Multiple magnetization paths in Barkhausen noise

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Barkhausen noise from small samples of an Fe-based Metglas showed partial reproducibility. Small changes in the swept field completely scrambled the pattern of Barkhausen jumps. For some sweep parameters, the Barkhausen pulses switched randomly between two patterns on successive sweeps. These results require that the largest of the Barkhausen peaks come from a many-degree-of-freedom model not simple domain-wall motion in a random field. [S1063-651X(96)51508-4]

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Although the irregularity of the rate of magnetization of ferromagnets, known as Barkhausen noise, has been known for many decades, the factors determining its statistics remain poorly understood [1–3]. One type of simple picture invokes single domain-wall motion over a quenched random coercive field, so that the temporal noise statistics are determined by the spatial statistics of the coercive field [2,4]. Another widely invoked type of simple picture, the Preisach model [5], invokes many independent few-state degrees of freedom. There have been recent claims that the noise spectra suggest ''self-organized criticality,'' a picture invoking many *coupled* degrees of freedom [6]. More generally, studies of the dependences of the onset of magnetic hysteresis and of reproducible Barkhausen events on field history [7] indicate that a complicated multidimensional free-energy landscape might be required. In this paper we examine detailed behavior of partially reproducible Barkhausen pulses [1], finding results clearly inconsistent with the any single-degree-of-freedom model.

For some metals, the simple single-degree-of-freedom domain-wall motion model of Allesandro *et al.* (ABBM) [4] does a remarkably good job of reproducing the distribution of Barkhausen voltages, the pulse duration statistics, the pulse intermittency, and other parameters as a function of field sweep rate [2,8]. However, the essential input to this model is the assumption that the coercive field $H_c(x)$ makes a random walk as a function of spatial position over a range covering the range of most of the Barkhausen domain-wall motions. Since, from the absolute magnitude of the Barkhausen pulses in a typical material, it is easy to find that the typical pulses involve motions of over 1 μm, it is hard to see how $H_c(x)$ could make a random walk over such large distances. For locally random pinning, in fact, $H_c(x)$ should itself be random over distances in excess of a domain-wall thickness, i.e., 10^{-2} μm, while a random walk implies that the *derivative* is random. Thus there is strong *a priori* reason to suspect that the ABBM statistics describe the collective pinning of an extended, flexible domain wall, involving many degrees of freedom and some kind of self-organization.

In this paper we describe some very simple, qualitative features of the behavior of the largest Barkhausen jumps in small samples of a ferromagnetic Metglas. The central idea is to see whether the magnetic field $H(t)$ uniquely determines the main structure in $V(t)$, the Barkhausen voltage. For a single-degree-of-freedom model, a domain wall dragged over a high point in $H_c(x)$ will always produce a spike in $V(t)$, as the subsequent domain growth is rapid. If $H_c(x)$ is the same on each sweep, $V(H)$ will be reproducible regardless of the detailed previous history of $H(t)$. Likewise, for Preisach models [5] each individual site has well-defined fields for flipping, regardless of history. If, on the other hand, the domain-wall motions consist of collective rearrangements, the effective pinning field depends on the previous domain-wall motions, allowing for instabilities between different collective pathways of magnetic rearrangement and for sensitive dependence of the Barkhausen pattern on field history.

The experiments were run on strips of the amorphous iron-based metallic alloy Metglas 2605TCA. The hysteresis loop was measured using a superconducting quantum interference device (SQUID) magnetometer (see Fig. 1). The width of the hysteresis loop is approximately 0.3 Oe. Saturation occurs at a field around 100 Oe, with a saturation magnetization of about 1000 emu/cm^3.

The Barkhausen noise was detected using both a closed-loop and open magnetic strip samples. Most of the data was collected using the open magnetic sample, 0.5 cm×3.9

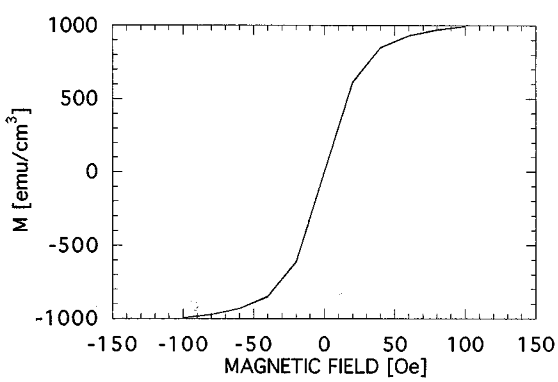

FIG. 1. The entire hysteresis loop, measured using a SQUID magnetometer. The loop width is approximately 0.3 Oe.

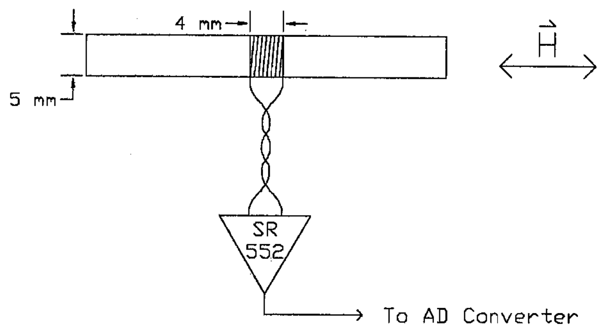

FIG. 2. The experimental setup for the open magnetic sample.

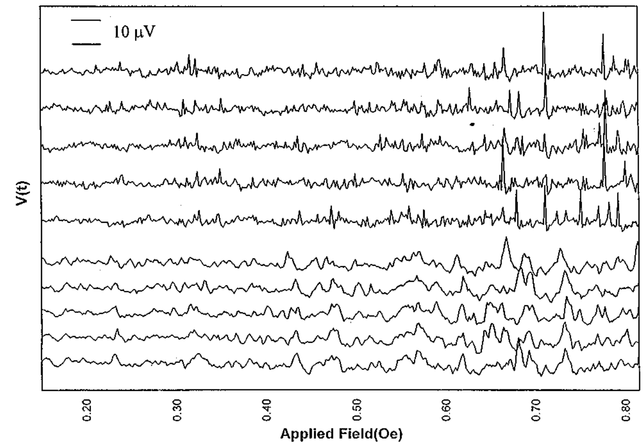

FIG. 3. A comparison of Barkhausen repeatability at driving frequencies of 10 Hz (five upper sweeps) and 100 Hz (five lower sweeps). The data are from the open strip sample, driven with a fixed-amplitude triangle wave.

cm×30 μm (see Fig. 2), but the particular results which form the topic of this paper were similar in both samples. To detect the noise 200 turns of 40 gauge enameled Cu wire was wrapped around the sample, over a width of 4 mm. The sample and the pickup coil were placed inside a solenoid which supplied the external field (triangle-wave sweeps of about 0.8 Oe were used). To reduce external noise the entire setup was placed in a double Mumetal container. The background dc magnetic field was under 0.1 Oe.

The noise from the pickup coil was amplified using standard low noise preamplifiers. The signal was anti-alias filtered and read into a computer using a 12 bit analog-to-digital converter. All data will be presented here simply in the form of time series.

Our data (see Fig. 3 presenting time series for driving frequencies of 10 and 100 Hz) showed high sweep-to-sweep reproducibility for some events, as has been previously reported [1]. The largest events are most clearly reproducible. As evident in the figure, the faster sweeps appear to give more reproducible spikes, but that effect will not be further discussed here.

The key observation is that for the large spikes, gross instability of the pattern can be found. Figure 4 shows consecutive sweeps at a driving frequency of 100 Hz with a peak field of 0.8 Oe using the open magnetic sample. There is perfect anticorrelation between the spike circled on the left and the spikes at 0.5 Oe and 0.68 Oe. The system appears to alternate randomly between the two magnetization paths for the same swept field. Similar behavior was found in the closed magnetic sample, as shown in Fig. 5. Several such switching patterns were found in each sample.

The alternation between the two magnetization paths occurred for varying amounts of time. The behavior shown in Fig. 4 lasted for nearly an hour. That shown in Fig. 5 lasted for only 10 min. Other observed switching patterns persisted

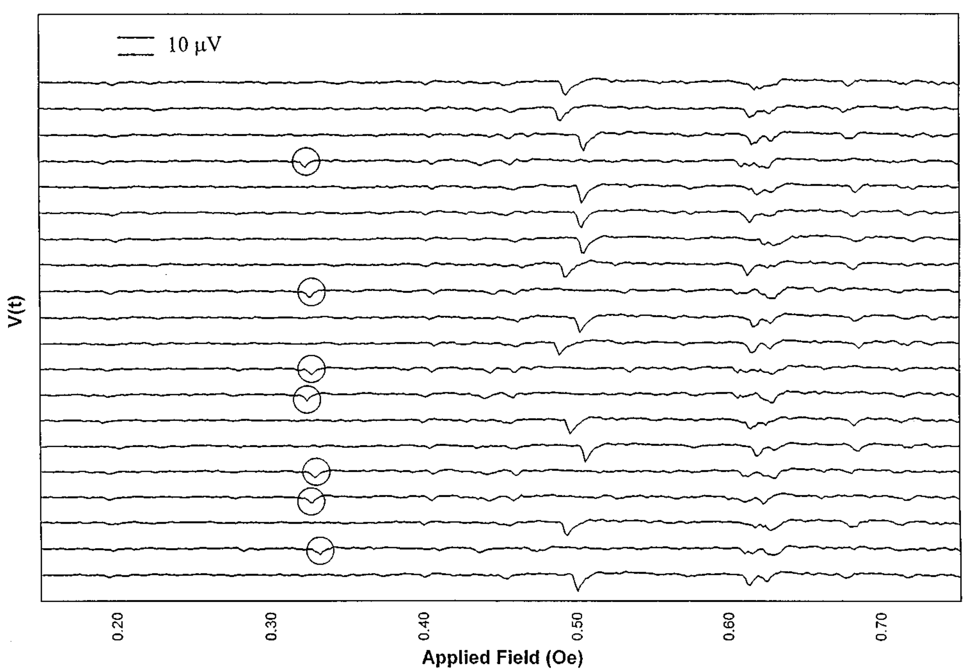

FIG. 4. An example of multiple magnetization paths. The sweeps were taken consecutively fixed sweep parameters. The ~4 μV event circled on the left is directly related to the occurrence of the event, roughly 8 μVin magnitude, that occurs at 0.5 Oe. Also note the relation between the circled even and the event that occurs at around 0.68 Oe.

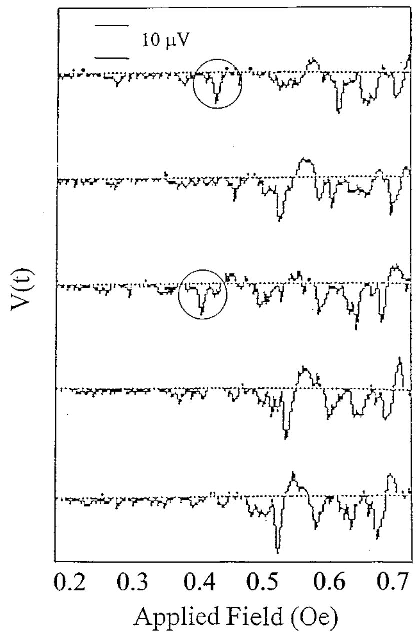

FIG. 5. Another example of two magnetizations paths, from the closed-loop sample. The event circled on the left determines the magnetization path at higher fields.

for up to 14 h.

The randomly switching pulse patterns were always found over only a narrow range of sweep amplitudes. For the open-sample a decrease in applied field sweep range of approximately 1% caused the system to reproducibly follow the pattern including the circled event of Fig. 4, whereas an increase of 1% caused the system to follow the pattern of the uncircled sweeps. Regardless of whether the initial pattern showed switching, changing the sweep amplitude by about 5% was usually adequate to completely change the detailed pulse pattern.

In principle, it would be possible for a local defect to fluctuate between two configurations, giving rise to fluctuations in the Barkhausen pattern. However, it would not be remotely feasible for such a defect to affect the coercive field at two widely separated spots, as would be required to give the correlated pattern fluctuations shown. The effective local field seen obviously depends strongly on the history of the previous jumps. We conclude that the switching among very different pulse patterns, on time scales very short compared to any permanent change in the sample structure, can only be due to large-scale organization of domain walls. Single-degree-of-freedom models as well as Preisach models cannot account for such results. Which version of models (e.g., [9]) which incorporate both randomness and interactions suffice remains to be tested.

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