Nano Mania

Before I jump into my subject, first let me say that I received several positive comments about my last column on the need for a Permanent Magnet Information Center. Unfortunately, no funding came along with the compliments, so we may have to wait a while for this one to happen. But I remain hopeful that some kind of focal point for permanent magnets will be created in the U.S.

In addition, let me add my congratulations to Walt Benecki on a job well done in writing his column for Magnetics Magazine over the last several years. I doubt that we will see another columnist who understands our industry so well *and* bears such a striking resemblance to Ernest Hemmingway. So I guess this now makes me the *senior* columnist, a title that I accept with humility. It didn't seem so long ago that I was just getting started.

I wanted to devote this space to the emerging science of nano technology as it applies to permanent magnets. The joke among academics these days is that any research proposal will be funded as long as the word nano appears in either the title or abstract, but preferably in both. While not completely true, it does give us an idea that there is a lot of interest in doing things on the nano scale.

What is the nano scale? It really means anything below 1 micrometer, one-millionth of a meter. That's 39 millionths of an inch or about 100 times smaller than the diameter of a human hair. Until now we have really been trying to control things on the micrometer scale, typically at the level of the grain, which is really just a collection of trillions of atoms, or what could be seen in a microscope. That is why we try to control things like particle size in this range. But at the nano level, we are trying to control things at the atomic level. It is a whole new world and requires us to think about materials differently. It is not like the famous Russian Matrushka dolls, where one doll fits neatly inside another larger doll. In the end, all the dolls are the same, except for their size. But as we work with materials on the nano level, their behavior is noticeably different, sometimes radically different, than on the macro level. It is both a challenge and an opportunity.

On the opportunity side of the coin, we have the potential for greater $(BH)_{max}$. This would be accomplished by a nanocomposite magnet, a mixture of a soft magnetic material and a permanent magnet material. The likely suspects to mix are Fe and NdFeB, but others are also possible. When combined correctly, we achieve a synergistic effect and see the best properties of both materials, i.e. high B_r and $(BH)_{max}$, along with decent H_{ci}. When it is not done correctly, we obtain an undesirable demagnetization curve and a poor magnet. But the potential is there for $(BH)_{max}$ greater than 64 MGOe, the theoretical limit of NdFeB alone, so it is a compelling target. There may also be a chance to lower the cost of the magnet, based on less expensive raw materials, if for example some iron replaces some NdFeB. But since the processing route is not well-established, this conjecture is premature.

As for challenges, there are many. The first one is that most of us who were trained in magnetism grew up with the single ion theory, which I will try to paraphrase briefly. It says, among other things, that we should imagine magnetic materials as collections of *non-interacting* grains. This approach works reasonably well in so many cases that it is easy to think that it is universally true. Of course, it is not, but its beauty is in helping us to take the first step in understanding magnetic materials. Now we need to mentally take the second step, that neighboring regions can interact and try to understand the basis of this interaction. In nanocomposite magnets, they *must* interact to achieve the synergistic effect. Clearly we need to change our thinking about the nature of magnetic materials if we want to be on the nano bandwagon.

The other challenges are more practical. Rare earth alloys are notoriously difficult to handle as the particle size is reduced. They will pick up oxygen from the air and may burn. The effect becomes more serious as the particle size is reduced. I have seen lots of fires with SmCo and NdFeB powders when the average particle size was around 4 micrometers. I can only imagine how pyrophoric nano sized powders would be. There are more general health and safety concerns for anyone working with any particle smaller than 1 micrometer. These challenges need to be addressed.

What is the way forward? Currently several groups are working in this area, but in a rather insular way. Eventually something will emerge, I am sure, but this is a tough nut to crack, especially for those interested in making a business with these materials. In that case, we need a way to make magnets consistently and inexpensively, not just once. There may be a faster way forward. The model I would suggest is the one used in Europe after the announcement of NdFeB magnets. The Concerted European Action on Magnets (CEAM) was formed by a group of a dozen or so industrial and academic participants, all with some interest in permanent magnets. The research and development work was divided between the members and the communication within the CEAM was frequent and thorough. A vast amount of information was generated in a short period of time. This may also be the best way to move ahead with nano magnets.

And now for something completely different. Fans of Monty Python will recognize this famous phrase as the cue that one sketch was over and another was beginning. In this case it means that I am off on a new and temporary adventure. By the time you are reading this column, I will be several weeks in to teaching a few physics classes at Alma College in Michigan. This is a brief stay; my wife and I will be there just for the fall semester. In some ways it is a happy homecoming, since we lived in Alma back in the 80's when I worked for Hitachi. In a future column I will report how I spent my time there.

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