Prizztech

Estimation on business potential of recycled NdFeB magnets

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1. Backgroud

NdFeB magnets are the key components in modern technology. Demand of these magnets is rising rapidly due to the electrification of the society. NdFeB magnets contain rare earth metals like neodymium, dysprosium and terbium, about one third of the magnet weight.

NdFeB material was invented in 1984. As a result of active development work, NdFeB magnets became more general in machine and electronics use in the 90's. Around 2010 first machines utilizing these magnets started to reach the end of life and recycling became a topic. At the beginning magnets were recycled in steel production and only iron was utilized. Rare earth metals remained as impurities in the recycled steel or ended up to landfill with slag.

Sharp prize peaks of neodymium and dysprosium in 2011 activated magnet recycling research. Aim of the recycling is to reduce the demand of virgin raw materials. One of the motivations in western magnet production is the reduction of the strong dependency on raw material import from China. Magnet recycling provides a good possibility to increase industrial independency.

At the same time, ecological features of industrial production processes have become more and more important. Sustainable production is nowadays a part of the product brand. This trend is also changing the demand of recycled products. The development work in the field of magnet recycling concentrates on finding ways to increase the amount of recycled material in the product without losing magnetic performance of the final product too much.

There are three main issues driving the magnet recycling development. First, there is an increasing amount of scrap magnets needed to be treated somehow. Second, the growing concern of uncertainty of the raw material supply in western magnet production. Third, the use of recycled raw material provides value to the customer as more sustainable product.

The operational environment is promising for magnet recycling. Still there are some technical and financial limitations that need to be considered. In this document these limitations as well as possibilities of magnet recycling business are discussed. Magnet recycling is profitable to the magnet producer if certain requirements are met. To become more common, it needs to be profitable for the entire value chain, from the collection and dismantling to the end use of recycled magnet products.

2. Recycling routes

NdFeB magnets are produced by powder metallurgical process, where NdFeB particles are joined together in a sintering process. NdFeB compound used as a raw material is produced by casting. Small NdFeB grains in the cast alloy are separated by hydrogen decrepitation and milling. Separated particles are then pressed and aligned in the presence of a magnetic field to form a green compact. Green compacts are sintered in high temperature to get fully dense magnets. Metallic neodymium in the material performs like a glue in the sintering process joining the NdFeB particles together. Sintered pre-products are machined by grinding, slicing or wire-cutting to final dimensions. Magnets need to be magnetized to generate their magnetic properties.

There are several possibilities to add recycled magnet material to the production process. In figure 1 these possible recycling routes are illustrated. If the shape and the magnetic properties of the collected used magnets are matching the requirements of a new application, only magnetization is needed.

However, this is uncommon. Usually, the used magnets are crushed and used as a raw material for new magnets. Crushed material can be added to the magnet production process in three different ways depending on the quality of the material.

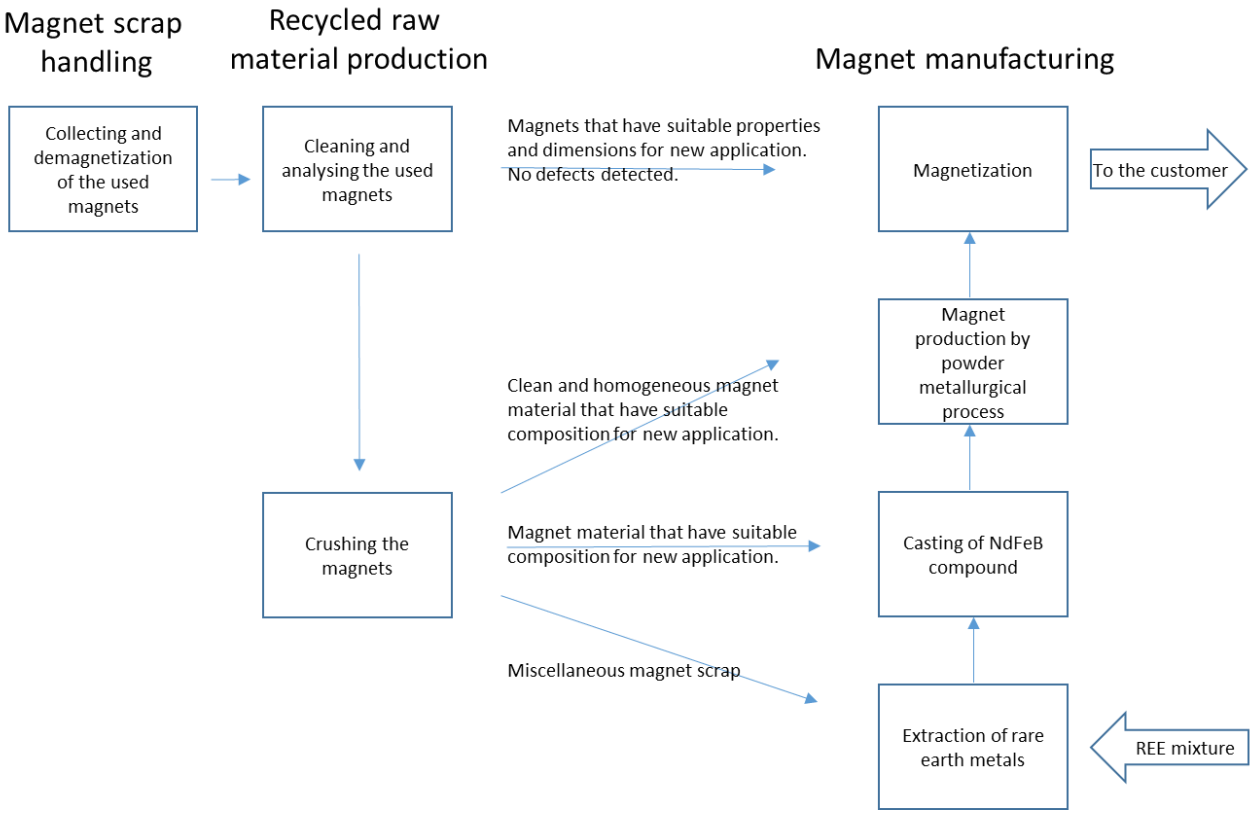

Figure 1. Four different routes to recycle NdFeB magnets depending on the properties of the used magnets.

The most energy efficient and economical way to recycle NeFeB magnet material is to add it straight to the powder metallurgical magnet production process. This means pulverization of the material and mixing it with some fresh neodymium rich NdFeB powder. By using this type of mixed powder, the shape and in some limits also the magnetic properties of the final product can be modified to meet the requirements of the application. This type of recycling process was demonstrated successfully in Circwaste project.

However, there are limitations in this type of recycling process. In the next chapter, technical requirements are presented for the magnet material that can be recycled by this type of process. If these requirements are not met, material from scrap magnets need to be taken to previous steps of the magnet production process, meaning casting of even the rare earth element (REE) extraction. This is more complicated, more energy consuming and more difficult to get profitable.

3. Technical requirements for recycling magnets by pulverization

The quality of the recycled magnet material is the most important factor, when determining the route, it should be recycled. High quality magnets can be recycled by pulverization. However, the original properties cannot be reached due to the fact, that each time material is powder metallurgically processed, it collects a certain additional quantity of impurities like carbon and oxygen. Quality means suitable composition including enough dysprosium and minimum quantity of impurities. The quality can be evaluated if the source of the magnets is known. Thus, the traceability of the recycled magnets is important.

In addition, there need to be sufficiently similar magnets available. The amount of similar scrap magnets needed depends on the production process batch size. Raw material of each batch needs to be homogeneous.

Prior to pulverizing, the scrap magnets need to be treated to remove coatings or oxidized surface layers. For this treatment magnets need to be big enough and preferably in one piece.

3.1 Traceability

Magnetic performance is the most important feature of the technical NdFeB magnets. It is designed to meet the needs of the application. Magnetic parameters can be adjusted by varying the composition of the magnet. Some applications need more magnetic power and some more thermal tolerance. Thermal tolerance can be improved for example by adding dysprosium to the material. The composition of the recycled raw material is fixed and can't be modified anymore. Thus, the end use of recycled magnets should be similar than the source of the scrap magnets. To be able to ensure the suitability of the recycled raw material to the magnets for certain applications, the source of the material should be known.

3.2 Homogeneity

To be able to design the magnet performance, the raw material needs to be homogeneous. Magnets are produced in batches and each batch is designed separately. This means that recycled raw material for each batch needs to be homogeneous meaning the source is the same or similar application. Suitable batch size in magnet production is roughly 300 kg. To be able to produce one batch of recycled magnets containing at least 50 % on recycled raw material, minimum of 150 kg of homogeneous magnet scrap is needed. Only big machines, like wind turbines include enough magnets. Smaller machines like elevator or electric vehicle motors are feasible sources only if there are many similar motors disassembled at the same time.

Magnets separated from electronic waste are miscellaneous and thus not suitable for recycling by pulverization route. Miscellaneous magnet scrap needs to be treated by casting to get more homogeneous NdFeB material or by extracting the rare earth elements for fresh magnet material production. There are currently no industrial RE-extraction processes available in Europe.

4. Financial limitation in recycled magnet production

From the point of view of an application manufacturer, the price of magnets produced from recycled raw material should not exceed the prize of virgin magnets. This sets the financial limits to the entire recycling value chain.

Raw material cost is the dominating cost in the NdFeB magnet manufacture and it is strongly dependent on the world market prices of rare earth metals. So, the value of the scrap magnet material is not constant but depends on both the quality of the material and the world market prices of REE.

Recycling companies are responsible for the collection and separation of the used magnets. There is business potential in magnet recycling, if the price of the material covers the extra costs caused by the special handling protocols required. There are also some additional costs to the magnet producer arising from the material analysis and design of new recycled magnet products. Overall material cost for the magnet manufacturer should actually be lower than the cost of virgin raw material, since there is always a risk of unwanted contaminants in the recycled material. The financial risks should also be considered when estimating the business potential.

4.1 Handling costs

Permanent magnet machines that have reached the end of life need to be disassembled carefully to get magnets out in one piece. Handling of strong magnets is difficult and dangerous, and therefore they need to be demagnetized by a heat treatment (above 400 °C) prior to handling. Careful disassembly and additional heat treatment increase the handling costs. The more there is magnet material in the end-of-life machine the more profitable the separation would be.

Coatings or oxidized surface layers of used magnets need to be removed prior to crushing. It is usually done by abrasive blast. The bigger the magnets are, the more cost effective the procedure is. Also, the weight loss resulting from the abrasive blast compared to the total weight of the magnet is smaller in big magnets.

4.2 Analysis and design costs

Each magnet production batch needs to be designed to meet the requirements of the customer. The composition of the material is the base for this design. Because of this, the composition of recycled raw material needs to be analysed. According to the analysis results, suitable composition for the virgin material to be mixed with the recycled raw material can be defined. This usually means some special composition, which must be ordered separately and cast for that certain application only. This can increase the cost of the virgin raw material. Each different batch of used magnets needs this analysis and design process. The bigger the batch, the lower the unit cost.

4.3 Risks

Recycled raw material includes always risks. If the magnets have faced accidents during the use, they may have corroded or contaminated some other way. Impurities like oxygen and carbon can destroy the magnetic properties of the final product. Usually only a small sample of a scrap magnet batch is analysed, and the contamination might not be revealed, if all magnets are not contaminated. This might lead to fail of some portion of the produced recycled magnets.

5. Business potential in recycled magnet production

The most important business potential lies in recycling of large magnets and series of similar middle size magnets. These can be found in large industrial motors and generators. Most potential source of recyclable magnets are dismantled wind turbines. One permanent magnet driven wind generator contains hundreds of kilograms or ever tons of magnets. It is sufficient for several production batches of recycled magnets.

Neorem Magnets produces magnets for motor and generator applications and can utilize recycled raw material from similar applications. It requires that customers can compensate the slightly lower magnetic properties of the recycled magnets in their machine design. Technical potential of the NdFeB magnet recycling was demonstrated in Cirwaste project. This demonstration and further studies on motor and generator dismantling have given important information to Neorem Magnets and recycling companies about the possibilities of magnet recycling. For example, Stena Recycling is developing recycling process for the entire windmill and recycling of magnets is included in the process.

Stena Recycling has facilities for recycling big machines in Tahkoluoto area in Pori, which is close to the Peittoo recycling park and next to Port of Pori. In Peittoo there is space, if Stena or some other recycling company needs land to store the parts of dismantled windmills before handling. In Pori area there is now knowhow, infrastructure and network of active companies developing the recycling value chain. At today's world market prices of rare earth metals, recycling of windmill magnets is likely to be profitable, since they are high quality magnets and easy to keep traceable.

Recycling of small magnets is more difficult to get profitable, since they need more processing, before they can be used as a raw material for new magnets. More research work is needed to find effective ways for their recycling. In case of smaller NdFeB magnets, the recycling process is more complex, including extra steps like REE extraction and casting. If European magnet production aims at raw material independency in the future, recycling process for small magnets needs to be developed as well.