

The next issue of Technical Tidbits will discuss magnetization curves.

Those involved in the field of engineering use many different units. The SI system is the most common, along with the US imperial system, the British imperial system, and variants of the metric system such as cgs. Many engineers are comfortable working with different unit systems, and it is usually straightforward to convert quantities from one system to another. However, the units used in the study of magnetism are different, and simple conversions from one system to another are not always possible. In electromagnetism, the two unit systems most often used are the **SI system** and the **cgs (Gaussian or emu)** systems. (Here, emu is short for electromagnetic units)

When considering the response of a material to an external magnetic field, the governing equation in SI units is $\vec{B}=\mu_0(\vec{M}+\vec{H})$. In cgs units, the governing equation is $\vec{B}=\vec{H}+4\pi\vec{M}$. The major difference between the SI and cgs systems is how they deal with permeability (and where the term 4π fits in the equations). In the SI system, μ0 (the free space magnetic permeability) is $1.257{\cdot}10^{-6}$ H/m = $4\pi{\cdot}10^{-7}$ T·m/A. In the cgs system, $\mu_0=1$. Therefore, the 4π term is hidden in the 1st equation above.

In these equations, $\vec{H}$ is the external magnetic field. $\vec{M}$ is the magnetic moment, which is the internal magnetic field generated by the material in response to the applied external field. $\vec{B}$ is the **magnetic induction**, which is the sum of the external applied field and the internal field generated by the material in response. Since the **magnetic moment ($\vec{M}$)** can either add to or oppose the applied magnetic field, the magnetic induction can be larger or smaller than the original applied field.

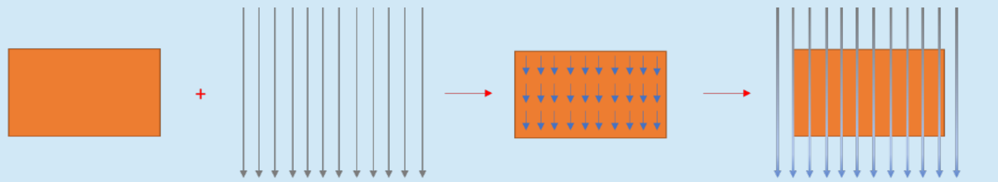

Figure 1 – Representation of Inductance.
A paramagnetic material (far left) with no magnetic fields around, is suddenly placed in an applied magnetic field (second from left). This generates a magnetization response in the material (second from right), resulting in an overall magnetic induction (far right), which is the sum of the applied field and the material response. B is stronger than H for this paramagnetic material. If it were diamagnetic, B would be weaker than H.

The magnetic field strength ($\vec{H}$) is measured in Amperes per meter (A/m) in SI units, and in Oersteds (Oe) in the cgs system. 1 A/m is the field strength of at the center of a 1 m diameter circular conductor carrying a current of 1 Ampere. 1 Oe is 10^3/4π A/m.

Induction ($\vec{B}$) is measured in tesla (T) in the SI system and gauss (G) in the cgs system. 1 T = 1 kg/As^2, and 1 T = 10^4 G.

Within each unit system, the magnetization ($\vec{M}$) depends on whether you are measuring the field strength per unit volume, or the field strength per unit mass. This adds further complexity to magnetic measurements. If you are comparing magnetization curves of two different materials, it is important to ensure that the same units of measurements were used including whether the magnetization was measured on a volume or mass basis. Therefore, knowledge of the material's density would be required to convert between the units.

MAGNETIC FIELDS AND UNIT SYSTEMS (CONTINUED)

The last quantity to consider is magnetic flux, which is measured in webers (Wb) in SI, and in maxwells (Mx) in the cgs system. 1 Wb = 1 kg m^2/As^2, and 1 Mx = 1068 Wb.

	SI Units	Gaussian/cgs/emu Units
Governing Equation	$\vec{B}=\mu_0(\vec{M}+\vec{H})$	$\vec{B}=\vec{H}+4\pi\vec{M}$
Free space permeability (μ_0)	$1.257\cdot10^{-6}$ H/m $4\pi\cdot10^{-7}$ T·m/A	1
Magnetic Field Strength ($\vec{H}$)	A/m	oersted (Oe)
Magnetic Induction ($\vec{B}$)	tesla (T)	gauss (G)
Volume Magnetization ($\vec{M}$)	A/m	emu/cm^3
Mass Magnetization ($\vec{M}$)	A·m^2/kg	emu/g
Magnetic Flux (Φ)	weber (Wb)	maxwell (Mx)

Table 1 – Units used in electromagnetic measurements.
Many of the units are named after people who made significant contributions to the study of electromagnetism. Note that there are significant differences between the SI and cgs unit systems. Particularly, in the cgs system magnetic permeability is dimensionless and emu is not really a unit, but more of a dimensionless placeholder. The cgs systems make electromagnetic calculations easier by taking permeability out of the equations, but the results are not consistent with units used in other physics and engineering disciplines, unlike SI units

For the sake of completeness, there are other variants of these systems used as well. One variant of the SI system uses the governing equation $\vec{B}=\mu_0(\vec{M}+\vec{J})$, where $\vec{J}$ is the magnetic polarization. In this system, magnetic induction is measured in Wb/m^2.

The key takeaway in all of this is that the you need to exercise extreme caution in converting magnetic properties from one unit system to another, for the simple reason that the basic governing equations are different depending on which units you use. This means that equivalent units are not easily interchangeable, as they would be in other science and engineering disciplines.

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Materion Performance Alloys
6070 Parkland Blvd.
Mayfield Heights, OH 44124

MATERION

Sales
+1.216.383.6800
800.321.2076
BrushAlloys@Materion.com

Technical Service
+1.216.692.3108
800.375.4205
BrushAlloys-Info@Materion.com

Written by Mike Gedeon of Materion Performance Alloys Marketing Department. Mr. Gedeon's primary focus is on electronic strip for the automotive, telecom, and computer markets with emphasis on application development.

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