SPECIFIC COIL NOISE INDUCED BY MAGNETIC MATTER AT PHASE TRANSITION TEMPERATURE

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It was found that a polycrystalline gadolinium sample forming part of a closed magnetic loop threading a coil induced substantial coil noise when its temperature corresponded to the transition temperature of gadolinium.

The following observations were made in the course of an experiment on thermo-magnetic energy conversion [1,2].

Our set-up is shown in fig. 1: an arrangement of permanent magnets (in some runs the magnets were replaced by iron bars exhibiting remanence) and iron slabs served as magnetic yoke and the test sample (Gd) was placed between the poles of this yoke. In such an arrangement flux changes within sample 1

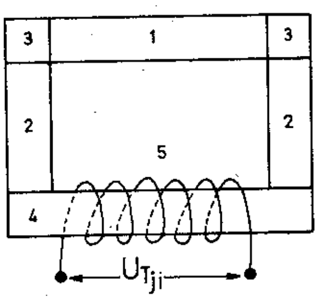

Fig. 1. Sketch of experimental set-up. 1: sample (Gd, 99.9% pure), 5.0 × 1.6 × 1.0 cm^3; 2: permanent magnets, or iron bars, 3.0 × 1.6 × 1.0 cm^3 each; 3: soft iron slabs, 1.0 × 1.6 × 1.0 cm^3 each; 4: soft iron slab, 7.0 × 1.6 × 1.0 cm^3; 5: coil (8000 turns, R = 466 Ω).

give rise to flux changes within iron slab 4 and thus are detectable by means of coil 5. Save its front and end faces and a small area bearing a temperature detector the sample was in thermal contact with the plane walls of a heat exchanger (not shown in fig. 1). Water of constant temperature circulated through the heat exchanger at a high rate in order to ensure uniform temperature across the contacting surfaces. All measurements were performed under thermal steady state conditions, i.e. at constant and practically equal values of sample and water temperatures ‡1.

For different sample temperatures we registered different noise levels across the open terminals of the coil. As a measure for the coil noise we took the average absolute deviation ‡2

$$\bar{U}_{Tj} = \frac{1}{N}\sum_{i=1}^{N} |U_{Tji} - U_{Tj}| \ .$$

of N individual signals U_{Tji} from their mean

‡1 We do not exclude a slight, though constant, temperature gradient within the sample in the vicinity of the faces in contact with the iron slabs.

‡2 As in these measurements the noise represents the "signal" this quantity is taken instead of the usual noise power.

$$U_{Tj} = \frac{1}{N}\sum_{i=1}^{N} U_{Tji} \approx 0.$$

$N = 100$ values of U_{Tji} were measured at a rate of 24 signals per second for the determination of U_{Tj} and $\bar{U}_{Tj}$. In figs. 2 and 3 the average

$$\bar{U}_{Tn} = \frac{1}{n}\sum_{j=1}^{n} \bar{U}_{Tj} ,$$

of $n = 10$ individual values of $\bar{U}_{Tj}$ is plotted against sample temperature. The vertical lines in the figures indicate the standard deviation for $\bar{U}_{Tn}$ out of the 10 individual values of $\bar{U}_{Tj}$.

In fig. 2 representative data are plotted which were obtained when the sample temperature was increased step by step. Fig. 3 shows the data for a step by step decrease of sample temperature. Thermal steady state conditions were resumed approximately three minutes after having changed the water temperature ‡3 as indicated. The data were taken after an additional elapsed time of approximately four minutes. The determination of $n = 10$ values of $\bar{U}_{Tj}$ took 46 s. The

‡3 Our set-up incorporated three temperature detectors; one was in thermal contact with the sample, two measured the water temperature at the inlet and the outlet of the heat exchanger, respectively.

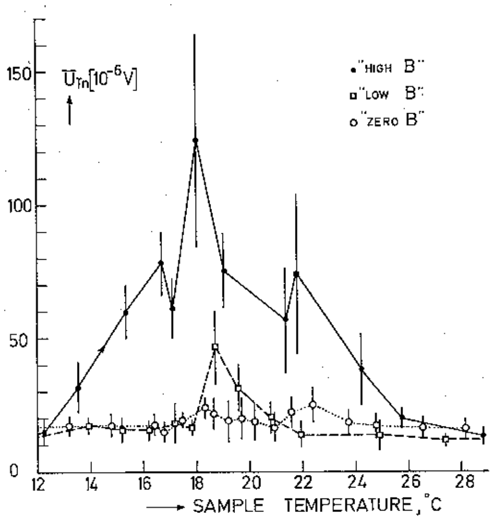

Fig. 2. Coil noise versus temperature of Gd sample as obtained in a step by step increase of sample temperature. (Initial temperature: 8°C.)

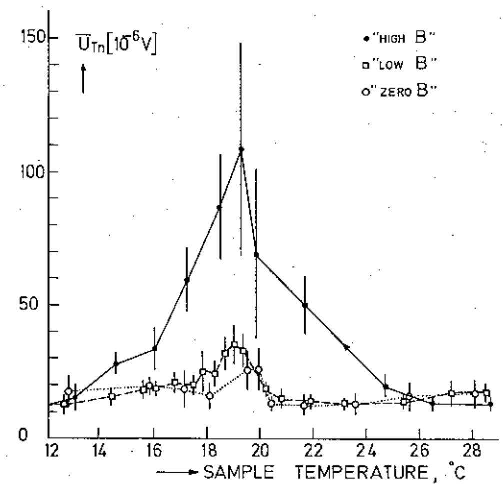

Fig. 3. Coil noise versus temperature of Gd sample as obtained in a step by step decrease of sample temperature. (Initial temperature: 48°C.)

noise, as expressed by $\bar{U}_{Tj}$, appeared to be randomly distributed rather than a monotonous function of time.

The "high B" results were obtained with the permanent magnets within the magnetic loop, as shown in fig. 1. The magnets had a rated remanent induction of 0.95 T. With a 1.2 mm thick Hall detector inserted between sample 1 and iron slab 3 we measured the following inductions: 0.37 T for 8°C, 0.25 T for 18°C and 0.12 T for 48°C sample temperature, respectively. The plotted data were obtained with no air gap between sample 1 and slab 3; however, insertion of the Hall detector hardly affected the noise data obtained, as comparative measurements showed.

For the "low B" measurements the permanent magnets were replaced by soft iron bars. The iron parts of our set-up exhibited some remanence, as was noticed with a Hall detector placed between sample 1 and slab 3, as before. In this arrangement we measured the following inductions: 8.3×10^{-3} T for 8°C, 3.2×10^{-3} T for 18°C and 2.1×10^{-3} T for 48°C sample temperature, respectively. Again the plotted noise data were determined with no air gap in the magnetic loop. Comparative measurements suggested that the 1.2 mm wide air gap weakened the noise signals slightly. However, the changes fell within the range of the indicated standard deviation.

Finally, for the "zero B" measurements all iron parts of our set-up had been thermally demagnetized [‡4]. We hesitate to interpret these results as anything else than inconclusive scatter.

From a comparison of figs. 2 and 3 it may be concluded that the overall noise level is somewhat higher in the case of a ferromagnetic to paramagnetic phase transition of the sample than vice versa. This difference is possibly meaningful; the preliminary character of our results does not allow a definite judgement, though.

Summary. Our results allow the following principal explanations for the physical origin of the measured specific coil noise:

(a) The ferromagnetic/paramagnetic sample (Gd) exhibits fluctuations of permeability μ when it is at phase transition temperature. These fluctuations could be caused by coupling and decoupling of spins in rapid succession at constant temperature, or by minute – and practically undetectable – fluctuations of sample temperature in a high $d\mu/dT$ gradient. In the presence of a magnetic field these permeability fluctuations would give rise to fluctuations of magnetic flux, which can be made visible as specific coil noise. Small fields would suffice to produce this effect.

‡4 The set-up was not shielded magnetically, though.

(b) Also, this noise could be interpreted as some kind of "Barkhausen noise" caused by temperature-dependent Barkhausen-type jumps of non-aligned domains (after nucleation or before destruction).

(c) It cannot be excluded that the measured noise has to be attributed to a combination of the suggested phenomena.

In any case, coil-noise measurements of this kind could provide an additional simple and viable method for the determination of phase transition temperatures [3], in particular under the influence of only small external fields.

Our results were obtained under non-optimum conditions. Further experiments expressly designed for coil-noise measurements with ferromagnetic and other type magnetic materials are suggested.

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References

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