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Applications of rare earth magnets in Japan

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The sintered rare earth magnet (RE magnet) production in Japan has reached 1698 tons in 1992 and its sales nearly equaled that of the sintered ferrite magnet. Its production in Japan has increased over 10 % per year. The NdFeB magnet production is over 70% of the total RE magnet production and it is an important aspect in the magnet market. Rapid expansion of RE magnet market is mainly attributed to computer peripherals such as voice coil motor and micro-motors. These markets will be stable but not expand substantially in the future. We must find new massive applications for increasing the RE magnet production.

1. INTRODUCTION

Production of sintered Rare Earth magnets (hereafter, RE magnets) in Japan has increased over 10 % per year for last ten years and reached 1698 tons in 1992. Sales reached a high of 52.2 billion Yen in 1991, and dropped to 47.5 billion yen in 1992 (Figure 1). The NdFeB magnet production has increased steadily since 1986 and exceeded 70 % of the total RE magnet production last year[1]. In the future, the application of sintered SmCo magnets might be restricted to special use because of its less cost performance; for example, use in high temperature atmosphere or in irradiation atmosphere. New materials are currently being researched, but none are superior to the NdFeB magnet at present[2]. The NdFeB magnet will play a major role in total RE magnet application for the next decade.

Rapid expansion of the RE magnet market is mainly attributed to the expansion of computer peripherals and micro-motors. The NdFeB magnet has accelerated the expansion of Voice Coil Motor (hereafter, VCM) for head access of the hard disk drive (hereafter, HDD)[3]. New applications have also been introduced for example, Magnetic Resonance Imaging equipment (hereafter, MRI)[4] and insertion devices (hereafter, ID)[5]. Although motors for automotive use are expected, the RE magnet is seldom used except as a sensor.

First, we will describe the outlook of sintered Rare Earth magnet applications in Japan. Then, the VCM application and the development of related technologies will be shown. Finally, future applications will be described.

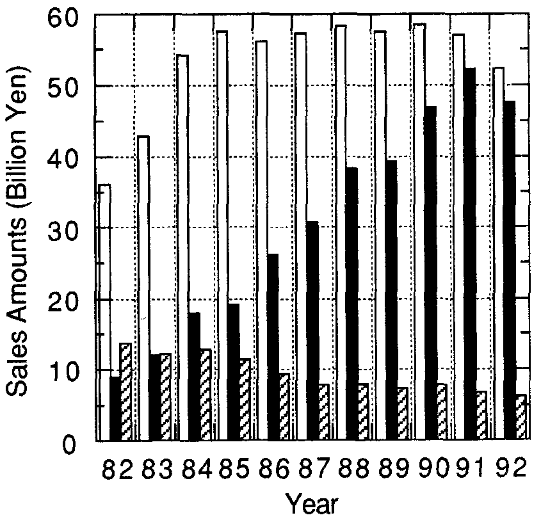

Figure 1. Sales Amounts of magnets in Japan[6]. Open bar, dark bar and slashed bar represent that of ferrite magnets, RE magnets and casting magnets, respectively.

2. OUTLOOK OF SINTERED RARE EARTH MAGNET APPLICATIONS IN JAPAN

Half of the sintered RE magnet goes into VCM for HDD. Requirements for a head actuator of HDD are miniaturizing (down-sizing), thinning and a high acceleration rate. VCM using NdFeB magnets meets the requirements. About 40 million HDD were produced in 1992 in the world and the HDD market grew about 20% per year for last several years, (Figure 2). More than 90 % of the total is a small sized HDD less than 3.5 inches. Small-size HDD is the primary market of the VCM that utilizes the NdFeB magnet. In addition, nearly 50% of the NdFeB magnet production is for the VCM. Among RE magnet applications, the largest market is the VCM, proving how important computer applications are. Since the world desktop computer market grew rapidly last year, and simultaneously the HDD market grew about 30 %. We can expect moderate growth this year. However a non-volatile semiconductor memory and HDD will compete with each other in an outer memory system of the computer in the near future. Therefore, the VCM market will be stable, but will not expand substantially in next decade.

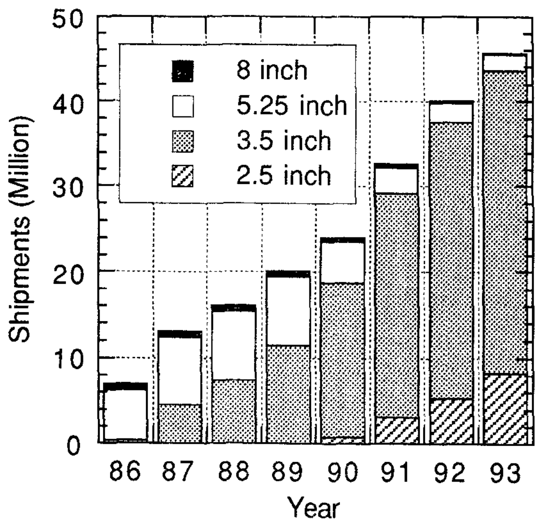

Figure 2. Shipments of HDD in the world[6].

In the MRI market of Japan (Figure 3), although a super-conducting magnet type is mainly used, a permanent magnet type maintains a constant share because of its easy maintenance and compactness. The permanent type uses NdFeB magnets, requiring the huge volumes of the NdFeB magnet. Twenty-five percent of the NdFeB magnet production goes into the MRI. In general, about a ton of the NdFeB magnet is necessary per one MRI system with the magnetic field of 0.2 T. About 50 systems of the PM type were installed per year in Japan. More than 1,500 of the MRI system had been installed until 1992 in Japan, but the market of the MRI systems is maturing. A foreign MRI market will become important hereafter.

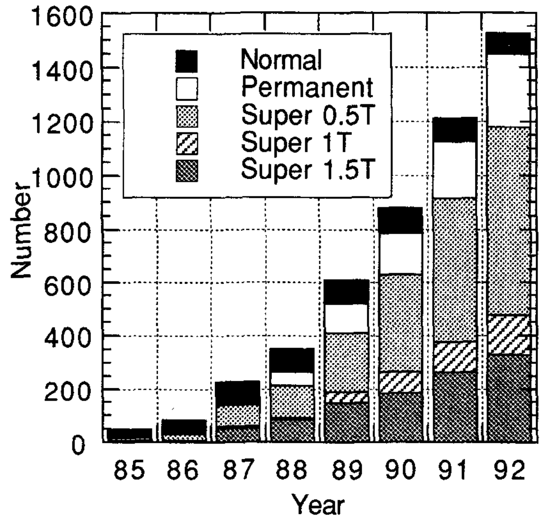

Figure 3. Number of installed MRI in Japan[8].

A motor using the RE magnet usually has power below 70 W. Those small motors are mainly used for audio and visual applications and computer peripherals. A typical application is a tape reel motor for a micro-cassette recorder, which uses a DC brush-less axial gap motor type. Recently, an increased production in tip RE magnets have been seen for the optical pick-up actuator of a compact disk drive[9] and a core-less vibration pocket bell motor. Both motors need over 1,000,000 magnet tips per month in Japan. But the weight of one magnet is less few grams. A large power motor using RE magnet is used in robot arms and so on. But production level is low because of the decrease in capital investment.

An automotive application is one of the biggest market for DC motors. Recently, automobiles use 40 to 50 pieces for motors, (Figure 4)[10]. Most of them employs the ferrite magnet. Examples of actuators using RE magnet are the idling speed control valve (ISCV) actuator, and the electric suspension. In addition, many RE magnet tips are used for position sensors and rotating sensors. Although a starter motor using the RE magnet was examined, this adaptation has not yet been reported. The overriding reason is the high cost of the RE magnet. Other reasons include poor corrosion resistance and poor temperature coefficient of the magnetic property. If these conditions do not change, mass consumption of the RE magnet in the automobile application is not to be expected in near future.

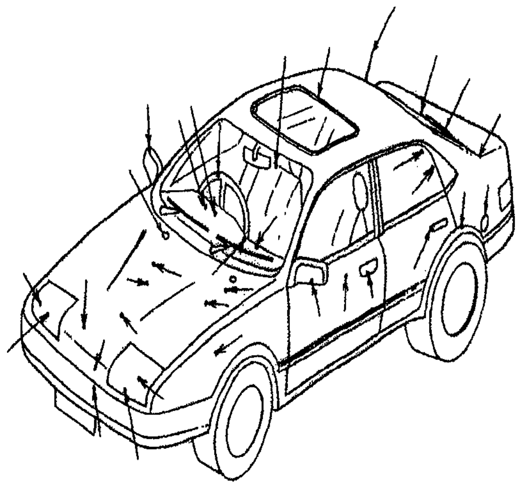

Figure 4. Motors, actuators and sensors used in the automobile. Arrows indicate positions where motors and etc. are used.

3. VCM APPLICATION

There are many types of VCM (Figure 5). Voice coil types are usually used in large size HDD, (more than 5 inches disk) while flat coil types are mainly used in small size HDD, (less than 3.5 inches disk). We call both

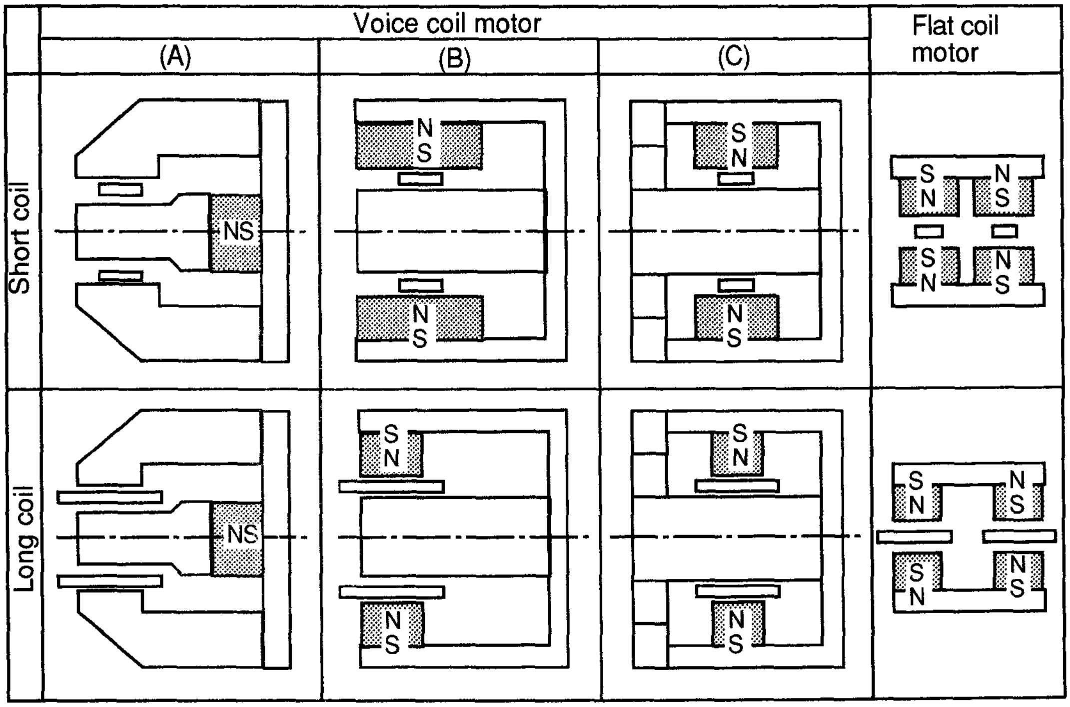

Figure 5. Various types of Head Actuator (VCM) for the hard disk drive.

types, VCM. Most VCM have been changing to the flat coil type. VCM is a linear direct motor, the characteristics are as the high acceleration rate, short stroke and each of control. Requirements for the HDD are short access time and accurate track flowing. The VCM meets these requirements. The flat coil VCM is smaller in volume and lower in inductance than those of the voice coil. The flat coil suits the small size HDD.

The driving force on the coil in the magnetic circuit gap is expressed in the following equation.

$$F = i\,B\,l + i^2 \frac{dL(x)}{dx} \qquad (1)$$

B represents the magnetic flux density of the gap, i represents the electric current in the coil and l represents the effective coil length which is forced to the electro-magnetic force. L(x) in the second term is inductance of the coil at the position x. The first term is dominant. Therefore, a high B value is best for obtaining a high acceleration rate.

There are some technical items that need to be improved in the flat coil VCM. The first is the magnetic property of the sintered NdFeB magnet, and the second is the film coating on the sintered NdFeB magnet and torque linearity. We have developed a high performance NdFeB magnet (Shin-Etsu's grade name, N45 and N42)[11]. These magnetization curves are shown in Figure 6. A powder metallurgy process is employed for producing RE magnets but our process is little bit different from the usual one. We employed a two alloys method (Figure 7). One alloy has a near composition of $Nd_2Fe_{14}B$ compound and other has a rare earth and cobalt rich composition. In the rare earth rich alloy, half of the rare earth element is composed of a heavy rare earth element such as dysprosium. Characteristics of this process are less oxidation of magnetic powder and the segregation of dysprosium at grain boundaries. The former characteristics are attributed to the rare earth rich alloy which is a cobalt rich composition. Although the rare earth rich alloy powder is easy to be oxidized, the oxidation of this powder is suppressed by the addition of cobalt. Therefore, near compositions of $Nd_2Fe_{14}B$ to the sintered magnet were realized which is sensitive to oxidation. The latter characteristics are attributed to a dysprosium distribution, which diffuses from the rare earth rich alloy to the $Nd_2Fe_{14}B$ alloy in the sintering process. The diffused dysprosium mainly distributes near the grain-boundary of the sintered $Nd_2Fe_{14}B$ particles. Dysprosium increases the effectiveness of coercivity. On the other hand,

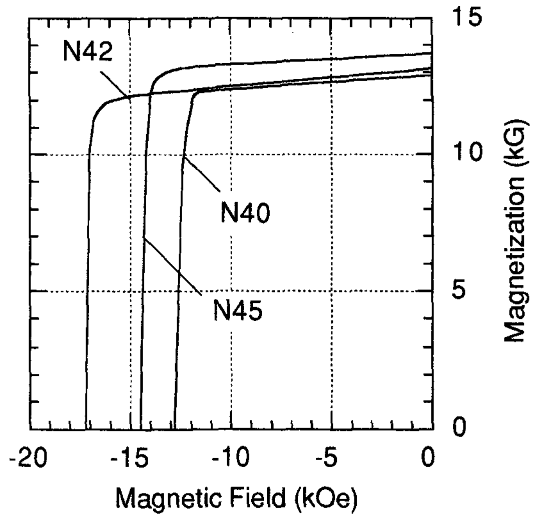

Figure 6. Demagnetization curves of N45, N42 and N40 grade magnets in Shin-Etsu.

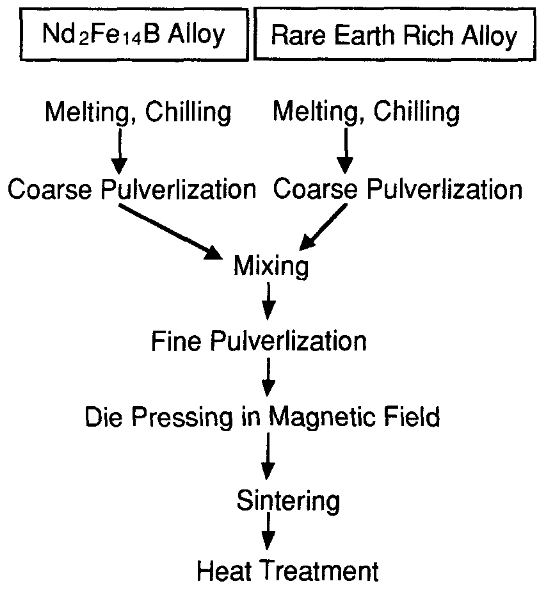

Figure 7. Process of two alloys method.

dysprosium decreases the saturation magnetization. The lack of dysprosium in the center region of sintered particles decreases the magnetization and increases the coercivity. The two alloys method is very simple and effective for producing a high performance magnet. In employing N45 magnet to VCM, the gap flux increases by about 10%.

The NdFeB magnet used in VCM is usually coated. The purpose of the coating is for corrosion resistance and for protection against magnetic micro-dusts produced from magnets. The electro-nickel plating is mainly used, which has an enough corrosion resistance[12]. The NdFeB magnet coated with the electro-nickel plating indicates no degradation for 100 hours under 120 °C and 2 atmospheric pressure. From these results, we can insure that an outlook and total magnetic flux do not change for 5 years or more in 65 °C and 50 RH %. The micro-dust protection is very important because dust may crush the head. Since head flying height from a magnetic media is 0.1 μm or less, the magnetic micro-dust attached to VCM is a serious problem. As the electro-nickel plating is not free from micro-pinholes, micro dust may be produced. In the former, we coated the Nd magnet with two layers of films, consisting of an electro-nickel plating and an electro-deposited coating for the upper layer. Since the reliability of the electro-nickel plating now increases, only a single coating of the electro-nickel plating is required.

Magnetic flux distribution in the gap of the flat coil (Figure 8) is not constant between a moving range of a coil. This non-linearity results in a nonlinear torque distribution. In order to obtain a torque linearity, we usually cut the sides of the magnet. These cuts effectively shorten the coil length in the center area of the magnet and improve the torque linearity. A mathematical analysis, such as the Finite Element Method (hereafter, FEM) is indispensable for obtaining an improved magnet shape. Since the flat coil VCM has no symmetry except its center line, three dimensional FEM analysis is necessary[13]. By using an engineering work station (EWS), this is possible. The gap flux density for each coil position is calculated; the coil moves into the angular range of ±15 °. There are several ways to obtain a moving torque. We employ the Maxwell stress method using the calculated magnetic flux density. Force has been expressed as the integral of the so-called

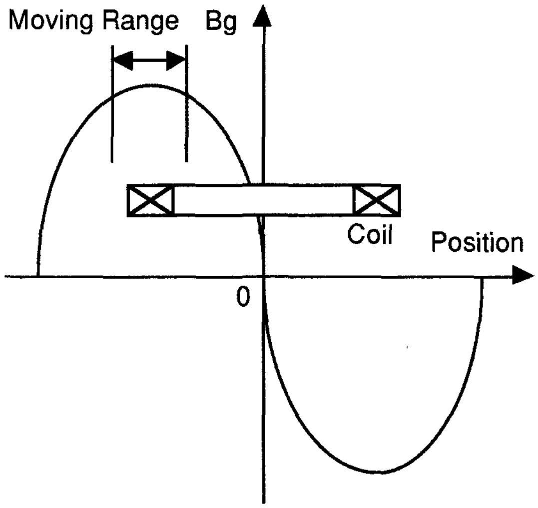

Figure 8. Schematic magnetic flux distribution of the flat coil type VCM

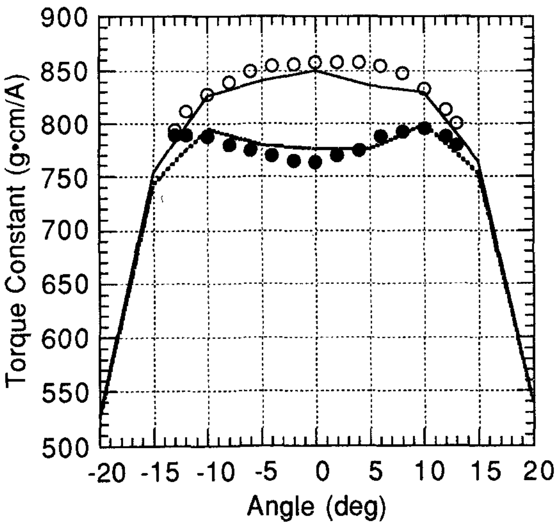

Figure 9. Angular dependence of the torque constant of a flat coil type VCM. The open and dark circles represent the measurement values for the original and cut models, respectively. The solid and dashed lines represent the calculated values for the original and cut models, respectively.

Maxwell stress tensor. It is found that the torque linearity is substantially improved in accordance to the magnet side cutting from Figure 9. A latch magnet for holding the magnetic head is attached to the VCM. In order to satisfy both the torque linearity and the holding force, FEM analysis is indispensable. Also, a transient phenomena, including an eddy current, is an important aspect. We have been able to calculate the transient current characteristics in the coil.

4. FUTURE APPLICATIONS

An automotive application will be the most promising one for RE magnet, but there are few examples at present. The introduction of ZEV (Zero Emission Vehicle) regulation in the California State of USA may trigger an electric vehicle market. At least one high power motor of 10 kW order is necessary per one car. The sintered RE magnet suits these motors. But, both an induction motor and a synchronous motor are also viable for an electric vehicle drive. It is not obvious whether the synchronous motor is superior to the induction one or not. Although the high power motor is an important part, a key part for the electric vehicle is not the motor but a battery, which has less performance at present. Also, a lack of an industry appropriate infra-structure, such as an electric station, is a serious problem for realizing the electric vehicle world. Although we can expect a mass market of RE magnet in the automobile industry, there are many unknown factors in enlarging the RE magnet production.

A linear synchronous motor might be another future application for RE magnet. It is expected to be applied to a linear elevator, a transportation in a factory or in a building, a vehicle such as a linear motor car and so on. A diagnostic application can be also expected. An artificial heart using a linear oscillatory motor is being developed.

Other than VCM and MRI uses in the RE magnet application, we can not find new applications for consuming a mass volume of the RE magnet. Although we can expect a steady expansion of VCM and MRI, we need additional large-scale applications in order to expand the RE magnet production in the next decade. New RE magnet materials have introduced new applications such as MRI in the past. But we may not be able to expect the same fortunate situation in the future. Because the NdFeB magnet has an excellent cost performance and it is difficult for new magnet materials to overcome the NdFeB magnet; it is opinion, we should not expect new materials and must seek new applications.

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