

## Permanent Magnet Materials for Motor



## Engineering

**KEYWORDS :** saturation magnetic flux density, rare earth permanent magnet, operating temperature range

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### ABSTRACT

*The magnet material and its characteristics are play important role in motor performance. In this paper we deals with different magnet materials, magnet safety, parameters of permanent magnet, mechanical properties, handling & magnetization etc...*

#### Introduction

##### Permanent Magnet Materials:-

**Saturation magnetic flux density:-** Bsat and corresponding saturation magnetic field intensity Hsat. At this point the alignment of all the magnetic moments of domains is in the direction of the external applied magnetic field.

**Remanent magnetic flux density Br, or remanence,** is the magnetic flux density corresponding to zero magnetic field intensity. High remanence means the magnet can support higher magnetic flux density in the air gap of the magnetic circuit.

**Coercive field strength Hc, or coercivity,** is the value of demagnetizing field intensity necessary to bring the magnetic flux density to zero in a material previously magnetized (in a symmetrically cyclically magnetized condition). High coercivity means that a thinner magnet can be used to withstand the demagnetization field.

#### I. EARLY HISTORY OF PERMANENT MAGNETS

A hard magnetic material called loadstone was mentioned by Greek philosopher Thales of Miletus as early as ca. 600 B.C. This was a natural magnetic mineral, a form of magnetite Fe<sub>3</sub>O<sub>4</sub>. Loadstone was given the name magnes because it was found in Magnesia, a district in Thessaly.

*The first artificial magnets* were iron needles magnetized by touching the loadstone. Man's first practical use of magnetism may have been the compass. **Around 1200 A.D. there are references in a French poem written by Guyot de Provins to a touched needle of iron supported by a floating straw.** Other references suggest that good magnet steel was available from China in about **500 A.D.**

The earliest systematic reporting of magnets was a classical paper by **W. Gilbert in 1600.** Gilbert described how to arm loadstones with soft iron pole tips to increase attractive force on contact and how to magnetize pieces of iron or steel. The next great advance in magnetism came with the invention of the electromagnet by J. Henry and W. Sturgeon in 1825.

**By 1867,** German handbooks recorded that ferromagnetic alloys could be made from nonferromagnetic materials and nonferromagnetic alloys of ferromagnetic materials, mainly iron. For example in 1901, Heusler alloys, which had outstanding properties compared to previous magnets, were reported. The composition of a typical Heusler alloy was 10 to 30% manganese and 15 to 19% aluminum, the balance being copper.

**In 1917 cobalt steel alloys and in 1931 Alnico (Al, Ni, Co, Fe) were discovered in Japan.** In 1983, also in Japan, Kato and Takei developed magnets made of powdered oxides. This development was the forerunner of the modern ferrite.

#### III PROPERTIES OF PERMANENT MAGNETS:-

**There are three classes of PMs currently used for electric**

#### motors:

- **Alnicos (Al, Ni, Co, Fe)**
- **Ceramics (ferrites), e.g., barium ferrite BaO×6Fe<sub>2</sub>O<sub>3</sub> and strontium ferrite SrO×6Fe<sub>2</sub>O<sub>3</sub> ;**
- **Rare-earth materials, i.e., samarium-cobalt SmCo and neodymium- iron-boron NdFeB**

#### • Alnico:-

The **main advantages** of alnico are its high magnetic remanent flux density and low temperature coefficients.

The temperature coefficient of Br is -0.02%/°C and maximum service temperature is 520°C. These **advantages** allow a high air gap magnetic flux density at high magnet temperature.

Sometimes, Alnico PMs are protected from the armature flux, and consequently from demagnetization, using additional mild steel pole shoes.

Alnicos dominated the PM motors market in the range from a few watts to 150 kw between the **mid 1940s** and the **late 1960s** when ferrites became the most widely used materials.

#### • Ferrites:-

Barium and strontium ferrites were invented in the **1950s.** A ferrite has a **higher coercive force** than Alnico, but at the same time has a **lower remanent magnetic flux density.** Temperature coefficients are relatively high. The maximum service temperature is 400°C. The main advantages of ferrites are their low cost and very high electric resistance, which means no eddy-current losses in the PM volume.

Ferrite magnets are **most economical** in fractional horsepower motors and may show an economic advantage over Alnico up to about 7.5 kw.

#### • Rare-earth permanent magnets :

During the last three decades great progress regarding available energy density (BH)<sub>max</sub> has been achieved with the development of rare-earth PMs. The rare-earth elements are in general not rare at all, but their natural minerals are widely mixed compounds. To produce one particular rare-earth metal, several others, for which no commercial application exists, have to be refined. This limits the availability of these metals.

**The first generation of these new alloys** based on the composition **SmCo<sub>5</sub>** and invented in the **1960s** has been commercially produced since the early 1970s. Today it is a well established hard magnetic material. SmCo<sub>5</sub> has the advantage of high remanent flux density, high coercive force, high energy product, liner demagnetization curve and low temperature coefficient. The temp. coefficient of **Br is 0.03 to 0.045%/°C** and the temp. coefficient of **Hc is 0.14 to 0.40%/°C. Maximum service temp. is 300 to 350°C.** It is well suited to build motors with low volume, high power density and class of insulation F or H. The cost is the only drawback. Both Sm and Co are relatively expensive due to their

supply restrictions.

With *the discovery in the recent years* of a second generation of rare-earth magnets on the basis of inexpensive neodymium (Nd), a remarkable progress with regard to lowering raw material costs has been achieved. This new generation of rare-earth PMs was announced by Sumitomo Special Metals, Japan, in 1983 at the 29<sup>th</sup> Annual Conference of Magnetism and Magnetic Materials held in Pittsburgh.

The Nd is a much more abundant in rare-earth element than Sm. **NdFeB** magnets, which are now produced in increasing quantities have better magnetic properties than those of SmCo, but unfortunately only at room temperature. The demagnetization curves, especially the coercive force, are strongly temperature dependent. The temperature coefficient of Br is -0.09 to -0.15%/°C and the temperature coefficient of Hc is -0.40 to -0.80%/°C. The maximum service temperature is 250°C and Curie temperature is 350°C. The NdFeB is also susceptible to corrosion. NdFeB magnets have great potential for considerably improving the performance-to-cost ratio for many applications. For this reason they will have a major impact on the development and application of PM apparatus in the future.

The latest grades of NdFeB have a higher remanent magnetic flux density and better thermal stability. Metallic or resin coating are employed to improve resistance to corrosion.

The most important application area of rare-earth magnets with about 40% of the sales are electrical machines. Other major areas of application are actuators in data storage technology, acoustic devices, and magnetomechanical devices (holding devices, couplings, magnetic separators, magnetic bearings). High performance rare-earth magnets have successfully replaced Alnico and ferrite magnets in all applications.

#### IV THE PARAMETERS OF PERMANENT MAGNETS:-

Permanent magnets provide a motor with *life-long excitation*. The only outlay is the *initial cost*, which is reflected in the price of the motor. Broadly speaking, the primary determinants of magnet cost are the torque per unit volume of the motor, the operating temperature range, and the severity of the operational duty of the magnet.

##### • Power density :-

For *maximum power density* the product of the electric and magnetic loadings of the motor must be as high as possible. The electric loading is limited by thermal factors, and also by the demagnetizing effect on the magnet. A high electric loading necessitates a long magnet length in the direction of magnetization, to prevent demagnetization.

It also requires a *high coercivity*, and this may lead to the more expensive grades of material (such as cobalt-samarium), especially if high temperatures will be encountered.

The magnetic loading, or airgap flux, is directly proportional to the remanent flux density of the magnet, and is nearly proportional to its pole face area. A high power density therefore requires the largest possible magnet volume (length times pole area).

With ceramic magnets the limit on the magnet volume is often the geometrical limit on the volume of the rotor itself, and the highest power densities cannot be obtained with these magnets. With rare-earth or other high-energy magnets, the cost of the magnet may be limiting factor.

With a straight demagnetization characteristic throughout the second quadrant and a recoil permeability of unity, the maxi-

mum energy-product (BH) max is given by

$$(BH) \max = Br^2 / (4\mu_0) \text{ j/m}^3.$$

##### • Operating temperature range :-

Because of degradation in the remanent flux density and in the coercive force, the choice of material and the magnet volume must usually be determined with reference to the *highest operating temperature*.

*Fortunately brushless motors have very low rotor losses*. The stator is easily cooled because of the fine slot structure and the proximity of the outside air. Consequently the magnet can run fairly cool (often below 100°C) and it is further protected by its own thermal mass and that of the rest of the motor.

The short-time thermal overload capability of the electronic controller would normally be less than that of the motor, providing a further margin of protection against magnet overtemperature.

##### • Severity of operational duty :-

Magnets can be demagnetized by fault currents such as short-circuit currents produced by inverter faults. In brushless motors with electronic control the problem is generally limited by the protective measures taken in the inverter and the control. The design must accommodate all the factors that stress the magnet, not only electromagnetic but thermal and mechanical as well.

#### V MECHANICAL PROPERTIES, HANDLING AND MAGNETIZATION

Magnets are often brittle and prone to chipping, but *proper handling procedures* are straightforward enough as long as the rules are followed. Modern high-energy magnets are usually shipped in the magnetized condition, and care must be taken in handling to avoid injury that may be caused by trapped fingers. A further *hazard* is that when two or more magnets are brought close together they may flip and jump, with consequent risk to eyes.

A very wide range of shapes is possible, but in motors the most common are arcs and sometimes rectangles. Tolerances in the magnetized direction can be held very close,  $\pm 0.1$  mm even for standard magnets.

#### VI MAGNET SAFETY:-

**Permanent magnets required strict adherence to safety procedures at all stages of handling and assembly:-**

- *Always wear safety glasses when handling magnets*. This is particularly important when assembling magnets into a motor. When a large pole magnet is being assembled from smaller magnets, the magnets have a tendency to flip and jump unexpectedly and may fly a considerable distance.
- *Work behind a plexiglass screen when experimenting or assembling magnet assemblies*. Watch out for trapped fingers, especially with large magnets or high energy magnets.
- *Avoid chipping* by impact with hard materials, tools, or other magnets.
- *Never dry-grind rare-earth magnets*-the powder is combustible. In case of fire, use L P argon or nitrogen dry chemical extinguishers-never use water or halogens.
- *PM motors generate voltage when the shaft is rotated, even when disconnected from the supply*. This may be obvious to an engineer, but is a potential safety hazard for electricians and maintenance personnel. Use suitable warning labels, especially on large machines.
- *When assembling a rotor to a stator, with either one magnetized, the rotor must be firmly guided and the stator firmly located*. Never leave magnetized members open or unprotected.

## VII CONCLUSIONS

The most important application area of rare-earth magnets with about 40% of the sales are electrical machines. Other major areas of application are actuators in data storage technology, acoustic devices, and magnetomechanical devices (holding devices, couplings, magnetic separators, magnetic bearings). High performance rare-earth magnets have successfully replaced Alnico and ferrite magnets in all applications.

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