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Hall e.m.f. and Intensity of Magnetization

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Previous experiments have indicated that the Hall e.m.f. depends on intensity of magnetization rather than upon applied field or magnetic induction. Additional evidence is offered, the most important being that provided by a material in which H and B-H are of the same order of magnitude.

IT HAS been shown by one of us[1] that in certain ferromagnetic materials the Hall e.m.f. E is a linear single-valued function of the intensity of magnetization B-H, but is neither a linear nor single-valued function of either the induction B or the applied field H.

The nature of the apparatus used at that time was such that it was possible to obtain accurate results on only two substances, namely, K.S. magnet steel and high carbon steel, and only after they had been hardened by proper heat treatment.

Whether the above rule is general or is merely characteristic of the two materials tested, should be thoroughly investigated on account of its theoretical importance. This is especially true since these two substances had somewhat similar magnetic properties. It was therefore decided so to modify and improve the apparatus that accurate measurements of E, B and H could be made on a great variety of materials.

Apparatus

In the old apparatus[1] the method of measuring the Hall e.m.f. with a Kohlrausch slide wire made the sensitivity proportional to the resistance of the test bar, forstalling the testing of low resistance bars. The Kohlrausch slide wire was replaced with a Wolff potentiometer which, together with decided improvements in the storage battery current supply, reduced the uncertainty in the e.m.f. measurements on all materials to $\pm 10^{-8}$ volts—less than half the uncertainty previously obtained in high-resistance materials.

The magnetic measurements were also considerably improved by the use of a high-sensitivity galvanometer shunted with a very low resistance which gave it excellent fluxmeter characteristics. Such a well-damped fluxmeter is essential for the accurate measurements of the slow magnetic changes occurring in the bars.

Procedure

The bar under test was first heat treated in an atmosphere of hydrogen, and then placed in the apparatus where it was measured by the step-by-step method described in the former paper.[1] The quantities E, B, and H were ob-

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[1] E. M. Pugh, Phys. Rev. **36**, 1503 (1930).

tained over the virgin curve and over several succeeding hysteresis loops. These same quantities were then measured over the normal magnetization curve by the method of reversals.

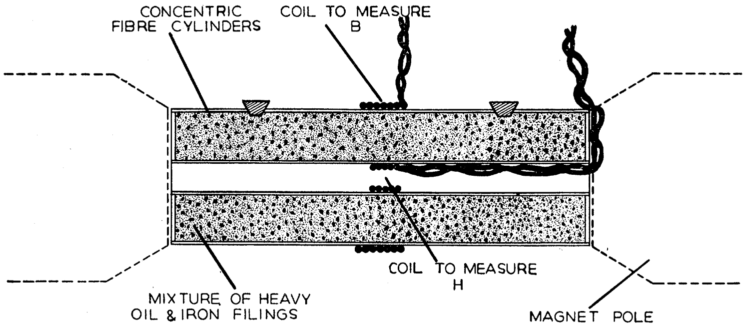

Fig. 1. Variable permeability cylinder to find value of H for samples of low permeability.

The following materials were tested after they had been carefully annealed and also after they had been quenched from a suitably high temperature,—electrolytic iron, high carbon steel, K.S. magnet steel, an iron-cobalt alloy (Fe 50 percent, Co 50 percent), and an iron-nickel alloy (Fe 70 percent, Ni 30 percent). The iron-nickel alloy is only slightly magnetic at room temperature, having a maximum permeability between 3 and 4. It loses its ferromagnetic properties at about 140°C.

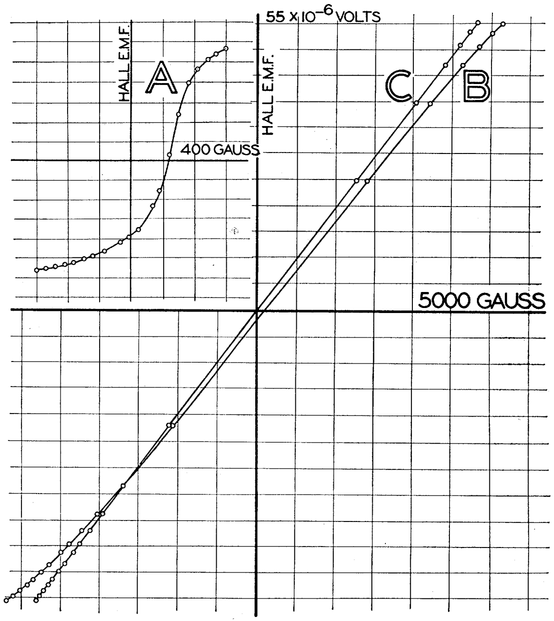

Fig. 2. Hall e.m.f. E in annealed K.S. magnet steel taken along the ascending branch of the first hysteresis loop. Plotted (A) against H, (B) against B, (C) against B-H. Current density 40 amperes per cm^2.

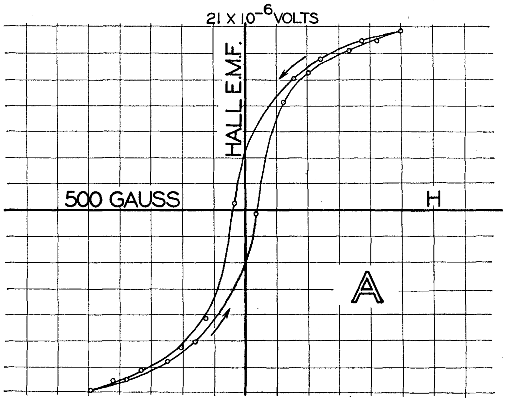

Fig. 3A.

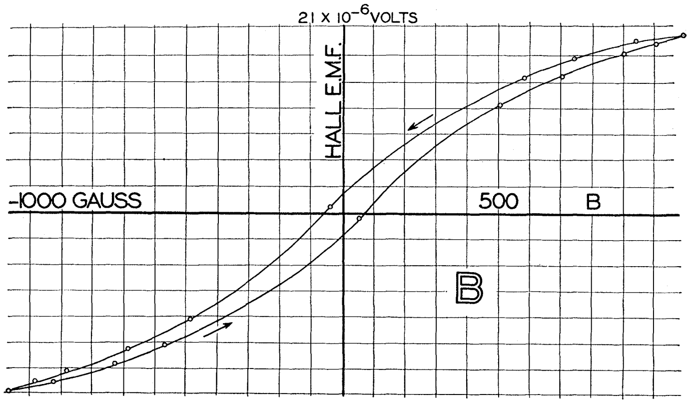

Fig. 3B.

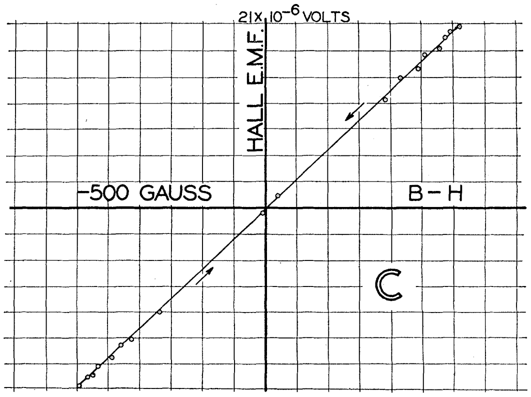

Fig. 3C.

Fig. 3. Hall e.m.f. in quenched iron-nickel alloy (Fe 70 percent, Ni 30 percent). (*A*) and (*B*) show the multiple-valued character of the curves with *H* or *B* as abcissae; (*C*) shows the single-valued character of *E* with *B*-*H* as abcissae. Current density 40 amp. per cm^2.

The tests on this slightly magnetic bar were far more conclusive than on any other specimen because in it the quantities *H* and *B-H* were of the same order of magnitude whereas in the other bars *H* was never more than 5 percent of *B-H*.

The saddle coil method[1] of measuring *H* was inapplicable to this slightly magnetic alloy and was discarded. Instead *H* was measured by substituting in place of the bar two concentric cylinders (Fig. 1) between the pole pieces of the electromagnet. The space between the cylinders was filled with a mixture of heavy oil and iron filings in such a proportion that the additional flux due to the iron filings was the same as the additional flux previously due to the test bar. Under these conditions the search coil around the inner cylinder enclosing air only measured the desired value of *H*.

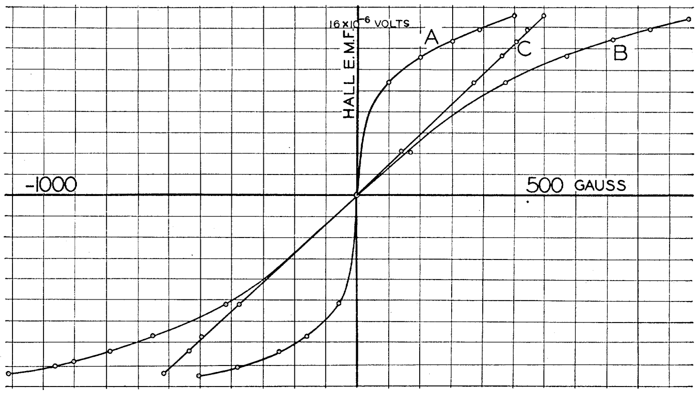

Fig. 4. Hall e.m.f. in baked iron-nickel alloy taken along the normal magnetization curve, where greatest accuracy is obtainable. Current density 40 amp. per cm^2. (*A*) and (*B*) show definite curvature of *E* with *H* or *B* as abcissae; (*C*) shows the linear character of *E* with *B-H* as abcissae.

RESULTS

Figs. 2, 3 and 4 are good examples of the results obtained. Fig. 2 shows the results obtained on the ascending branch of the first hysteresis loop following the annealing of K.S. magnet steel. While the intensity of magnetization was different on the different successive hysteresis loops, no change was found in the ratio of *E* to *B-H*. *In each material tested the ratio E/(B-H) remained constant, dependent on temperature and previous heat treatment only, for all of the magnetic changes to which it was subjected.*

The best results were obtained with the iron-nickel alloy (Figs. 3 and 4) which, because of its low permeability, furnished a very exacting test of this relationship. It is here obvious that the graph of *E* is curved and multiple valued (Figs. 3A and 3B) when plotted against either *H* or *B* but is straight and single valued against *B-H*, Fig. 3C. The greatest accuracy is attained in taking a normal magnetization curve because the method of reversals eliminates the cumulative errors of the step-by-step method. Fig. 4 shows the Hall e.m.f. curve taken along the normal magnetization curve of the iron-nickel alloy.

It was not possible to make measurements over a large range of temperatures with the apparatus but the variation of the ratio $E/(B\text{-}H)$ in electrolytic iron and in the iron-nickel alloy was investigated over the range available (Fig. 5). In this region the ratio $E/(B\text{-}H)$ varies linearly with temperature whereas both E/B and E/H plotted against temperature give curves.

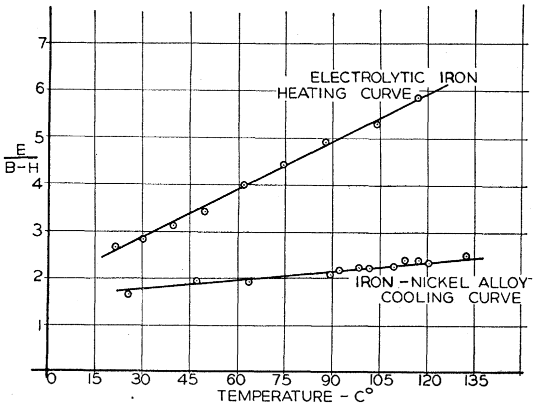

Fig. 5. Variation of ratio $E/(B\text{-}H)$ with temperature in electrolytic iron and in the iron-nickel alloy.

These and previous results furnish convincing evidence that the Hall e.m.f. should be considered as a function of the intensity of magnetization alone.

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