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XVIII. *On Errors in Magnetic Testing due to Elastic Strain.* By
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SOME years ago, in the course of magnetic tests on sheet material, Mr. T. L. Eckersley and one of the authors noticed that considerable errors were sometimes introduced by even slight bending of the sheets or strips. Mr. Eckersley worked out the stresses, and these, in combination with the known effects of compression and tension,* were found to be sufficient to account in a general way for the observed results. Only a few systematic experiments were made at the time, but recently a more comprehensive series have been carried out. The following description of some of these will serve the object of the present Paper, which does not aim at absolute results, but rather indicates the order of the errors that may occur in various cases. Hence the reader must not be too critical of the methods employed, as their accuracy was sufficient for the purpose in view. Two methods, A and B, were used.

In method A a single length of strip, which was flat in the unstrained condition, was bent into ring form, care being taken to avoid permanent set as much as possible. The slightly overlapping ends were securely clamped, and the ring was evenly wound with secondary and primary coils. These windings were of thin wire arranged close to the strip so as to keep the ring as flexible as possible. While in this condition of temporary strain, the ring was tested for permeability and hysteresis by the ballistic method. The greater part of the temporary strain was then annulled by changing the circular form into a square by sharp bends at four places. The windings were not removed for this alteration. The ballistic tests were then repeated. As will be seen by the results given below, the changes observed were considerable. The effect of the bends at the corners (which would worsen the magnetic qualities) has been ignored, and the square form has been considered as giving the condition of "no strain."

In method B two strips of the material, with suitable uniform windings, were clamped flatwise at the ends by two solid yokes,

* See Ewing "Magnetic Induction in Iron and Other Metals," Chapter IX. (Third Edition, 1900).

forming with them a long rectangular magnetic circuit. This circuit could be tested with the strips flat or bent to any desired amount. Permanent set at various curvatures could be applied, and the strips could be restored to their original flat form after any of the bending processes.

Tests were made both on ordinary (*unalloyed*) soft transformer sheet and on silicon iron (containing about 3 per cent. of silicon). The latter is much the harder material, and showed correspondingly greater alterations due to temporary strain.

FIG. 1.—PERMEABILITY OF SILICON IRON. RING METHOD.

N=No strain. T=Temporary.

The accompanying curves and tables show some of the results obtained. The curves are marked in each case as follows :—

N, No strain.

T, Temporary strain.

P, Equal permanent strain.

Tables 1, 1A, 2 and 2A (with Figs. 1 and 2) refer to the ring method, and the others to the yoke method. In the latter method, after the effects of temporary strain had been tested, the strips were allowed to unbend back to the straight condition. When re-tested they gave practically the same results,

both for permeability and hysteresis, as in the original unstrained condition. This interesting fact is not indicated in Fig. 3. It will be seen from that figure that the temporary

FIG. 2.—HYSTERESIS IN SILICON IRON, RING METHOD.

N=No strain. T=Temporary strain.

FIG. 3.—PERMEABILITY OF SILICON IRON, YOKE METHOD.

N=No strain. T=Temporary strain. P=Equal permanent strain.

strain has considerably greater effect on the permeability and the hysteresis than the equal permanent strain has.

TABLE I.

Ordinary transformer iron (0.31 mm. thick). T, ring 23 cm. diameter ; N, bent into square.

$\mathcal{H}$	N, no strain.		T, temporary strain.		μ_0/μ_1
	$\mathcal{B}$	μ_0	$\mathcal{B}$	μ_1	
1	1,800	1,800	1,390	1,390	1.29 ₅
2	5,780	2,890	4,600	2,300	1.26
5	10,080	2,016	8,980	1,796	1.12
10	12,340	1,234	11,780	1,178	1.05
20	13,880	694	13,780	689	1.01
50	15,530	311	154,80	310	1.00

TABLE 1A.

Same ring as in Table 1.

$\mathcal{B}_{\max.}$	Hysteresis loss. Ergs per c.c. per cycle.		Increase per cent.
	N, no strain.	T, temporary strain.	
5,000	1,117	1,214	8.7
10,000	3,628	3,968	9.4

TABLE 2.

Silicon-iron (0.31 mm. thick). T, ring 50 cm. diameter ; N, bent into square.

$\mathcal{H}$	N, no strain.		T, temporary strain.		μ_0/μ
	$\mathcal{B}$	μ_0	$\mathcal{B}$	μ	
1	6,510	6,510	4,640	4,640	1.40
2	9,330	4,665	6,980	3,490	1.34
5	12,090	2,418	9,980	1,996	1.21
10	13,440	1,344	12,230	1,223	1.09
15	14,110	941	13,510	900	1.14 ₅
25	14,870	595	14,700	588	1.01

TABLE 2A.

Same ring as in Table 2.

$\mathcal{B}_{\max.}$	Hysteresis loss. Ergs per c.c. per cycle.		Increase per cent.
	N, no strain.	T, temporary strain.	
5,000	468	558	19.2
10,000	1,552	1,850	19.2

TABLE 3.

Silicon-iron (0.42 mm. thick) by yoke method.

N, strips straight.

T, bent temporarily to arc of circle 18 cm. radius.

P, bent with permanent set to arc of same circle.

H	N, no strain.		T, temporary strain.		P, permanent set.	
	H	μ	H	μ	H	μ
1	6,580	6,580	4,220	4,220	4,700	4,700
2	9,210	4,605	5,710	2,855	6,580	3,290
5	11,770	2,354	8,340	1,668	9,450	1,890
10	13,100	1,310	10,640	1,064	11,900	1,190
20	14,170	708	13,200	660	13,870	693
30	14,820	494	14,550	485	14,740	491

TABLE 3A.

Same sample as in Table 3.

H _{max}	Hysteresis loss. Ergs per c.c. per cycle.		
	N, no strain.	T, temporary strain.	P, permanent set.
10,000	1,458	1,834	1,754

It should be mentioned that the results here given are only examples of cases in which the effects were somewhat pronounced; in some other samples which were tried the same amount of bending gave much less change. This is quite to be expected, for the total effect is a differential one, the permeability being sometimes increased by the tension and decreased by the compression resulting from the bending. It is, however, to the existence of the worse cases that attention has to be drawn.

In the Richter method of testing hysteresis loss the sheets are bent into the form of a ring of 50 cm. diameter. Although this gives a curvature which appears to be very moderate, the results given in Table 2A show that the slight bending may cause errors (in the hysteresis loss) of more than 10 per cent. From the above investigation the general conclusion follows that in all magnetic tests it is important that the greatest care should be taken to avoid not only permanent deformation but also temporary elastic strain.

ABSTRACT.

In magnetic tests on sheet material considerable errors may occur if the sheets or strips are tested while in bent form. These errors, which are in general agreement with the known effects of compres-

sion and tension, were investigated experimentally with one or two forms of magnetic circuit similar to those sometimes occurring in practice. In one method a single length of the strip was bent into ring form with ends clamped together. This was wound with flexible primary and secondary coils, and tested for permeability and hysteresis, while in the condition of temporary strain. The temporary strain was then annulled by changing the circular form into a square by sharp bends at four places. The magnetic tests were repeated, and usually a considerable alteration was observed. For example, a silicon-iron ring 0.3 mm. thick and 50 cm. in diameter (the size used in Richter's method of testing hysteresis and eddy current losses) showed a decrease of 40 per cent. in the permeability for $H=1$ due to the bending. The hysteresis loss was increased by 19 per cent. In another method the ends of two strips were clamped in yokes, and tests were made with different amounts of bending. It was found that temporary strain has considerably greater effect on the permeability than equal permanent strain has.

DISCUSSION.

Prof. C. H. LEES pointed out that the authors had not clearly distinguished between the effects of stress and strain, and that the results would be more intelligible if this distinction were made. The condition called by them "temporary strain" was strain plus stress, while that called "equal permanent strain" was the strain without the stress. From the point of view of the molecular dynamical theory he thought the effects of stress ought to be separated from those of strain.

Dr. S. W. J. SMITH expressed interest in the results and, referring to the difference between the effects produced by temporary stress and by permanent strain, thought there was no reason to expect any simple relation between them. Under different fields, in the same material, or under similar fields, in other materials, the effects might even be opposite to one another in sign.

Prof. T. MATHER asked if the sheets were ever annealed after being bent, before testing them by Richter's method, as this would seem to remove the objections against the method.

Mr. A. CAMPBELL, in reply, admitted the advisability of separating the effects of stress from those of strain. The advantage claimed for Richter's method was that it in no way mutilated the sheets. If they were annealed after they were bent into a cylinder this advantage would be destroyed.