magnetfabrik bonn

Applications Brief

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The Effects of Temperature on Permanent Magnets

1. Introduction

In typical applications such as in motor vehicles, household appliances, electric motors or in mechanical engineering, permanent magnets are subject to fluctuations in temperature throughout their service life, and this affects their magnetic properties. In this context, distinctions have to be made between the different types of stresses, for instance cyclic stress, longterm stress, etc.
Although the manufacturers of materials for permanent magnets provide information on material characteristics at different temperatures, such information is insufficient for deriving accurately the effects that are applicable to the specific application under different stresses.
For sensor applications in particular, understanding the processes that cause the strength of magnets to diminish with time and temperature is of crucial importance when designing the system.
It was for this reason that Magnetfabrik Bonn started a series of longterm trials at the beginning of 2007 in order to systematically identify the effects on the various materials. Data on the effects of more than 8000 hours stress at 130 °C and 150 °C is now available and is summarized in this paper.

2. Measurements

The sample magnets must be magnetically isolated during the measurements, i.e. they must be kept at a considerable distance from each other. Otherwise, the magnetic field of the samples would stabilize or destabilize neighboring samples and distort the measurements, particularly over longterm trials. In order to test a number of samples over long periods, Magnetfabrik Bonn GmbH developed miniature furnaces with PID temperature controllers that allow the magnetic field to be measured while the samples are being subjected to thermal stress. The size and the efficient insulation mean that it is possible to maintain several samples at 150 °C with a power consumption of less than 30 watts.

3. Effects of thermal stress

The properties of all magnetic materials depend to a greater or lesser degree on the ambient temperature. In physical terms, the effects of temperature are fully described by curves plotting demagnetization against temperature. Because the demagnetization curves are generally reduced to the characteristics remanence B_r, coercivities H_{cB} and H_{cJ} and maximum energy product $(BH)_{max}$, the material manufacturers generally document the corresponding coefficients for linear change over temperature. Because the energy product is roughly quadratically dependent on the remanence for most materials, it is often the case that only the linear coefficients $\alpha(B_r)$ and $\beta(H_{cJ})$ are specified in the material characteristics tables. Both values indicate the percentage change of the characteristic from 20 °C to 120 °C, in each case with reference to the value at 20 °C. The linearization is an approximation that can lead to extremely incorrect results, particularly when extrapolating for values above 120 °C.
The magnetic characteristics and the demagnetization curves at different temperatures can be downloaded from the "Products" section of the Magnetfabrik Bonn GmbH web site.
As far as the user is concerned, the physical description of a material often fails to provide practical infor-

mation for evaluating their application. In this context, a far more important question is often how the magnetic field of a permanent magnet at a fixed position changes as a function of time and temperature. Qualitatively different effects occur here, and these are described briefly below. All three effects occur together, and their sum effect must therefore be considered.

Reversible effect

The magnetic field changes reversibly with temperature. As a good approximation, this is proportional to the remanence and is not dependent on the type of magnetization and the shape of the magnet. Since a first approximation of this reversible change is linear, i.e. it shows a constant increase or decrease per degree Celsius, a characteristic that roughly corresponds to the coefficient $\alpha(B_r)$ is sufficient to describe it.

To take an example, $\alpha(B_r)$ = 12 %/100 K means that the magnetic field changes by 0.12 % per degree Celsius with reference to the room temperature field value at any location.

Irreversible changes over temperature

In the case of rare earth magnet materials, the coercive field also decreases as temperature increases as well as the remanence, i.e. the two coefficients $\alpha(B_r)$ and $\beta(H_{cJ})$ are negative. In the case of hard ferrites on the other hand, the coercive field decreases at low temperatures, i.e. $\beta(H_{cJ})$ is positive. The coercive field describes a magnet's stability with respect to demagnetization, i.e. partial demagnetization can occur with rare earth magnets at high temperatures and with hard ferrite magnets at low temperatures. This results in a change to the magnetic field the first time the relevant temperature is reached. This loss is not compensated for when the temperature is restored and is therefore irreversible.

This weakening stabilizes itself as a result of the loss of magnetization and the selfdemagnetizing field it generates. There is no further decrease or only a slight decrease when the magnet is heated or cooled to the same temperature. Compared with the reversible change to the field, the irreversible losses are more complex to describe and depend not only on the magnet material, but also on the shape of the magnet and the type of magnetization as well as on any external fields applied.

Irreversible loss over time

In the event of repeated temperature cycles or long aging times, rare earth materials exhibit progressive, irreversible demagnetization losses over very long periods. These arise partly as a result of delayed thermal demagnetization and as a result of chemical changes in the material.

The delayed thermal demagnetization is determined by an Arrhenius law, i.e. there is a logarithmic progression across the aging time. This logarithmic dependency means that the loss can be demonstrated almost entirely after a period of a few minutes or hours. Further change over days and months is then only very slight.

In addition, however, some materials exhibit a considerable progressive loss of magnetic field strength over long time periods. This loss is caused by different physical processes and can, for instance, be traced back to a slow but continuous chemical decomposition at high temperatures.

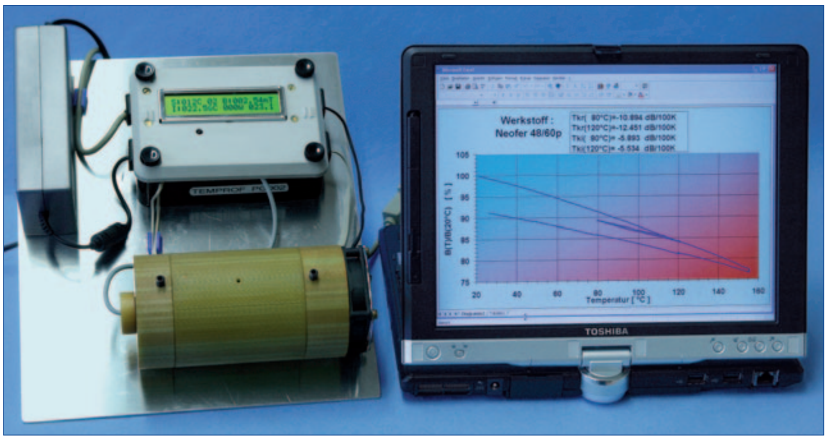

Figure 1: View of the furnace developed for these measurements

Material: Neofer 48/60p

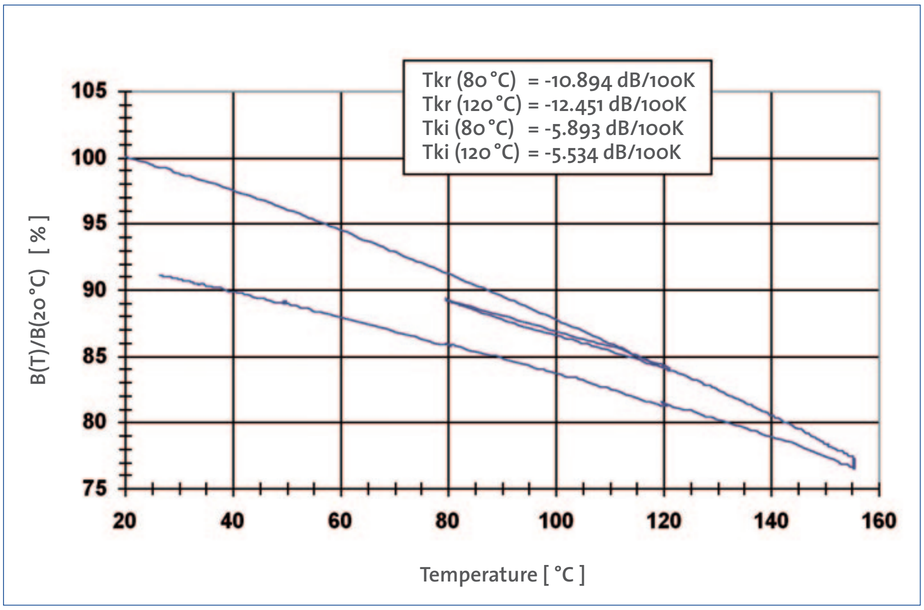

Figure 2: Measurement of the reversible and irreversible field change for a sample magnet using the material Neofer 48/60p, 14x14x2.5 mm, dipole magnetization

Neofer 48/60p

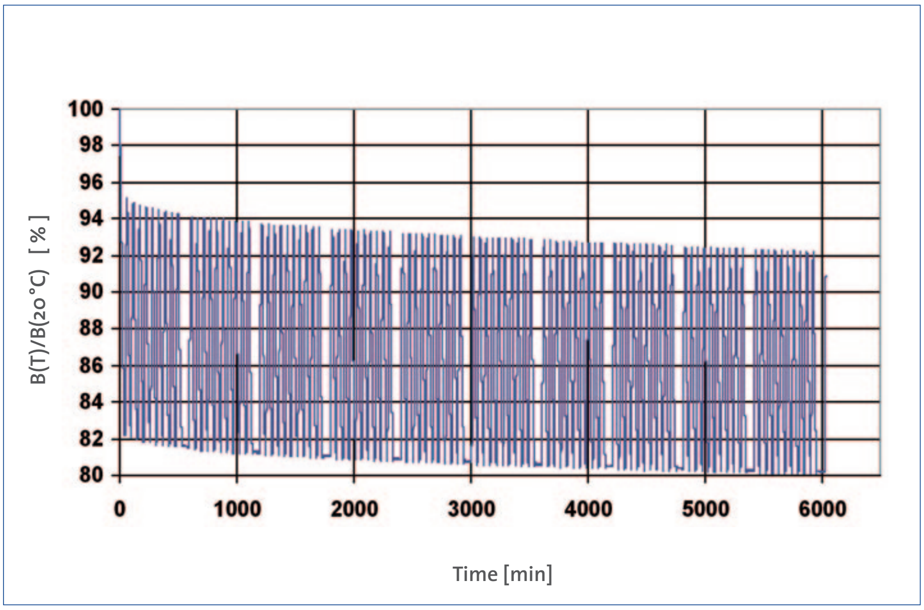

Figure 3: Measurement of a sample magnet under temperature cycles.
Material: Neofer 48/60p, Ø16x2.5 mm, dipole magnetization

Neofer 48/60p

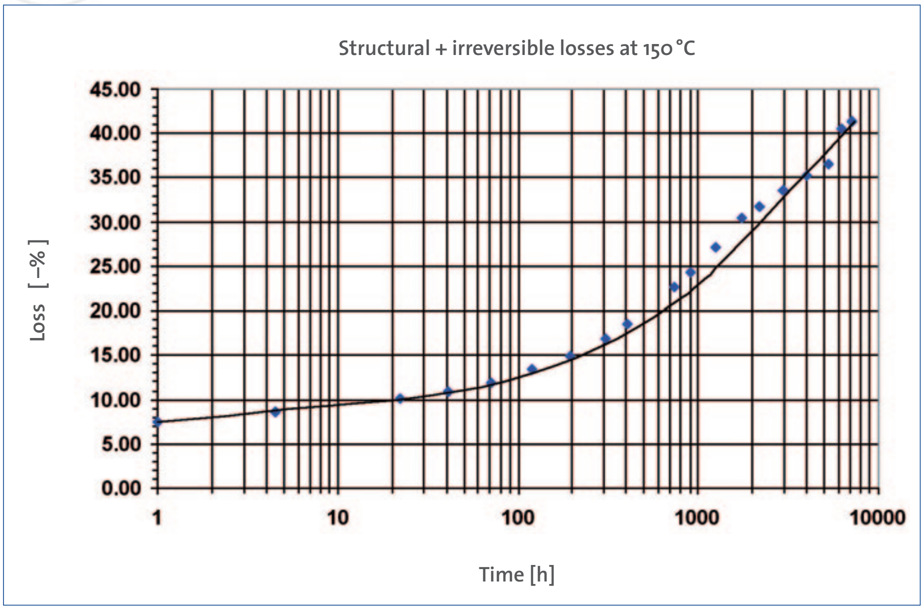

Figure 4: Measurement of sample magnets over long time periods as an Arrhenius plot. Material: Neofer 48/60p, 14x7x3 mm, axial magnetization

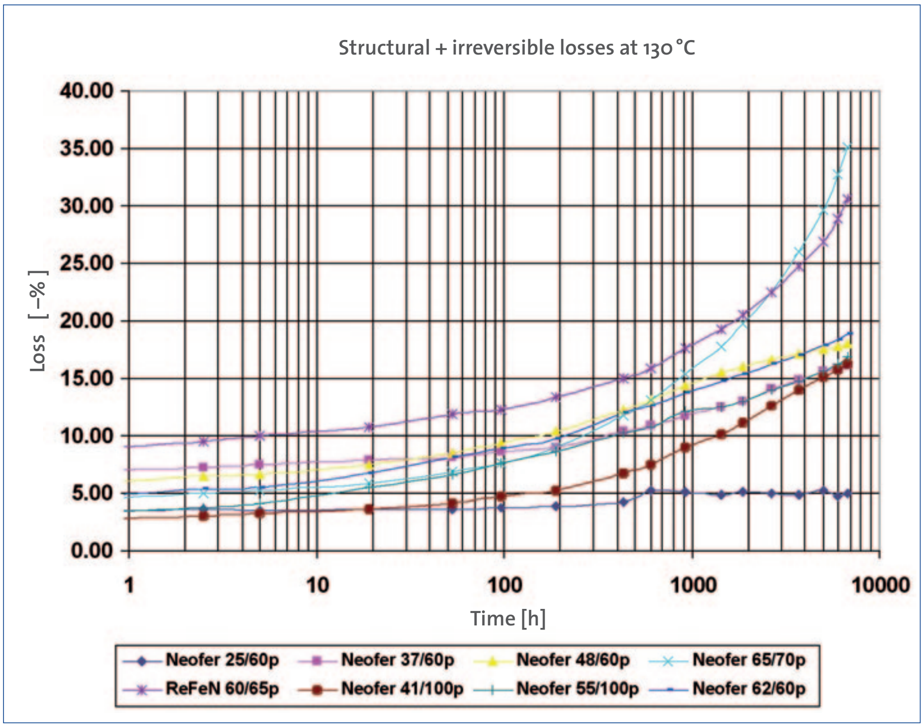

Figure 5: Measurement of sample magnets over long time periods as an Arrhenius plot. Sample material: 14x7x3 mm, axial magnetization

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Magnetfabrik Bonn GmbH
Dorotheenstrasse 215 • D-53119 Bonn
Phone 02 28 - 7 29 05 - 0 • Fax 02 28 - 7 29 05 - 37
verkauf@magnetfabrik.de • www.magnetfabrik.de

4. Conclusion

No irreversible losses were observed on the ferrite materials we investigated in a temperature range above room temperature up to 160 °C. Our range of products includes a number of standard materials for which longterm exposure to 150 °C for up to 6000 hours and the magnetic working ranges that typically occur can be classified as absolutely non-critical.

The reversible losses of the polymer-bonded hard ferrite magnets can be well approximated using the linear remanence coefficient $\alpha(B_r) \approx 20$ %/100 K.

The following aspects need to be considered for designs using the Neofer p® materials investigated:

- Reversible losses for all temperature changes in a typical range of 11-13 %/100 K
- Irreversible losses depending on the material, working point and duration of stress as of approx. 80 °C
- Longterm losses and cyclic losses as of approx. 120 °C-130 °C depending on the material. A range of materials that are suitable for exposure to 150 °C for durations of the magnitude of a few hours are not recommended for designs requiring exposure of 6000 hours and more.

The results of these investigations are able to qualitatively describe the fundamental trends. However, reliable estimation for a given application requires a testing procedure designed to suit the application, because the longterm losses in particular also depend on the environmental conditions and possibly also on any electrochemical contact with other metals.
We are happy to support you in assessing your application and selecting the magnet materials and type of magnetization for the sensor type under consideration. If time and temperature are factors which may potentially have any influence, we can, together with you, examine any suitable countermeasures such as deliberate overdimensioning. Put us to the test!

The experts in permanent magnets

Magnetfabrik Bonn has 75 years of experience, and the extensive skills gained over these years in all aspects of materials, production techniques and applications have made us not only a leading provider of permanent magnets but also one of the leading experts in the field. We use these skills to find solutions to the complex tasks faced by our customers. Our range of products includes a wide spectrum of materials that we produce in our own facilities. Our highly automated production ensures cost-efficient manufacturing and provides our customers with additional advantages over the competition. Quality and environment management systems testify to our commitment to continuous improvement and to our sense of responsibility. No matter whether you need a mass-produced product or tailored magnet systems as functional assemblies, just have a word with our experienced specialists.

TÜV CERT
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ISO 14001:2004
Zertifikat: 01 104 052181

magnetfabrik bonn

Magnetfabrik Bonn GmbH
Dorotheenstrasse 215 • D-53119 Bonn
Phone 02 28 - 7 29 05 - 0 • Fax 02 28 - 7 29 05 - 37
verkauf@magnetfabrik.de • www.magnetfabrik.de

How to reach us

magnetfabrik bonn

Magnetfabrik Bonn GmbH
Dorotheenstraße 215 • D-53119 Bonn

Tel. (+49) (0)2 28 - 7 29 05 - 0
Fax (+49) (0)2 28 - 7 29 05 - 37
E-Mail (for sales) verkauf @magnetfabrik.de
Internet www.magnetfabrik.de
Registergericht Bonn, HRB 4774 • VAT-ID-No.: DE 122 117 630

Representatives in Germany

Berlin, Brandenburg
D-14532 Stahnsdorf
Horst Seifert Industrievertretungen
Inhaber Sascha Seifert
Mucheweg 6
Tel. +49 (0) 30 - 8 15 13 44
Fax +49 (0) 30 - 84 72 24 39
E-Mail h.s.i@web.de

Bremen, Hamburg, Mecklenburg-Vorpommern, Sachsen-Anhalt (Nord), Schleswig-Holstein
D-22587 Hamburg
Heinrich J. Merck e.K.
Hasenhöhe 40 b
Tel. +49 (0) 40 - 87 08 63 - 0
Fax +49 (0) 40 - 87 08 63 33
E-Mail heinrich.merck@hj-merck.de

Baden-Württemberg
D-72116 Mössingen
Dieter Schönheinz
Technik und Vertrieb
Lembergweg 18
Tel. +49 (0) 74 73 - 78 77
Fax +49 (0) 74 73 - 78 99
E-Mail tb-disch@t-online.de

Bayern
D-84089 Aiglsbach
Technisches Büro Wolfgang Pfaff
Burgweg 20
Tel. +49 (0) 87 53 - 96 03 11
Fax +49 (0) 87 53 - 96 03 96
E-Mail tb-pfaff@tb-pfaff.de

Sachsen, Sachsen-Anhalt (Süd), Thüringen
D-99425 Weimar
Technisches Büro Dr.-Ing. Rathsack
Dichterweg 5
Tel. +49 (0) 36 43 - 90 24 90
Fax +49 (0) 36 43 - 5 32 02
E-Mail dr.rathsack@t-online.de

Nordrhein-Westfalen, Rheinland-Pfalz
D-40885 Ratingen-Lintorf
Heyderhoff GmbH Elektrotechnik
Rehhecke 25
Tel. +49 (0) 21 02 - 918 - 136
Fax +49 (0) 21 02 - 1 77 14
E-Mail kontakt@heyderhoff.de

Hessen, Nordrhein-Westfalen, Rheinland-Pfalz, Saarland
D-53119 Bonn
Magnetfabrik Bonn GmbH
Dorotheenstraße 215
Tel. +49 (0) 2 28 - 7 29 05 - 0
Fax +49 (0) 2 28 - 7 29 05 - 37
E-Mail verkauf@magnetfabrik.de

Foreign Representatives

Austria, Hungary, Croatia, Slovenia, Slovakia, Czech Republic
A-1150 Wien
Dieter Pelzel Industrievertretungen
Plunkergasse 22
Tel. + 43 - 664 - 504 89 91
Fax + 43 - 1 - 985 64 75
E-Mail dpi@pelzel.at

Brazil
BR-95001-970 Caxias do Sul/RS
Sulbras Sistemas Magnéticos
BR 116, km 141, Bairro Sao Cristóvão
Caixa Postal 749
Tel. + 55 (0) 54 283 - 1866
Fax + 55 (0) 54 283 - 1938
E-Mail carlos@sulbras.com.br

France
F-92100 Boulogne-Billancourt
TECHNA France Sarl
Jean-Pascal Aner
55, rue d'Aguesseau
Tel. + 33 - 1 - 41 31 51 63
Fax + 33 - 1 - 41 31 51 60
E-Mail jp.aner@techna-france.com

Italy
I-20129 Milano
AME S.r.l.
Via Plinio, 55
Tel. + 39 - 02 - 29 51 40 26
Fax + 39 - 02 - 29 40 08 87
E-Mail ame@ame.it

Switzerland
D-72116 Mössingen
Dieter Schönheinz
Technik und Vertrieb
Lembergweg 18
Tel. +49 (0) 74 73 - 78 77
Fax +49 (0) 74 73 - 78 99
E-Mail tb-disch@t-online.de

Turkey
TR-34 670 01 Iketelli Istanbul
MUTLU LTD. STI. Iketelli Organize
Kücük Sanayi Bölgesi Metal
IS SITESI, 20 Blok No:21
Tel. + 90 - 212 - 671 07 92
Fax + 90 - 212 - 671 07 94
E-Mail mutlultdco@superonline.com

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