

Current Status of Permanent Magnet Industry in the United States

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Abstract

The permanent magnet industry in the United States has been declining in recent years due to offshore competition and lack of breakthroughs in new magnet research. Although the United States represents the largest market for neodymium-iron-boron (Nd-Fe-B) magnets, there are no US Nd-Fe-B producers left; all US suppliers of this material are either distributors or value-added resellers of product produced in Asia and Europe. Primary applications include automotive, personal computers, commercial motors and generators, medical, meters and gauges. The production of Sm-Co magnets has been steady over the last decade primarily due to strong demand in aerospace and military markets. Main applications include high performance specialty motors and generators, space propulsion systems, inertial devices, medical devices, and traveling wave tubes and other high power microwave amplifiers. Alnico magnet production still exists in the United States to address specialty applications but has been flat in recent years. In this paper we will provide a brief review of the manufacturing activities and main permanent magnet applications in the United States.

Keywords: Permanent magnet, magnet industry, Sm-Co magnets, Nd-Fe-B magnets, magnet applications

1. Introduction

Sintered SmCo_5 and $\text{Sm}(\text{Co},\text{Fe},\text{Cu},\text{Zr})_z$ magnets were developed in late 1960s and 1970s, respectively. SmCo_5 magnet has very high magnetocrystalline anisotropy, which results in high intrinsic coercivity. The residual induction, on the other hand, is relatively low at ~8750 G. The maximum energy product of SmCo_5 magnets is ~18 to 20 MGoe. Research activities in 1970s were focused on the enhancement of residual induction without significant reduction of intrinsic coercivity. The focus shifted from SmCo_5 to another intermetallic compound, $\text{Sm}_2\text{Co}_{17}$. The first attempts included adding Fe at the expense of Co, but attempts to develop high intrinsic coercivity in $\text{Sm}_2(\text{Co},\text{Fe})_{17}$ alloys were not very successful until the mid 1970s when Cu and Zr were

introduced to $\text{Sm}(\text{Co},\text{Fe})_z$ alloys. It was found that the cellular microstructure formed by the addition of Cu and Zr is critical for the development of intrinsic coercivity in $\text{Sm}(\text{Co},\text{Fe},\text{Cu},\text{Zr})_z$ magnets, which have a maximum energy product of as high as 33 MGoe.

Cobalt is a strategic metal and is brought to market as a result of Cu and Ni mining operations located in relatively unstable parts of the world. Supply has grown with demand but the price has been volatile. This volatility stimulated research to develop a Co-free magnet material and led to the Nd-Fe alloy system. Replacement of cobalt with the more abundant element Fe not only reduced the cost but also increased the saturation magnetization of the material. Replacement of Sm with the more abundant element Nd

also reduced the cost and increased the saturation magnetization. But early experiments did not yield good magnetic properties. The addition of boron proved to be critical for the formation of the new $\text{Nd}_2\text{Fe}_{14}\text{B}$ phase, although it was intended only for helping the formation of an amorphous phase using a melt-spinning process at the very beginning. In 1983, $\text{Nd}_2\text{Fe}_{14}\text{B}$ based magnets were introduced. Acceptance and commercialization of this new material occurred very quickly.

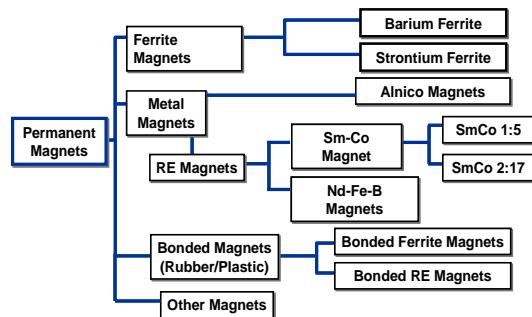


Figure 1. Various types of permanent magnets

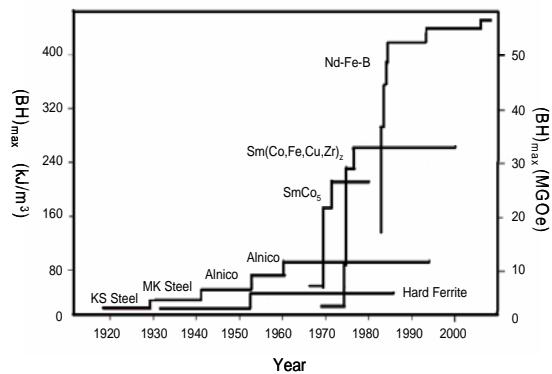


Figure 2. Maximum energy product of permanent magnets developed in the last century

Figure 1 shows an overview of all the various types of permanent magnets available today. Figure 2 shows the maximum energy product, $(BH)_{max}$, of permanent magnets developed in the last century. Significant progress in the maximum energy product of permanent magnets was made in 1970s, 1980s and 1990s. Although the scientific community

has made some good progress in the development of new phases and new processes during the late 1990s and 2000s, no real progress in the development of commercially viable rare earth permanent magnets, since the discovery of Nd-Fe-B magnets, has been made.

2. Rare Earth Magnet Industry in the United States

The permanent magnet industry has been declining in recent years due to a number of reasons, including:

- (1) Low-cost magnets from China squeezed the profitability of U.S producers;
- (2) Many customers for permanent magnets have relocated to Asia. (It makes sense for the magnet producers to be closer to their customers);
- (3) The majority of rare earth metals come from China; Chinese magnet producers are close to the inexpensive raw materials as well as low-cost labor force and engineering talent;
- (4) The quality of permanent magnets made in China has improved significantly;
- (5) Industry consolidation.

In the 1990s, there were at least four major Nd-Fe-B magnet producers in the United States, Ugimag, Hitachi, Crumax, and Magnequench. Today there are no Nd-Fe-B magnet producers left in the U.S. Magnequench relocated its headquarters and R&D Center to Singapore and its production facilities to China, while the magnet production plants of Ugimag, Hitachi and Crumax are closed in the United States.

There were at least five Sm-Co producers in the United States in 1990, including EEC, Arnold, Crucible, Hitachi, and Ugimag. Today, EEC is the only vertically integrated Sm-Co magnet producer in the United States. Ugimag was closed in the 1990s, Hitachi's Michigan facility was closed in 2005, while

Arnold consolidated its SmCo manufacturing capability to its UK facility, which was recently closed as well. EEC serves a small Sm-Co magnet market with very demanding applications. Expertise in this area is one of the reasons for its commercial success in the U.S. market.

There is still significant production capability today for bonded magnets in the United States. Main players in the bonded magnet arena include Magnet Applications, Ltd. (recently acquired by Bunting Magnetics), Tengam, ECS, Arnold, Magnum Magnetics, and Electrodyne.

United States also has production capability for Alnico magnets. Major Alnico producers in the U.S. include Thomas & Skinner, Arnold and the Permanent Magnet Company.

3. Rare Earth Resources

China is the world's largest producer and largest consumer of rare earth materials. About 94% of the rare earth oxides (REO) and almost 100% of the rare earth metals consumed today are produced in China. About 50% of the total rare earth oxides and rare earth metals are consumed in China.

The price of rare earth oxides and metals declined significantly in the 1990s and early 2000s, which was primarily due to the competition between Chinese companies. But since late 2005, neodymium prices have increased significantly. This is primarily due to the strong demand worldwide, mining quotas, active enforcement of environmental policies and shutting down offenders in China. The production of rare earth metals elsewhere has become more attractive due to price hikes, although China may still remain as the lowest cost producer in the near future. Global demand of rare earth oxide is estimated at about 100,000 - 120,000 metric

tons in 2007, and forecasted to grow at about 9% per year through 2012. Supply shortfalls are predicted in the near future as domestic consumption in China could exceed supply in 10 years.

After production suspension for almost a decade, Chevron Mining, Inc., formally Molycorp, started recently to process bastnasite from its current inventory at the Mountain Pass Mine, which is located about 50 miles south of Las Vegas, NV. The Mountain Pass mine has been an integral player in the rare earth industry for over 50 years. Today, the global demand for rare earth products has led to robust and growing markets. Mountain Pass has responded by restarting separation capabilities and once again manufacturing rare earth products. Table 1 shows the composition of the bastnasite at Mt. Pass [1].

Table 1. Composition (in wt%) of bastnasite at Mt. Pass [1]

La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Other REO
33.2	49.3	44.3	12	0.8	0.11	0.18	0.016	0.031	0.063

4. Value-Added Business in the Permanent Magnet Industry

Value-added magnet business, such as the production of assemblies and or subsystems, is doing well in the United States. Some magnet producers and fabricators offer design services using finite element analysis, such as Dexter, Arnold and EEC. This trend will continue because offshore producers may not be able to provide this service effectively.

5. Permanent Magnet Applications

Some major magnet applications are related to more efficient motors and generators. Therefore we could not start the discussion

of future permanent magnet markets without mentioning the oil market.

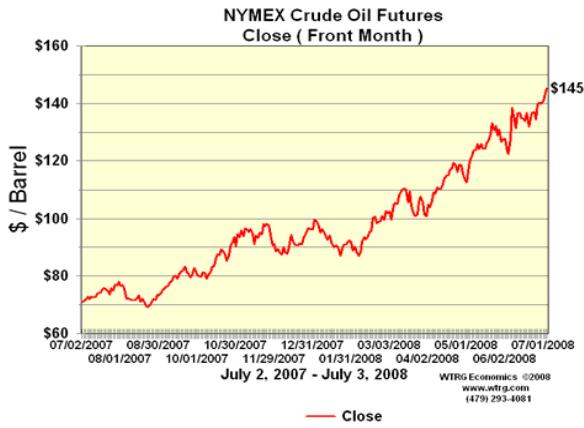


Figure 3. NYME crude oil futures in the last 12 months [2]

The crude oil futures went up significantly in the last 12 months and are currently above \$140 per barrel. Figure 3 shows crude oil futures on the New York Mercantile Exchange (NYMEX) in the last 12 months. Consumers felt the pinch at the gas pumps. Renewable energy, therefore, has become a hot topic and a profitable business. Wind power, hydropower, ocean wave and solar power are receiving more attention. These are also called clean energy because there is almost no environmental pollution.

Hybrid Electric Vehicles

The development of electric vehicle (EV) technology has taken on an accelerated pace with increasing concerns of energy efficiency and environmental protection. With the price of oil at over \$140 per barrel, hybrid vehicles are getting more attractive to consumers too. Several hybrid electric vehicles (HEVs) are on the market today. Best sellers include the Toyota Prius, the Honda Insight and the Honda Civic. All major car producers are developing more energy efficient hybrid vehicles, and consumers will have more and more choices which should, eventually, help to drive the price down. Certainly, the current

premium of about \$6000 for a hybrid vehicle will decrease in the future. According to the United States Environmental Protection Agency, the 2008 Prius (see Figure 4) is the most fuel-efficient car sold in the U.S. [3].



Figure 4. Toyota Prius hybrid electric car

More and more passenger safety devices and comfort/convenience features are being added to cars, most of which use some form of permanent magnets. Examples include airbags and seat belt sensors, electric power steering, liquid level sensors, sunroof motors, and door lock actuators. These new and/or improved features in cars and trucks are another driver for the permanent magnet industry.

Wind Generators

Some wind power generators use permanent magnets. The rapid development of wind generation capacity is also related to current high oil prices and the green energy movement. Figure 5 shows a 21st century wind farm in the California Central Valley and offshore wind turbines near Copenhagen [4].

The wind power industry is in an era of substantial growth, both globally and in the United States. About 20,000 MW of wind power capacity was added in 2007 worldwide, the highest volume achieved in a single year. GE Wind was the dominant producer of wind turbines in the U.S. market

in 2007. Other major players in this field include Vestas, Siemens, Gamesa, and Mitsubishi.



Figure 5. Top: A 21st century windfarm in the California Central Valley. Bottom: Offshore wind turbines near Copenhagen

bringing the cumulative total to 16,904 MW, according to a report from U.S. Department of Energy [5]. Figure 6 shows the annual capacity and cumulative U.S. wind power capacity.

Permanent Magnet Motors

Apart from automotive applications, there is increasing demand in permanent magnet motors in a variety of applications to replace mechanical and/or hydraulic systems in order to reduce the cost of maintenance. The high efficiency of permanent magnet motors is certainly getting more and more attractive due to high-energy costs. Some specialty motors and generators for defense and medical applications also use rare earth permanent magnets. High power density motors and generators generally use high-energy product, sintered Nd-Fe-B magnets with high intrinsic coercivity.

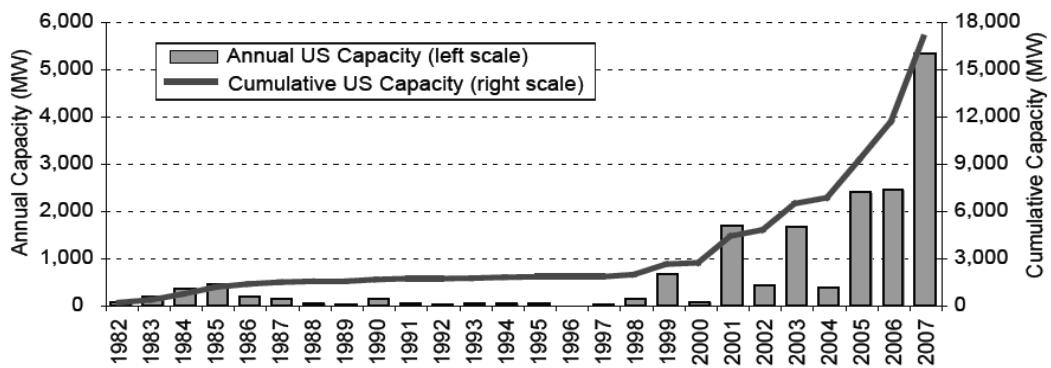


Figure 6. Annual capacity and cumulative capacity of U.S. wind power capacity

Medical Applications

Permanent magnet motors are used in surgical drills, saws and other medical tools. Sm-Co magnets are used due to the ability to withstand harsh autoclave conditions.

Permanent magnet MRIs use large quantities of Nd-Fe-B magnets in each unit. Demand from developing countries for permanent magnet MRIs is expected to be a significant driver in the growth of this application. Other magnet applications in medical devices are

emerging for applications such as steering catheters through the vascular system of the body.

Consumer Electronics and Computers

Permanent magnet applications in DVD, CD, cell phones and home appliance will continue to grow. Increasing demand is expected to come from developing countries to keep pace with ongoing lifestyle improvements. There are currently more than 600 million cell phone subscribers in China. Assuming exponential growth in this market continues as we've seen in the U.S., that number will easily double in a few short years. Voice coil motors and hard disc drives in computers will also continue to grow as the internet becomes an increasingly essential tool for business, leisure and communication. Growth will again come from developing countries whose per-capita ownership of PCs is much lower than that in the developed world.

Traveling Wave Tube Amplifiers

A traveling wave tube is a microwave signal amplification device, used in space and ground communications, and in electronic warfare for missiles, ships and combat aircraft. Sm-Co magnets are used due to their high thermal stability and low reversible temperature coefficient of B_r .

Inertial Devices

Temperature-compensated Sm-Co based magnets are required for applications in accelerometers and gyroscopes for inertial guidance systems. These devices require constant magnetic field over a temperature range, typically -50°C to +150°C.

Other Applications

There are many other applications for permanent magnets, such as actuators,

inverters, magnetic bearings and regulators, accelerators or colliders, ultra-high vacuum equipment, magnetic holding devices, magnetic implantable devices, magnetic separation systems, and down-hole drilling instruments.

6. Summary

Production activities in the United States have declined in recent years. New material development may revitalize the US magnet manufacturing industry in the future. The value-added business for magnet producers and fabricators in the United States is doing well. The demand for permanent magnets is expected to be strong in the next decade due to new applications, population growth, and development of emerging markets.

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