

MAGNETIC MATERIALS OVERVIEW

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Magnetic materials provide the "driving force" that turns our electric motors, generates electricity in power stations and sound in our speakers, and stores information on our credit cards and computer disks. Materials science has created magnetic materials far more powerful than those available only a few decades ago, resulting in a tremendous impact on modern technology.

Review of magnetism basics

Magnetic fields are created by electric charges in motion (electric currents, orbital motion of electrons, SPIN of electrons)

Magnetic fields exert forces on electric charges in motion (current-carrying wires, charged-particle beams, orbital motion of electrons, SPIN of electrons)

Materials categories

If atoms have no net spin, materials are diamagnetic (weakly repelled by field)

If a net spin, but uncoupled to neighbors, paramagnetic (weakly attracted)

If equal net spins are coupled antiparallel, antiferromagnetic (weakly attracted)

If unequal net spins are coupled antiparallel, ferrimagnetic (strongly attracted)

If net spins are coupled parallel, FERROMAGNETIC (very strongly attracted)

Only ferri- and ferromagnetic materials are considered magnetic materials

Hard and soft magnetic materials

"Soft" (temporary-magnet) materials lose their net magnetization (form domains) when a magnetic field is removed - used for AC or on-off applications

"Hard" (permanent-magnet) materials retain their magnetization after field is removed - used for applications requiring a steady magnetic field

Properties of magnetic materials

Saturation magnetization is a measure of the magnetic field a material can produce when all atomic magnets are aligned - how "magnetic" it is

Coercivity is the reverse magnetic field required to reduce the net magnetization to zero - how "permanent" it is. ("soft" = low coercivity, "hard" = high coercivity)

(Other properties often quoted are the permeability of soft materials, which varies inversely with coercivity, and the energy product of hard materials, related to area of "hysteresis loop" & depends on both coercivity and saturation magnetization)

History of hard (permanent-magnet) materials

Lodestones - natural magnets based on magnetite (Fe_3O_4)

Carbon steel (Fe-C) 18th-c. England (horseshoe shaped or bar magnets)

Alloy steel (Fe-C+W, Mo, Cr, Co, etc.) - 19th and early 20th-c. (horseshoe or bar)

Alnico (Fe+Al,Ni,Co) - 1930s & 1940s - helped Allies win World War II

Hard Ferrite (Ba-Fe-O or Sr-Fe-O) - 1950s & 1960s - higher coercivity, cheap!

Rare Earth (Sm-Co, Nd-Fe-B) - 1970s-1990s - VERY powerful, but NOT cheap

Applications

Hard (permanent) magnetic materials are used in applications requiring a steady magnetic field. Recent increases in coercivity (resistance to demagnetization) and energy product (dependent on both coercivity and saturation magnetization, and related to the area within the hysteresis loop) have greatly increased the use of permanent magnets in modern technology. The widest applications are in motors, speakers, and sensors, but large quantities of Nd-Fe-B magnets are also used in permanent-magnet MRI systems, each of which uses about 2 tons of permanent magnet.

For most applications, the amount of permanent magnet required is inversely proportional to the energy product. Available energy products have increased by a factor of fifty since the 1930s, allowing a corresponding decrease in the size of the magnet, and thus the size of the device. (e.g., small motors made possible by Nd-Fe-B magnets spin the disks and move the heads in computer disk drives, and small speakers produce music in the tiny earphones of iPods and the like.)

At least as important have been increases in coercivity by even greater factors, which allow a greater flexibility of magnet shape. Low-coercivity steel magnets required long bar magnets or horseshoe shapes to minimize demagnetization from reverse fields produced by the north and south poles at the ends of the magnet. (Before the advent of alnico magnets in the 1930s, telephone receivers were long and separate from the speakers because they included a long horseshoe-shaped steel magnet.)

Materials for magnetic recording have also improved dramatically in recent years. The first magnetic recorder, patented in 1898, used steel piano wire. Magnetic tapes employing particles of iron oxide coated on plastic tapes were developed in Germany in the 1930s. Such tapes were used in the first commercial computers in the 1950s, and advanced versions remain in use today for audio and video applications, but today's computers instead store information in patterns of north and south poles on disks coated with thin films of cobalt-rich alloys.

There have also been dramatic improvements in the properties of soft magnetic materials. Decreases in coercivity have decreased the energy losses of soft materials in ac applications, as have increases in electrical resistivity. Many transformers today use

amorphous Fe-rich alloys, cooled so rapidly from the melt that they are unable to crystallize. An area of extensive current research is materials for recording heads, and improved materials have contributed to the remarkable increases in the density of information storage (bits per square inch).