Time-Dependent Demagnetization in Sintered NdFeB Magnets

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Abstract: In the design of permanent magnet devices it is important to ensure that no demagnetization will occur under operating conditions. BH curves, measured or calculated, are typically used in the selection of a suitable magnet material. The measured BH curves of the selected magnet material are expected to reveal the conditions, i.e. temperature and working point, at which demagnetization starts to occur. However, demagnetization is a time-dependent process and the measured BH curve shows only an image of the magnetization state of the material after a fairly short exposure time. Long-term irreversible flux losses detected in sintered NdFeB magnets cannot be deduced from the BH curves of the material. Loss measurements for at least 1000 hours are needed to give a reliable picture of the long-term loss behaviour of the magnet. For an industrial NdFeB magnet of 38SH grade with a permeance coefficient of 0.5, the maximum working temperature was found to be 110 °C.

Key words: demagnetization, flux loss, NdFeB, stability

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1. Introduction

Permanent magnet technology has great potential in the modern motor and generator industry. There are, however, some doubts about the stability of the magnetic properties in the long term. The time dependence of magnetization and demagnetization has been studied extensively, but mostly on the time-scale of seconds [1-4]. The information obtained may be useful in the design of magnetic data storage devices, but is not relevant for motor designers, who need stability information on the scale of years. There is no evidence that results obtained in measurements within a few seconds or minutes would be applicable on a wider timescale.

The long-term stability of rare earth permanent magnets is discussed in one technical report by IEC [5]. The report presents measured irreversible losses as a function of time between 1 and 1000 hours. However, the corrosion protection of the samples was not mentioned. In the long term, corrosion would cause permanent losses in addition to demagnetization. Corrosion can be considered as the main reason for long-term instabilities after the plateau of constant flux loss per logarithmic time cycle, as described in [IEC/TR62518, 2009 #1305].

Our previous studies have demonstrated that irreversible flux losses in sintered NdFeB magnets kept at a stable elevated temperature obey the logarithmic time dependence at least in the timescale of 1 to 10 000 hours (over 1 year), if sufficient corrosion protection is applied [6]. In this work we compared the long-term flux loss behaviour of a sintered industrial NdFeB magnet with its measured BH curve data.

2. Method

Samples were prepared by water cutting from a larger block of industrial 38SH material. The sample size was 10x10 mm and the height varied between 2.3 and 5.2 mm, leading to permeance coefficients (load lines/workng points) ranging from 0.5 to 1.3. The BH curves of the material were measured with a HymPulse magnetic properties tester at Metis Instruments & Equipment Nv. The samples were fully magnetized in a 3.5 T pulsed field. The reference value of the flux of each sample was measured with a Helmholtz coil immediately after magnetization. The samples were then placed into ovens with stable elevated temperatures. Corrosion protection was performed by wrapping the samples in aluminium foil. The samples were taken out of the ovens at logarithmic time intervals. The samples were cooled down to room temperature and remeasured with a Helmholtz coil. A minimum of 10 measurements were performed within a time period of 1000 hours. Based on the measurements, logarithmic trend curves were determined to describe the loss behaviour of each magnet.

3. Results and Discussion

3.1. BH Curves

The BH curves of the studied material measured at 20 °C, 100 °C and 140 °C are presented in Fig.1. At room temperature the BH curve is linear, but at 100 °C a small knee occurs. At 140 °C the knee is even clearer. The load lines representing the permeance coefficients of 0.5, 0.8 and 1.3 are also shown. At 100 °C all the working points are far away from the knee. At 140 °C some of the working points have already fallen off the linear part, while some of them remain on the linear part of the curve.

3.2. Losses at 140°C

Based on the BH curves one would expect some losses in samples with Pc = 0.5 at 140 °C, but samples with Pc = 1.3 are expected to be stable. Figure 2, however, also shows...
losses in those samples. The initial loss after one hour increases with a decreasing $P_c$, and for samples with $P_c = 0.5$ it is as much as 15%. The slope of the trend line also increases with a decreasing $P_c$. As the $P_c$ decreases the deviation of the measurement points from the trend line also increases. It can be seen that the measurement points take a more curve-like form, saturating towards a fixed loss level. The reason for this might be the changes in self-fields of the magnets as demagnetization proceeds.

The total loss expected after 30 years can be estimated from the trend lines in Fig. 2. Correspondingly, the loss after 1 second can be calculated, if the logarithmic trend is assumed to continue from the second scale onwards. Calculated losses after 1 second, after 1 hour, and after 30 years are plotted as a function of permeance coefficient in Figure 3. The flux losses decrease smoothly as the permeance coefficient increases. The curve for loss after 1 second, however, crosses the zero line at $P_c = 1.15$, and at $P_c = 1.3$ the calculated loss after 1 second is positive, which is physically impossible. This raises the question whether logarithmic loss behaviour is valid across the timescales of seconds and hours. Similar results were obtained with other materials as well and the effect was more pronounced in materials with higher $H_{ci}$. No clear explanation for this was found.

3.3. Maximum Working Temperature

The magnet producer reports the maximum working temperature for this type of magnet to be 150 °C. According to the measurement data presented in Fig. 2, even 140 °C would be too high a temperature at least for magnets with a $P_c < 1.3$. For the smallest sample ($P_c = 0.5$) at 140 °C, the initial loss after 1 second is estimated to be 8% and the total loss after 30 years will increase to 26%. These losses are far too high to be accepted in applications. To find a more suitable operating temperature, we repeated the test for the magnets with $P_c = 0.5$ at temperatures of 130 °C, 120 °C, 110 °C and 100 °C.

The detected flux losses are presented in Fig. 4 as a function of time. Trend curves are extended to reach 30 years time. The curves clearly show that below 110 °C the magnet is stable and that above 110 °C losses start to occur. So the maximum working temperature for this kind of magnet could be taken as 110 °C.

At 130 °C (also at 140 °C to some extent) the loss behaviour seems to be step-like rather than a continuous line. This is probably due to some instabilities of temperature. After the first loss measurement, the samples were exposed to a temperature a few degrees higher than the 130 °C that was set. This caused a substantial flux loss,
which gave rise to a stabilizing effect. Thus, further losses follow a more or less horizontal line until demagnetization starts again with a sudden drop in magnetization. In the long run, the effect of this event is of no significance, but it does affect the accuracy of the estimated losses after 30 years. In this case, measurement points up to 10 000 h would be preferred to achieve more accurate estimates.

Flux losses can also be presented as a function of temperature for different exposure times, as shown in Fig. 5. This figure indicates that after a very short period of time, such as 1 second, no losses are expected even at 130 °C, but time-dependent losses will be almost 20 % in 30 years. Rapid BH curve measurement cannot detect this time-dependent demagnetization. Again, the calculated losses after 1 second at 120 °C and 130 °C, are unrealistically slightly positive.

4. Conclusions

Long-term irreversible flux losses in sintered NdFeB magnets were the focus of study here. No simple connection between the measured BH curves and the detected open circuit flux losses were found. Time dependent demagnetization starts at a lower temperature and a higher Pc than the BH curves would indicate.

Based on long-term flux loss measurements, the maximum working temperature for a magnet with a certain Pc can be determined. The maximum working temperature determined by this method will assure that no demagnetization will occur even after many years, as long as the temperature is kept below the maximum and the opposite magnetic field is kept below the self-field of the tested magnet. Losses due to oxidation are not taken into consideration and sufficient corrosion protection is needed to avoid permanent losses.

The maximum working temperature for the NdFeB material of 38SH grade with Pc = 0.5 studied here was determined to be 110 °C.

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References