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Evaluation of Barkhausen Noise Signal for Different Grain Sizes of Non-Oriented Iron-Silicon Material

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The magnetization of soft magnetic materials is characterized by numerous irreversible steps from the Barkhausen jumps, which are inherent to the material. With adequate measurement apparatus and signal processing, the global occurrence of these jumps can be observed as the Barkhausen noise, that can be in theory related with microstructural properties and the magnetization process. The relationship between Barkhausen noise and material properties can and has been used to investigate the material state in-situ and in a non-invasive manner. This work investigates the relationship between the material's grain size and the Barkhausen activity near saturation. A calculated indicator relating magnetization state and Barkhausen activity is presented, and its relationship with the grain size is shown.

Index Terms—**Barkhausen noise, grain size, non-oriented electrical steel.**

I. Introduction

Electrical machines are widely used in all kinds of applications, and its use is only increasing further and further, together with the demand for more performant and efficient machines. With the central role in the magnetic core of such machines, the understanding of non-oriented electrical steel is essential to design and improve electrical machines to a high standard. The magnetization process and hysteretic characteristic according to domain theory is due to reversible and irreversible domain wall movement and domain rotation processes. One of the main mechanisms involved in the magnetization of these materials is characterized by the domain wall movement, which can be hindered by pinning-points on the material microstructure which obstruct its movement, producing what is called Barkhausen jumps, where the domain walls suddenly jump from one pinning-point to the next, which, in the scale of standard magnetic measurements, can be measured during magnetization as Barkhausen noise [1] [2].

Barkhausen noise has been used as a non-invasive technique for analyzing the condition of steels [3], as it relates with the microstructure parameters from the material [4] [5] [6]. In this work, the Barkhausen signal of a non-oriented electrical steel is analyzed and an indicator for when Barkhausen jumps a saturation state is obtained. This indicator is then compared with the grain size of the measured samples.

II. Methodology

Measurements are conducted on samples of non-oriented FeSi material annealed at $970\,^{\circ}\mathrm{C}$ with different grain sizes, with its average values ranging from $35\,\mu\mathrm{m}$ to $88\,\mu\mathrm{m}$. The magnetization current is controlled in order to achieve a sinusoidal polarization. The measurement equipment is composed by magnetization and measurement coils similar to a standard Single Sheet Tester (SST) with the addition of a Barkhausen sensor. The Barkhausen sensor is a wounded ferrite core positioned at the center of the sample perpendicular to magnetization direction on the sample, similar to the equipment shown in [7].

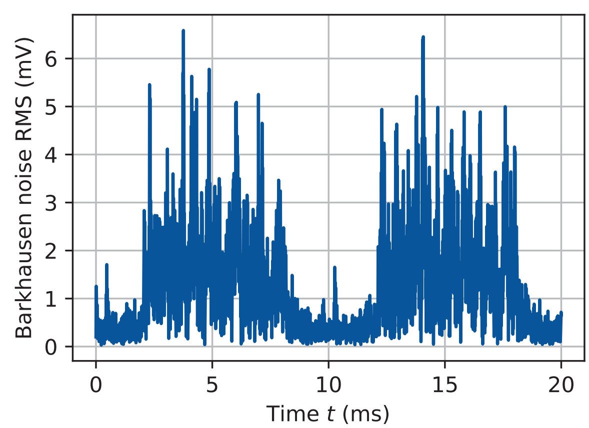

Fig. 1: RMS of the Barkhausen noise at $1.8\,\mathrm{T}$.

The Barkhausen noise signal is obtained by filtering the acquired signal with a band-pass filter with cutting frequencies of $10\,\mathrm{kHz}$ and $100\,\mathrm{kHz}$. The signal is then processed with a moving RMS window, which represents the related energy of the Barkhausen activity over time. Figure 1 presents the processed Barkhausen noise for one sample with maximum polarization of $J_{\mathrm{m}} = 1.8\,\mathrm{T}$.

Figure 2 shows the calculated energy over time for one sample, similar as defined by [4] [3], the units are normalized by dividing each value by the total energy calculated this way, thus representing the proportion of Barkhausen activity over time (1), where $v(t)$ is the measured voltage in the Barkhausen sensor after filtering. The measured polarization is also shown in order to compare with the overall magnetization state of the material.

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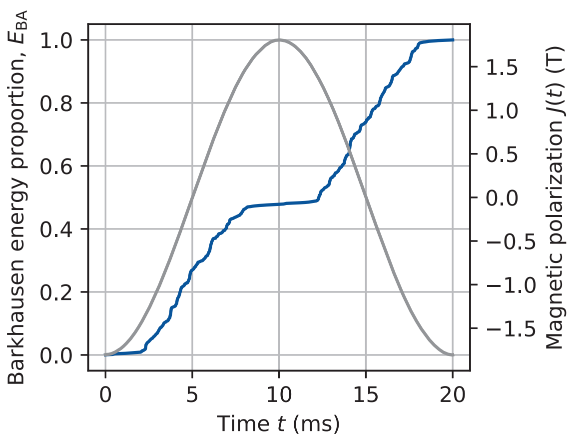

Fig. 2: Proportion of Barkhausen activity over time for $J_{\mathrm{m}} = 1.8\,\mathrm{T}$ (blue) and Acquired polarization $P(t)$ over time (gray). Notice that the maximum $J_{\mathrm{m}} = 1.8\,\mathrm{T}$ occurs at $10\,\mathrm{ms}$.

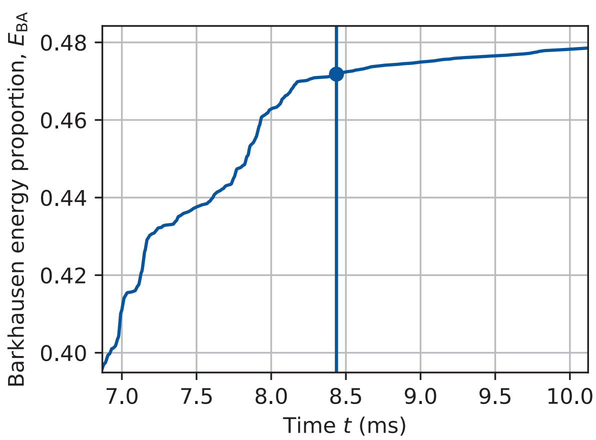

Fig. 3: Proportion of Barkhausen activity overtime for $J_{\mathrm{m}} = 1.8\,\mathrm{T}$, with detail on the calculated interval of inactivity.

$$E_{\mathrm{BA}}(t) = \frac{1}{E_{\mathrm{total}}} \int_0^t v^2(t)dt \quad (1)$$

An "inactivity interval" can then be calculated by finding the point where the amount of Barkhausen activity which occurred is smaller than a threshold E_{inac}. Figure 3 shows the calculated inactivity interval, where the last significant increase in the Barkhausen energy proportion obtained is around $8.5\,\mathrm{ms}$, and therefore there is around $1.5\,\mathrm{ms}$ of inactivity before the signal reaches its peak at the $10\,\mathrm{ms}$ mark.

III. Results

The samples with varying grain sizes were measured in the aforementioned conditions, and then processed accordingly. Figure 4 shows the calculated inactivity interval over the average grain size of the samples. A linear tendency can be observed, where bigger grain sizes have a lower inactivity interval, meaning that for the smaller grain sizes, magnetization discontinuities (i.e., hindering of domain wall movement and sudden domain rotation) stop at lower polarization values, resulting in a higher inactivity interval.

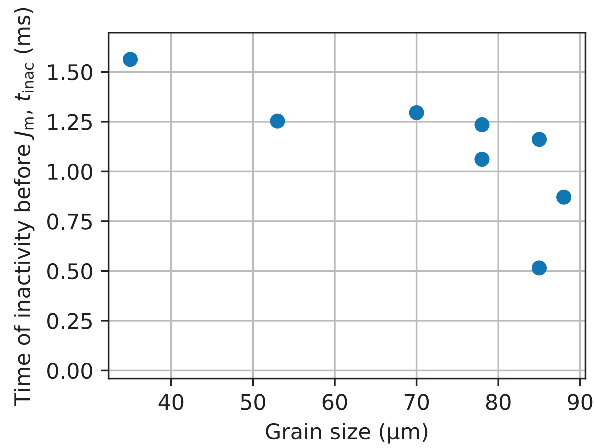

Fig. 4: Evaluated time of Barkhausen inactivity before maximum polarization is achieved at $1.8\,\mathrm{T}$.

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