APPLICATIONS OF HIGH ENERGY DENSITY PERMANENT MAGNETS

W. Kappel

R&D Institute for Electrical Engineering ICPE-Advanced Research
Splaiul Unirii 313, sector 3, Bucharest, Romania
Phone : +40 021 – 346.72.31, fax: +40 021 – 346.82.991, e-mail: kappel@icpe-ca.ro

Abstract. The permanent magnets have today many applications in the industry and are key components in devices of the electrical engineering, almost 75 % being used in motors, generators and actuators. The limit of the 10 billion Euros in the market of permanent magnets is surpassed in the year 2000 and the world market for permanent magnets will continue to grow strongly at 10 – 15 % annually. Powder technology is, and will remain, the preferred, and for some materials, the only method of hard permanent magnet preparation, and already accounts for over 80 % of the market [1].

The development of the rare earth magnetic materials (starting with 70's) has influenced significant and positively the application of the permanent magnetic materials owing to their large energy product and increased volume efficiency. Fastest growth will be in Nd-F-eB materials, the world production for will reach more than 39,110 t/year [2]. These are high performance magnets based on $Nd_2Fe_{14}B$ compound, whose performances exceeded that of the conventional permanent magnetic materials Alnico and hard ferrites, showing very high energy densities $(BH)_{max}$ of 145 to 400 kJ/m^3 (~ 18 to 50 MGOe) and coercivities over 24 kA/cm (~ 30 kOe).

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

a. Applications that make use of the tractive and/or repelling force of the magnet, i.e., 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, is used to do mechanical work. The following applications are in this category:
   - Magnetic separators, magnetic holding devices, such as magnetic latches;
   - Magnetic torque drives;
   - Magnetic bearing devices.

b. Applications that make use of the magnetic field of the magnet to convert mechanical energy to electrical energy:
   - Magnetos;
   - Generators and alternators;
   - Eddy current brakes (used widely for watt-hour meter damping).

c. Applications that make use of the magnetic field of the magnet to convert electrical energy to mechanical energy:
   - Motors;
   - Meters;
   - Loudspeakers;
   - Relays;
   - Actuators, linear and rotational.

d. Applications that use the magnetic field of the magnet to direct, shape and control electron or ion beams:
    - Magnetic focused cathode – ray tubes;
    - Traveling wave tubes
    - Magnetrons;
    - Ion pumps;
    - Cyclotrons.

The purpose of a permanent magnet is to produce flux in the working gap of a device. Obviously, all permanent magnetic material will produce flux, but depending upon the working application, certain materials types, grades and shapes will be more efficient than others. The following is a breakdown by product applications that are most suitable for a material's characteristics:

- The key attributes of cast Alnico are: mechanically strong, cast to a variety of shapes, very temperature stable, can change magnetic orientation and high remanence B_r and magnetic energy $(BH)_{max}$ characteristics compared to ceramic materials.
- The key attributes of sintered Alnico are mechanically strongest of the Alnicos and close tolerances pressing/typically minimum grinding.

but both cast and sintered Alnico have low coercivity H_c when compared to ceramic or rare earth materials.

The general 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, meters, instruments, controls, relays, watt-hour meters (bearings and dampeners);
Automotive sensors, loudspeakers, cow magnets, distributors;
Communications, receivers, telephones, microphones.

Key attributes of the ferrite (ceramic) magnets are: economical high H_c and ${}_JH_c$ compared to Alnico. On the negative side, ceramics are good for simple shapes only, very fragile, require expensive tooling and temperature sensitive (0.2 %/^{o}C). Generally, the ferrite magnets are used in: d.c. permanent magnet motors used in the automobile industry for blowers, window lifts, windshield wipers, etc., separators to remove ferrous materials from liquid powder and bulk commodities, Magnetic Resonate Imaging (MRI), magnetos used on lawnmowers, outboard motors, DC brushless motors with controllers for speed and direction.

While being quite expensive, Sm-Co magnets are high H_C and ${}_JH_C$, high $(BH)_{max}$, very good temperatures ability and powerful for size, but, on the negative side, Sm-Co alloy is price sensitive, due to the Co supply and demand. Sm – Co is used in the traveling wave tubes, computer ring disc drives, d. c. motors (where temperature stability is vital, such as military use-satellite systems, small military motors), sensors, growing automotive applications and linear actuators.

Key reasons for using Nd-Fe-B permanent magnets are high energy for size, more economical than Sm-Co, good in ambient temperature situations, very high H_c and ${}_JH_c$ output, but, on the negative side of Nd-Fe-B permanent magnets are relatively high price, corrosion that can result in loss of energy and temperature coefficient of 0.13 %/degree centigrade. For the permanent magnets based on Nd-Fe-B alloys, some of the ever-growing list of uses is: linear actuators, speakers, microphone assemblies, magnetic separators, d.c. motors and automotive starters, servo-motors, hammer bank printers, computer rigid disc drives,

The further improvement of current magnetic materials relies on nanostructuring. Likewise, miniaturisation of MEMS requires materials having a high coercivity and remanence in order to maintain high force capability at reduced sizes. Promising candidates in both fields are rare earths magnets such as NdFeB and SmCo. When were prepared as thin films, the materials can be grown with complementary magnetic textures, NdFeB films typically possess a perpendicular magnetic anisotropy with the easy magnetic axis perpendicular to the substrate, whereas for SmCo films the easy axis commonly lies within the film plane. The NdFeB film permanent magnets are important for future advances in microsensors, micromotors and MEMS [3,4]. The miniaturisation of these microdevices requires magnetic thin films with high coercivity and remanent magnetization in order to provide strong forces [5].

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