ELSYS Note

Hot Steel: Influence on Core Losses

This note illustrates the influence of temperatures up to 250 °C on core losses and the magnetization demand of electrical steel sheets. Measurements are conducted using an adapted high-temperature Epstein frame and a stator core as a ring probe, both made of M330-50A electrical steel.

Introduction

For efficient operation, electrical steel sheets are crucial due to their unique magnetic properties, which enable low core losses and high magnetic permeability. In industrial environments or stressed integrated drive systems, elevated ambient temperatures can lead to significant temperature increases within electrical machines. Specifically, it addresses the research question: **“How do temperatures up to 250 °C influence core losses and magnetization demand of electrical steel sheets in practical applications?”**

Test setup

For this study, electrical steel sheets made of M330-50A (P1) are used, which is a classical-used grade for electrical machines driven by grid or inverter in industrial application, e.g. pumps or fans. The stator core P4 comes from a pump application and is also made of M330-50A. For determining the magnetic properties, a test coil designed as an Epstein frame [1] in Fig. 1 is used. To realize the target temperature range of 25 °C to 250 °C, the complete measurement setup was installed in a controllable furnace. All materials can withstand temperatures up to 250 °C. Type K temperature elements are installed for temperature monitoring.

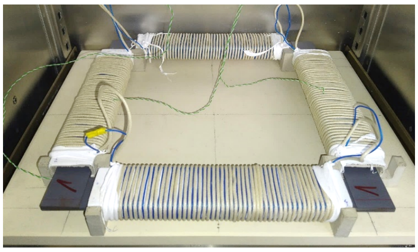

Fig. 1: High-temperature Epstein frame P1

The measurement of the stator core P4 in Fig. 2 is performed according to [2] and is placed again in the furnace.

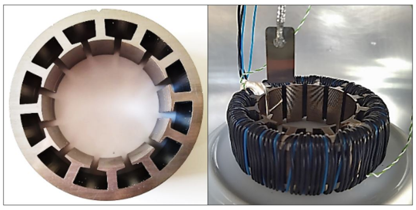

Fig. 2: Stator P4 temperature test setup

Magnetization demand

Fig. 3 shows the commutation curves for P1 and P4 in comparison to room temperature of 25 °C and the maximum measured temperature of 250 °C. In the range of increasing saturation of the materials, there is no temperature influence recognizable. For low magnetic polarizations in the range up to 0.4 T (P1) there is a slight improvement in the magnetization demand. Between this range and the beginning of saturation, the magnetization demand for a given magnetic polarization increases. This can be seen more clearly in Fig. 4,

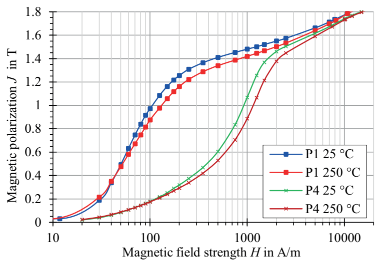

Fig. 3: Magnetization curve P1 and P4 at 25 °C and 250 °C

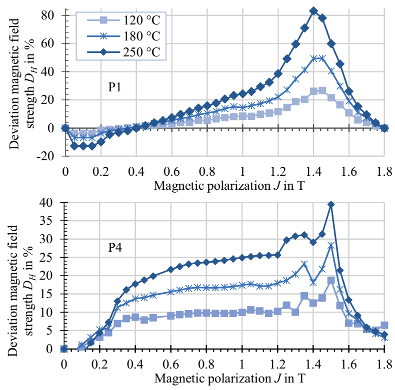

Fig. 4: Deviation of H related to 25 °C, P1 and P4

where the deviation of the magnetic field strength over the polarization range is shown for all investigated temperatures with respect to the 25 °C measurement. The highest deviation is reached at about 1.3 T to 1.5 T through 250 °C with 82 % for P1. The magnetization curve of the examined stator core P4 is highly affected by the manufacturing process. Thereby, the initial magnetization curve P4 at 25 °C in Fig. 3 shows a big shift to higher magnetic field strengths, compared to an unaffected electrical steel such as P1. Nevertheless, a temperature-dependent shift of the magnetization curve at 250 °C can also be observed for P4, which reaches in a maximum deviation of the magnetic field strength of about 40 % at 1.5 T and 250 °C in Fig. 4. Thus, the temperature influence on an electrical steel probe, which has already experienced manufacturing-related influences, is significantly lower, but not negligible. In addition, even at low magnetic polarizations from about 0.2 T, P4 shows an additional demand for magnetic field strength of the order of 25 % over the entire average flux density range.

Specific core losses

Fig. 5 compares a selection of the specific core losses determined with the high-temperature Epstein-frame for P1. The frequency bands from 50 Hz to 1200 Hz at 25 °C, 120 °C, 180 °C, and 250 °C are considered as a function of polarization. A uniform decrease of the specific core losses can be observed with increasing temperature.

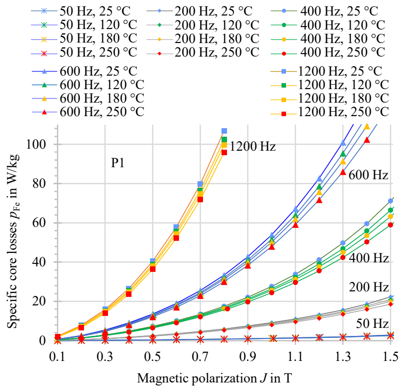

Fig. 5: Specific core losses at different frequencies and temperatures, P1

Fig. 6 shows the percentage decrease in specific core losses from 25 °C to 120 °C, 180 °C and 250 °C for f = 50 Hz, 200 Hz and 400 Hz over the magnetic polarization from 0.1 T to 1.6 T of the investigated electrical steel sheets P1 and P4 for a selection of the investigated operating points.

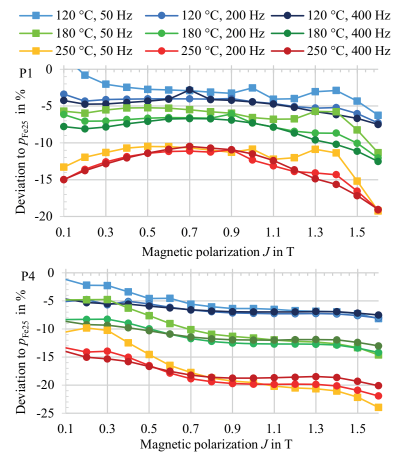

Fig. 6: Deviation of core losses at 50 Hz, 200 Hz and 400 Hz, P1 and P4 in relation to 25 °C

For each investigated temperature, a loss band can be formed within which the core losses lie at the three different frequencies. This band is almost constant over the entire polarization range and tends to decrease with increasing temperature. Within the individual temperature bands, a slightly stronger loss reduction can be seen with increasing frequency. P1 shows a loss band of about −5 % at 120 °C and −15 °C at 250 °C. The manufacturing affected sample P4 also shows uniform specific core losses reduction for the same temperature bands at different frequencies. Furthermore, it is clear that for the processed electrical steel sheet with increasing magnetic polarization, the specific core loss decrease is much more pronounced with increasing temperature as the magnetic polarization increases. For example, P1 reaches a loss decrease of −14.9 % at 50 Hz, 1.5 T and 250 °C, while P4 reaches −22.1 % at the same operating point.

Conclusion

The magnetization demand across all test probes increases with magnetic field strength in the medium and high polarization ranges below saturation. At low magnetic polarizations, a slight improvement is observed in P1 due to temperature, though this is unlikely to have practical significance. Specific core losses consistently decrease with rising temperature across the measured polarization range, with minimal variation due to excitation frequency.

References

[1] DIN e. V. *Magnetic materials - Part 2: Methods of measurement of the magnetic properties of electrical steel strip and sheet by means of an Epstein frame; EN 60404-2:1998 + A1:2008*. Berlin, 1.2009.

[2] DIN e. V. *Magnetic materials - Part 6: Methods of measurement of the magnetic properties of magnetically soft metallic and powder materials at frequencies in the range 20 Hz to 100 kHz by the use of ring specimens; EN IEC 60404-6:2018 + AC:2018 + A1:2021*. Berlin, 1.05.2022.