Permanent Magnet Applications

How are magnets used?
To answer this, we will review the key features of each product type and provide example applications for each. (Additional information can be found in Rollin J. Parker's book *Advances in Permanent Magnetism*, pages 183-247).

Permanent magnet applications can, in general, be divided into four categories, as follows:

CATEGORY #1:
Based on the Coulomb Force Law

Applications that make use of the attractive and/or repelling force of a magnet: the attraction between a magnet and a soft magnetic material, such as a piece of iron or steel, or the attraction or repulsion between two magnets, utilized to do mechanical work. The following applications are in this category:

- Magnetic separators and magnetic holding devices such as magnetic latches
- Magnetic torque drives
- Magnetic bearing devices

CATEGORY #2:
Based on Faraday's Law

Applications that make use of the magnetic field of the magnet to convert mechanical energy to electrical energy or to change the electrical characteristics of materials in the magnetic circuit. Some of these applications are:

- Magnetos
- Generators and alternators
- Sensors (for example, variable reluctance, Hall effect, and GMR types)
- Eddy current brakes (used widely for watt-hour meter damping). (This application could be listed under electrical to mechanical energy conversion; but as mechanical energy is used to create the eddy currents, it will be included here.)

CATEGORY #3:
Based on the Lorentz Force Law

Applications that make use of the magnetic field of the magnet to convert electrical energy to mechanical energy. Some of these applications are:

- Motors
- Meters
- Loudspeakers
- Relays
- Actuators: linear, and rotational

CATEGORY #4
Based on the Lorentz Forces on Free Electron Charges and charged particles

Applications that use the field of the magnet to direct, shape and control electron or ion beams. Examples of these applications:

- Magnetically focused cathode-ray tubes
- Traveling Wave Tubes (TWTs)
- Magnetrons, BWO's, Klystrons
- Ion Pumps
- Cyclotrons

Matching Arnold Products to Applications

The purpose of a permanent magnet is mostly to produce flux in the working gap of a device. Depending upon the application, certain material types, grades and shapes will provide a better price-performance proposition than others. The following is a listing by product type of applications most suited to a material's characteristics.

FERRITE (CERAMIC) MAGNETS
Key advantages of sintered ferrite magnets are:

- Economical - high output-to-price ratio
- High Hc and Hci compared to Alnico
- Usable to high temperatures
- Outstanding corrosion resistance

On the negative side, ferrite magnets are:

- Available only in simple shapes
- Fragile (prone to chipping, cracking)
- Require expensive tooling for manufacture
- Temperature sensitive with regard to flux output (reversible temperature coefficient of

induction of -0.2%/°C) generally limiting their usefulness to less than 150 °C
- Generally limited to use above -40 ºC (-40 °F) since their coercivity decreases as temperature decreases

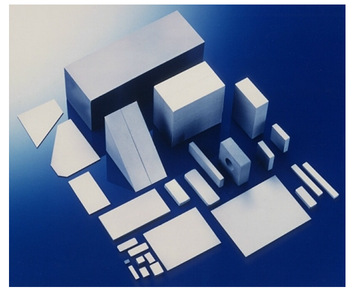
Ferrite Magnet Applications
Ferrite magnets are often used in:

- DC permanent magnet motors, especially for the automotive industry where applications include starter motors, blowers, window lifts, and windshield wiper motors
- Separators to remove ferrous materials from liquid, powder and other bulk commodities
- Magnetos used on lawnmowers, garden tractors and outboard motors
- DC brushless motors, some with controllers. Widely used in the electronics industry for remote controls, cooling fans, etc.
- In latches and clamps

NEODYMIUM (Neodymium-Iron-Boron)
Key reasons for using Neodymium are:
- Very high magnetic energy for size
- Widely available
- Good in ambient temperature situations; strongest magnet material at and near room temperature
- High coercivity (Hci) grades are available

On the negative side, neodymium magnets are:
- Subject to corrosion that can result in loss of energy or failure
- Somewhat temperature sensitive (reversible temperature coefficient of induction of -0.07 to -0.13%/ degree centigrade depending upon grade)
- Requires heavy rare earth substitution for performance above 80 °C

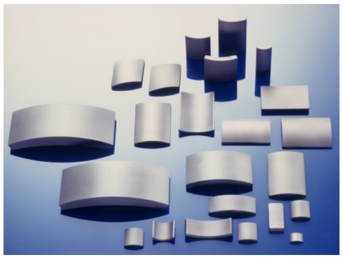
Neodymium Applications



New uses for neodymium magnets are continually being exploited. Some of the current applications are:
- Computer rigid disc drives: spindle motors and voice coil motors (for positioning the read-write head)
- Hammer-bank (dot matrix-type) printers
- Speakers and headphones including ear buds and cell phone speakers
- Hearing aid transducers
- Microphone assemblies
- Magnetic separators
- Brushless DC, variable speed and servo Motors

SAMARIUM COBALT
The first commercialized rare earth magnets were made from samarium cobalt and they are still used in applications requiring high energy output at high temperature with good temperature stability:
- Have high Hc, Hci and BHmax
- Are very temperature-stable - - grades are available for use from 2 Kelvin to over 500ºC
- Are powerful for their size
- Have good corrosion resistance

On the negative side, samarium cobalt magnets are:
- Moderately expensive because of the samarium and cobalt content
- Require careful handling to prevent chipping and breaking



Samarium Cobalt Applications
Samarium Cobalt is used in these general applications:

- Traveling wave tubes
- D.C. Motors, especially where temperature stability is vital, such as in satellite systems, aircraft generators, and small military-use motors
- Sensors, especially for automotive applications
- Linear actuators.

BONDED MAGNETS

These are truly "engineered products" whose properties are tailored to meet specific performance requirements. The magnetic material can be powders of any of the other magnetic materials or combinations of them. Binders include thermo-plastics (nylon, PPS), thermo-elastomers (polyethylene, polyurethane), and epoxies.

Magnets can be simple in shape such as rectangles, arcs or cylinders. Or very complex shapes including gear teeth and graded thickness. A particular advantage of injection molding is the combining of the magnet material with another component. This can be accomplished in one of three ways.

- Insert injection molding - - the component is usually a metal or higher temperature plastic wherein the magnetic compound is molded over, inside or around the second component
- Co-injection molding - - where two or more materials are molded simultaneously
- Multi-step injection molding - - the higher temperature injection compound is formed followed by the lower temperature material

Key attributes are:

- Resistant to chipping and breaking (except that PPS is moderately brittle when fully cured)
- Complex shape capability
- Complex magnetizing patterns possible
- Wide range of properties, both magnetic and physical
- Insert molding can reduce overall system cost
- Precise dimensions without secondary finishing
- Combinations of magnetic powders can be used for averaging of properties

Some shortcomings are:

- Lower flux output due to dilution by the non-magnetic binder
- Maximum temperature limited by binder and the reactivity of the magnet powder to less than 80 °C for thermo-elastomers and less than 180 °C for thermoplastics and epoxy except that ferrite in engineering binders can be used to 200 °C

Bonded Magnet Applications
Examples of bonded magnets:

- **Flexible** (calendered and extruded)
  - ✓ Magnetic signs
  - ✓ Door gaskets
  - ✓ Micro-motor magnets
- **Injection Molded**
  - ✓ Magnetically coupled drives
  - ✓ Sensor magnets (ABS, TPS, etc.)
  - ✓ Small motor magnets
  - ✓ Air core and stepper motor gauge magnets
- **Compression Bonded**
  - ✓ Brushless DC motor magnets
  - ✓ Linear actuators

CAST and SINTERED ALNICO

Alnico was the first high performance permanent magnet material. Developed during the period 1932 through 1970, it was widely used in motors and permitted the development of key technologies such as radar.

Attributes of Cast Alnico are:

- Mechanically strong however grain-oriented grades (alnico 5-7 and 9) are somewhat brittle
- Cast to a variety of shapes
- Most temperature stable permanent magnets
- High Br and BHmax characteristics compared to ceramic magnets (up to 10 MGOe, 80 kJ/m^3)
- Are moderately corrosion resistant, often requiring no protective coating

The key attributes of Sintered Alnico are:

- Mechanically the strongest of the Alnicos
- Close tolerance pressing, typically with minimum finish grinding
- Magnets can be very small

On the negative side, alnico magnets:

- Exhibit low coercivities of between 650 and 1900 Oersted (depending on grade)

Alnico Applications

Examples of applications for both cast and sintered Alnico are:

- Electron tubes, radar, traveling wave tubes.
- Separators, holding magnets, coin acceptors, clutches and bearings.
- Magnetos, motors, generators, gauges, controls, relays, watt-hour meters (bearings and dampeners).
- Communications - receivers, telephones, microphones, bell ringers, musical instruments (guitar pickups).
- Automotive sensors, loudspeakers, “cow magnets”, distributors.

IRON-CHROME-COBALT and VICALLOY

Arnold’s FeCrCo product is called Arnokrome®. Like Vicalloy, it is a malleable alloy (can be rolled, bent and formed). Key attributes of Arnokrome and Vicalloy are:

- Mechanically tough
- Cast, roll, and/or form to a variety of shapes
- Arnokrome is Machinable
- Very temperature stable
- Usable over a wide temperature range
- Coercivity can be adjusted through mechanical working and heat treatment
- High Br and BHmax characteristics compared to ceramic magnets

Some shortcomings of Arnokrome and Vicalloy are:

- Low coercivity (compared to the rare earth and ferrite magnets)

Figure description: Arnokrome hysteresis rings with two multipole injection molded drive magnets

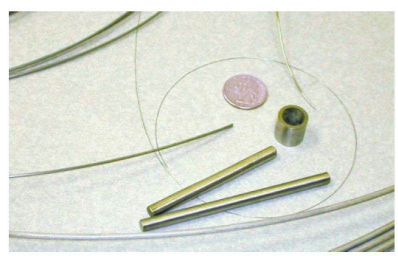


Figure description: Arnokrome rod and wire

Iron-Chrome-Cobalt and Vicalloy Applications
Examples of applications for both materials:

- Hysteresis coupled drives
- Holding magnets (where flexibility and physical strength are required)
- Hysteresis brakes

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