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IN SEARCH OF NEW HIGH PERFOMANCE MAGNETS

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There was a time when it seemed that permanent magnets were only used to rescue dressmakers' pins from the depths of thick-pile carpets, or as compass needles to guide lost travellers. They were also found in certain measuring instruments and magnetos, but it was the electromagnet that was used for more sophisticated applications such as loudspeakers and electric motors.

Developments in materials science have long since changed all that. New ways were found to enhance the properties of existing permanent magnets and, with the discovery in the 1970s that rare-earth metals could improve them even further, a turning point was reached. Since then the use of new permanent magnets has grown rapidly, and often at the expense of electromagnets.

This has caused something of a mini-revolution in those industries where magnets are used extensively. The opportunities provided by the new generations of permanent magnets have already influenced the design of many electromechanical devices, forcing equipment makers in almost every field to take a fresh look at their products.

In the early days it appeared that cobalt and samarium were the key elements in the development of new magnetic materials. But in 1982 Sumitomo in Japan and General Motors in the United States announced almost simultaneously their discovery of neodymium-iron-boron (Nd-Fe-B) alloys with astonishing magnetic characteristics.

Neodymium-based magnets were found to have a magnetic energy storage capacity 75% higher than cobalt-samarium ones, and were much less expensive to produce. This opened up the prospect of cheap high-performance magnets which could have many applications in a wide variety of fields. Designers at General Motors used the Nd-Fe-B magnets to halve the size and weight of starter motors without sacrificing power. As the Americans put it: "More flux for your bucks".

Research now seems to indicate the unlikelihood of achieving similar improvements in the magnetic performance of cobalt-based alloys. Cobalt is also very expensive, and located in areas considered risky in terms of its security of supply. Neodymium and boron, on the other hand, are available in sufficiently large quantities in all Continents; and in spite of the increasing demand for neodymium it is significantly cheaper than cobalt.

At present there are two known ways of making Nd-Fe-B alloys for magnets. The Japanese material "neomax" produced by Sumitomo uses powder metallurgy while General Motors' "magnaquench" magnets are produced by a spin smelting technique. These processes differ from one another in both the preparation of the raw materials and their subsequent treatment. Which of the two is the most economical has yet to be ascertained, although experts believe that the spinning process may have the edge.

In 1986, General Motors became the first company in the world to install Nd-Fe-B permanent magnets in cars on a commercial basis. They are now fitted into starter motors, windscreen wipers and ventilation motors and supplied to all GM units in the United States, Asia and Europe. The fact that the company was prepared to invest $ 60 million in this operation shows the importance it attaches to these new magnets and the advantages they offer.

General Motors and Sumitomo between them hold the most important basic patent applications. The West German firm Vacuumschmelze now has a licence from Sumitomo to produce Nd-Fe-B material in its own plant, and has been marketing it under the trade name "Vacodym". But for many European materials manufacturers the licence fees asked for by the Japanese are too high; and GM licences cannot be obtained.

European industry has long been interested in the development of magnetic materials, and historically many of the fundamental discoveries in magnetism have originated in Europe. But with the discovery of a new generation of permanent magnets by researchers in the United States and Japan, a new challenge has been thrown up. It is essential for Europe to response to this challenge with a sense of urgency and a high degree of cooperation if the opportunity is not to be lost.

New uses for permanent magnets

Permanent magnets play an important role wherever there is a need to convert electrical energy into mechanical energy or vice-versa. Nd-Fe-B magnets, with their high energy storage capacity, have low electrical power requirements. This can be used either to achieve a greater efficiency than other magnets of comparable dimensions, or to lower significantly their size and weight for a variety of applications. In both cases the performance/cost ration is much greater.

Because of the high magnetic force, Nd-Fe-B materials can be used in applications where permanent magnets have usually been unsatisfactory. This is the case with Nuclear Magnetic Resonance instruments used in medical diagnosis. To achieve a magnetic field of several Tesla, these devices used super-conducting magnets which were cooled by liquid helium. Nd-Fe-B magnets can be used without extreme cooling, and are therefore cheaper. Their incorporation in NMR equipment could lead to important reductions in both investment outlays and operating costs.

The same applies to particle accelerators which need high magnetic fields to steer and focus charged particle beams. The cost savings which could be achieved in this field of scientific research could allow the apparatus to be put to other technical uses.

The greatest marketing opportunities of these new magnets are to be found in the consumer field: applications for motor cars, household equipment and electro-acoustic products such as loudspeakers and microphones. In addition to lower costs and power savings, such applications will certainly bring higher reproduction quality to Hi-Fi equipment.

As a result of early tests carried out on electric motors which use new magnets, their use in electrically powered motors cars is being considered: the Italian firm Plymotor of Genoa for example, has built a disc drive motor whith remarkable performance figures. A propulsive performance of approximately 60 kW was obtained with a total weight of 18 kgs and at 12.000

r.p.m. A medium class saloon in a higher performance category (over 80 H.P.) could quite easily be built, and on the basis of present day weight and performance estimates, could even be powered using existing heavy lead batteries.

Generally speaking, Nd-Fe-B magnets will soon replace cobalt-samarium magnets whenever low cost magnetic performance at not too high an ambient temperature will be required. They will lead to further reductions in the size of parts and components without diminishing magnetic performance.

The greatest economic interest lies in uses which cover power generators, loudspeakers and microphone systems. Due to the magnetic advantages of Nd-Fe-B magnets, many applications will also be found in measuring instruments, relays, permanent magnets or magnetic clutches. Technical experts generally consider that the rapid introduction of new materials for magnets will make the conversion or re-design of instruments a necessity.

A particularly interesting example is the magnetic suspension rail system. The Krupp Widia Company supplied permanent magnets for the suspension system bodies used in the first suspension rail in Berlin which was inaugurated on May 1st 1987 for the town's 750th Jubilee. This experimental new type short-range transport system began with samarium-cobalt magnets, but these are being replaced by Nd-Fe-B magnets.

Today's market for magnets is estimated at $ 700 millions. Around 10% of this amount is taken up by high performance magnets, and it is expected that Nd-Fe-B magnets will show a growth rate of 10% per annum in the Nineties. In this rapidly developing market, the Americans and the Japanese are still in the lead. European industry cannot afford any longer to be dependent on others for the materials.

Opportunities for European Community Research

Neodymium or other rare-earth metals mixed with iron form, together with Boron, materials endowed with a highly complex structure. Scientists have recognised that there are countless combinations which could be turned into alloys and which would not be covered by the patents which have been applied for. This concerns their stoichiometric construction and, more importantly, their production and manufacturing processes.

In addition, all known Nd-Fe-B materials used in magnets have a Curie temperature which is very much lower than other materials. In practical terms, this meant that overheating above 150° C should be avoided.

Neodymium-Iron binary alloys only attain Curie temperature of 15-20° C. and even though they were known as early as the 1960s for their high performance, they were not appreciated for this reason. It was only in the 1970s that scientists discovered that the addition of boron to create ternary alloys significantly increased the Curie temperature.

Sumitomo worked with neodymium and other rare-earth metals, making patent claims which mentioned 8-20% rare-earths metals, 2-28% boron, with the rest being iron. The global formula $R_{15}Fe_{77}B_8$, where R stood for the rare-earth metals, was considered as an efficient alloy, but other compositions were also suggested.

This clearly showed how complicated the crystalline structure of these ternary materials was, and how great the chances are for discovering many more high performance materials for magnets made from R-Fe-B. This offers many opportunities for research in the European Community.

Outside the existing patent claims, there is room for much more progress in fundamental research, in the development of economic manufacturing processes, and research into practical applications. There exists in Europe today a significant pool of expertise in the relevant disciplines - solid state physics, materials science, metallurgy, and electrical engineering - but this talent is scattered throughout the twelve Member States.

The role of the European Community is to marshall this talent in a collaborative framework which will allow Europe's high potential in this field to be realised. This framework is known as CEAM: Concerted European Action on Magnets, and links universities, industry and research institutes throughout the Community.

Its primary aims are:

i) to develop high-performance iron-based rare-earths permanent magnets, and design novel devices which exploit their exceptional properties;

ii) to generate European collaboration by exchange of scientists, and stimulate a new generation of researchers to undertake projects in applied magnetism of industrial relevance;

iii) to provide a skills and information base to permit European industry to exploit the advanced magnets effectively.

Participation in CEAM, which began in the summer of 1985, was open to laboratories which have an active interest in the field. The idea of such cooperation was born at a special workshop on "Nd-Fe Permanent Magnets: Their Present and Future Applications", held in Brussels on 25 October 1984, sponsored by the European Commission in the framework of an existing materials programme on Substitution and Materials Technology.

The Commission subsequently agreed to support CEAM for two years from 15 October 1985 with a grant of 2.5 million Ecu (approximately $ 2.4 million) from the Stimulation Programme. Within the CEAM project, more than fifty laboratories are participating from nine countries in the European Community (Spain and Portugal joined the Community on January 1, 1986, and two Spanish laboratories are now also associated).

The research programme falls into three broad areas: materials, magnets and applications. The materials group is composed largely of physicists and chemists who are working on phase diagrams, searching for suitable new alloys and examining the intrinsic and extrinsic magnetic properties of rare-earth alloys, particularly those with the $Nd_2Fe_{14}B$ structure.

The magnets group mainly involves metallurigists and materials scientists, with significant industrial participation. They are primarily concerned with the microstructure of magnet alloys and the numerous problems of magnet processing and stability. The third group focuses on both electromagnetic and magnetostatic applications of the new magnets. Many participants here are electrical engineers and specialists in computer aided design working in industrial companies and universities.

Sources:

Nd-Fe Permanent Magnets, I.V. Mitchell, Commission of the European Communities, Brussels, November 1985.
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The Editors