On the Use of Chilled Cast Iron for Permanent Magnets

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diminishes the critical value of the leakage coefficient (see § 9 and fig. 8).

(9) Eddy currents diminish the critical distance, increase the critical value of the retardation, and increase the leakage coefficients. (See § 12.)

(10) For the same frequency, initial flux-density, and material, increase of diameter of the specimen increases the critical distance, has little or no effect on the critical retardation (hence making $d\theta/dx$ near the origin less), and diminishes the leakage coefficients: in fact, we find that the critical distance is approximately proportional to the diameter, and the critical value of the leakage coefficient inversely proportional to the diameter. (See § 14 and Tables XXI., XXIII., XXIV.)

(11) For the same specimen and initial flux, increase of frequency increases the initial value of $d\theta/dx$, increases the critical values of the retardation and the leakage coefficient, and slightly diminishes the critical distance. (See figs. 1, 2, and the Tables.)

(12) For the same specimen and frequency, increase of initial flux increases the critical distance (see fig. 4), increases the critical value of the retardation (fig. 4), and reduces the critical value of the leakage coefficient (see fig. 5): also for low values of the initial flux F_0 , $d\theta/dx$ near the origin increases with F_1 , but seems to approach an upper limit for high values of F_0 (see fig. 4).

XXIV. *On the Use of Chilled Cast Iron for Permanent Magnets.* By ALBERT CAMPBELL, B.A. (From the National Physical Laboratory.)*

EARLY in the past year an interesting paper † was published by Mr. B. O. Peirce of Harvard University, drawing attention to the fact that chilled cast-iron is in many

* Read January 26, 1906.

† Amer. Acad. Proc. xl. 22. pp. 701-715, April 1905. Dr. Watson has kindly drawn my attention to Mr. J. R. Ashworth's experiments on chilled cast-iron rods (Proc. Roy. Soc. vol. lxii. p. 210, Dec. 9, 1897); he found that the magnetic quality of these was comparable with that of tungsten steel.

instances a suitable material for permanent magnets. As the subject is of interest to scientific experimenters and of considerable importance to instrument makers, I undertook some time ago a short research upon it, with a view, firstly of obtaining some measurements by standard methods, and secondly of finding, if possible, an easy method of chilling the material so as to give good results.

Form of Test Pieces.—The cast iron tested was of ordinary commercial quality and was obtained in the form of rods and rings. The rods, which were of rectangular section, were shaped to dimensions usual in such tests, viz., 10 cm. $\times$ 1 cm. $\times$ 1 cm.

By using rods of these dimensions it is easy to compare the results with those for various kinds of steel which we have already tested or with those published by Madame Curie * and other observers.

Two rings were tested; they were of rectangular section, their mean diameters being nearly equal (12.5 and 13.0 cm.). Their cross-sections, however, were very different, being 1.00 sq. cm. and 6.0 sq. cm. respectively. The object of testing a thick and a thin ring was to find if our method of chilling was effective for the hardening of thick castings.

Heat Treatment.—All the test pieces were heated to 1000° C. in a gas muffle furnace, the temperature being measured by a thermo-junction in the usual way. Each piece was removed from the furnace and quickly chilled in water at the temperature of the room. As Mr. Peirce has pointed out, great care is necessary in handling the cast iron at this high temperature (so near its melting-point) for it becomes very brittle. For this reason the thick ring was placed in the furnace on a U-shaped piece of wrought iron, it was lifted out by means of this support, and the two were plunged together into cold water. By this method the brittle material could be handled without risk of breakage.

Tests on Rods.—After the chilling, the rods were magnetized to saturation by means of a very strong magnetic field.

* *Bulletin de la Société d'Encouragement pour l'Industrie Nationale*, Jan. 1893.

This was produced by a solenoid consisting of 70 turns with a length of 16 cm. and having a resistance of about 0.1 ohm. A large current was sent through this coil by connecting it for a very brief interval to a 50-volt circuit (by the process commonly known as "flashing"). Each rod was then tested for

- (1) The maximum remanent flux density B (at the medial section of the bar).
- (2) The coercivity H_0 , *i.e.* the value of the demagnetizing magnetic force required to annul this remanent magnetism.

(1) In order to measure the medial B , a small square search-coil of 20 turns of very fine wire was used; it was just large enough to slip along the rod. The search-coil was connected to a calibrated ballistic galvanometer, and, when the coil was slipped off the rod, the resulting deflexion gave the required B in the usual manner.

(2) The coercivity was found by Madame Curie's method, as follows:—The magnetized bar was fixed at the centre of a long solenoid, a search-coil being so arranged that it could be slipped off the bar from the mid position and replaced without removing the bar from the solenoid. By sending a measured current through the solenoid the bar was subjected to a known demagnetizing field. This field was gradually increased until the search-coil when slipped off gave no throw on the galvanometer, thus showing that B had been reduced to zero. The value (H_0) of the magnetic force when this took place is a good indication of the permanence of the remanent magnetism.

If H_0 is large, we should expect the bar to hold its magnetism very obstinately. The following table gives the results for four of the rods (Nos. 1 to 4). For the sake of comparison the corresponding numbers are given for exactly similar rods (M and A) of hardened magnet steel of well known makers, M being supplied by Marchal of Paris, and A coming from the Alleward Forge.

Fig. 1.

Fig. 2.

TABLE I.

Marks.	Material.	Maximum Remanence.	Coërcivity.
No. 1	Chilled Cast Iron.	1775	52.8
No. 2	" "	1670	48.9
No. 3	" "	1690	50.4
No. 4	" "	1850	52.1
M	Magnet Steel.	2550	55.5
A	" "	2950	73.0

The above results show that the hardened cast iron rods are not very much inferior to the ordinary magnet steel (M) either in original strength or in power of resisting demagnetization.

Tests on Rings.—Primary and secondary coils were wound on each of the chilled rings, and the (H , B) curves shown in fig. 1 (p. 343) were determined by the ordinary ballistic method. In addition to these the coërcivities (H_0) were found for a number of different values of B , and the (H_0 , B) curves are also shown.

Fig. 2 gives the (H , B) curves for the thin ring before and after chilling.

We see from fig. 1 that, after chilling, the thick ring is magnetically very similar to the thin one; and thus it is evident that, by the treatment already described, a quite heavy casting can be satisfactorily hardened throughout. Since the thin ring had the same cross-section as the rods, we may assume that its magnetic hardness was equal to theirs. The experiments here described amply confirm Mr. Peirce's results, and show that large cast iron magnets can be made cheaply and easily; we hope that this short paper will draw the attention of our instrument makers to the matter. In conclusion I would express my thanks to Dr. H. C. H. Carpenter for his kind help in the chilling of the specimens.