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MAGNETO-RESISTANCE CHANGE OF FERROMAGNETICS IN ALTERNATING MAGNETIC FIELD

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ABSTRACT. The resistances of nickel and Ni iron permalloy have been studied under the effect of an alternating magnetic field alone and also under the effect of an alternating and a direct magnetic field simultaneously. It has been observed that the application of a gradually increasing alternating field in the absence of a direct field produces no change in the resistance of the specimen, until it has a value equal to the coercive field of the specimen ; and if the alternating field is increased beyond this value the resistance increases in the same way as it does in the case of the direct field. In the presence of a direct field, the alternating field first causes a decrease in the resistance and after a certain value has been reached, corresponding to which the resistance is minimum, the resistance begins to increase as usual. A definite relation has been observed between this particular value of the alternating field and the direct field. Further, it has been observed that the resistance of the specimen increases beyond its original value at zero alternating field, only when the alternating field is greater than the sum of the direct field and the coercive field of the specimen. Theoretical explanation of the above observations has been given.

INTRODUCTION

The magneto-resistance change of ferromagnetics in an unidirectional field has been the subject-matter of investigation of various workers ; but as far as the author is aware very little work has been done relating to magneto-resistance change in alternating magnetic fields. Some recent workers [1, 2] have shown that the passage of alternating current through a ferromagnetic wire alters to a considerable extent its electrical properties. This change in the electrical properties is a complex effect and may be partly due to the passage of alternating current as such through the material, partly of the nature of skin effect due to the permeability changes in the ferromagnetic caused by the alternating magnetic field of the alternating current and partly due to the alternating magnetic field itself. It is the purpose of this work to throw some light on the effects of an alternating magnetic field on the resistance of ferromagnetics as separated from the effect of passing an alternating current through the specimen and the consequent skin effect.

EXPERIMENTAL ARRANGEMENTS

It is known[3] that the resistance of a ferromagnetic wire undergoes no change due to the passage of a direct current within moderate limits. For this reason, a constant direct current of the value of 0·1 Amps, as read by an ammeter placed in series with the specimen, was used for measuring the resistance of the wire, throughout the whole experiment. For measuring the resistance, the well known Kelvin's double bridge was used and with this arrangement, a resistance change of the order of 10 micro-ohms could be determined with accuracy, which was found enough for the purpose in view. The specimen in the form of a wire was placed longitudinally in the centre of a solenoid, the length of which was much greater than that of the wire, so that the full wire could be subjected to an uniform magnetic field. The solenoid consisted of two sections of wires wound one above the other, through one of which a direct current could be passed and through the other, an alternating current, and in this way, the specimen could be subjected either to a longitudinal direct magnetic field or to a longitudinal alternating magnetic field or to both simultaneously. Two specimens of wires were investigated. One was of pure nickel and the other was of Ni-iron permalloy of low coercivity. The coercivities of the two specimens were determined by the usual magnetometer method

RESULTS

TABLE I.

Nickel.

Coercive field—7·80 Gauss. Length of the wire—57·5 cms. Diameter of the wire—0·048 cms. Resistance of the wire—0·336 ohms.

Alternating Longitudinal Field in Gauss.	Direct Longitudinal Field—Nil.	Direct Longitudinal Field—19·3 Gauss.		Direct Longitudinal Field—39·6 Gauss.	
	dR in Ohms × 10^{-4}.	dR due to Alternating field alone in Ohms × 10^{-4}	Total dR in Ohms × 10^{-4}.	dR due to Alternating field alone in Ohms × 10^{-4}	Total dR in Ohms × 10^{-4}.
0	0	0	5·14	0	8·40
2·75	0	...	.	..	...
3·62	0	..	..	...	..
5·43	...	0	5·14	..	...
10·13	1·44	0	5·14	0	8·40
14·47	2·70	0	5·14	0	8·40
21·71	4·14	0	5·14	−0·36	8·04
28·04	5·76	1·08	6·22	−0·72	7·68
36·18	7·20	3·42	8·56	−0·54	7·86
54·27	11·52	6·84	11·98	1·56	9·96
72·37	14·04	10·16	15·30	4·68	13·08
90·45	16·56	12·70	17·84	6·48	14·88
108·54	19·62	16·20	21·34	9·18	17·58

TABLE II.

Ni-Iron Permalloy.

Coercive field—1.40 Gauss. Length of the wire—53.5 cms. Diameter of the wire—0.045 cms. Resistance of the wire—1.67 Ohms.

Alternating Longitudinal field in Gauss.	Direct Longitudinal Field Nil	Direct Longitudinal field—4·88 Gauss.		Direct Longitudinal field—9·65 Gauss.		Direct Longitudinal field—19·5 Gauss.		Direct Longitudinal field—38·6 Gauss.	
	dR in Ohms × 10^{-4}.	dR due to Alternating field alone in Ohms × 10^{-4}.	Total dR in Ohms × 10^{-4}.	dR due to Alternating field alone in Ohms × 10^{-4}.	Total dR in Ohms × 10^{-4}.	dR due to Alternating field alone in Ohms × 10^{-4}.	Total dR in Ohms × 10^{-4}.	dR due to Alternating field alone in Ohms × 10^{-4}.	Total dR in Ohms × 10^{-4}
0	0	0	5·36	0	15·41	0	22·11	0	32·16
1·26	0		...	...	...	...	...	..	...
1·81	2·06	0	5·36	0	15·41	...	...	.	...
2·71	3·69	0	5·36	...	...	...	...	.	...
3·62	5·36	—1·01	4·35	...	...	0	22·11	. .	..
3·98	...		...	—0·34	15·07	...	..	...	...
4·52	...	—1·34	4·02	.	...	...	...	...	.
5·43	7·37	0	5·36	—0·67	14·74	0	22·11	...	...
7·60	...	...	.	—1·34	14·07	—1·34	20·77	...	...
7·96	..	...	...	...	...	...	.	0	32·16
10·49	13·40	6·70	12·06	...	.	...	...	.	.
10·85	...	..	.	—0·67	14·74	...	. .	...	
11·22	...	...	...	...	...	—2·06	20·05	. .	
15·20	16·08	11·73	17·09	0·34	15·75	—3·35	18·76	—1·37	30·79
18·09	...	..		...	...	—2·68	19·43		
21·71	20·10	13·40	18·76	7·03	22·44	0	22·11	—3·35	28·81
25·33	...	.	...	...	...	...	...	—4·69	27·47
28·04	24·12	16·75	22·11	10·05	25·46	2·06	24·17	—6·37	25·79
32·06	...	...	...	...	..	...	...	—5·36	26·80
36·18	27·47	21·41	26·80	12·06	27·47	5·36	27·47	—3·35	28·81
43·42	...	...	...	...	...	...	.	—0·37	31·79
54·27	32·16	26·13	31·40	19·40	34·81	9·72	31·83	1·01	33·17
72·37	36·85	27·81	33·17	21·44	36·85	11·39	33·50	2·35	34·51
90·45	38·50	20·80	35·16	23·12	38·53	13·20	35·51	5·02	37·18
108·54	38·50	20·50	34·86	25·46	40·87	15·70	37·81	6·37	38·53

Tables I and II give the results obtained with nickel and Ni-iron permalloy, respectively. The second column in both the tables gives the resistance change of the specimens when subjected to only alternating magnetic field. The other columns represent the measurements taken with a simultaneous application of a direct and an alternating magnetic field. The results are best appreciated with reference to fiigures 1 and 2 which are graphical representations of the results obtained.

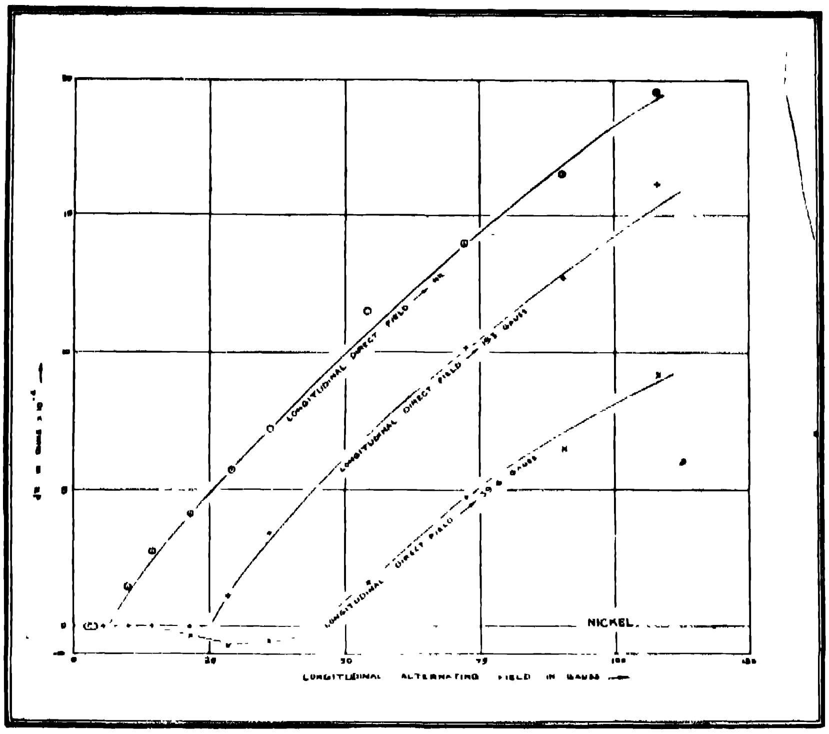

FIGURE 1.

It will be seen that when a ferromagnetic wire is subjected to a gradually increasing alternating magnetic field alone, the resistance of the wire undergoes no change in the beginning till a certain value of the alternating field is reached and then if the field be further increased, the resistance increases practically in the same way as it does under a direct magnetic field. The particular value of the alternating field after which the resistance begins to increase, which we shall call H_0, agrees with the coercive field H_c of the specimen, as will appear from table III. The magnitude of the change of resistance with alternating field appears to be of the same order as that with a direct field as table IV shows. The smaller resistance change with alternating field merely points to the fact that a portion of the alternating field perhaps goes to overcome the coercive field of the specimen and hence the resistance changes in alternating field refer to smaller fields than

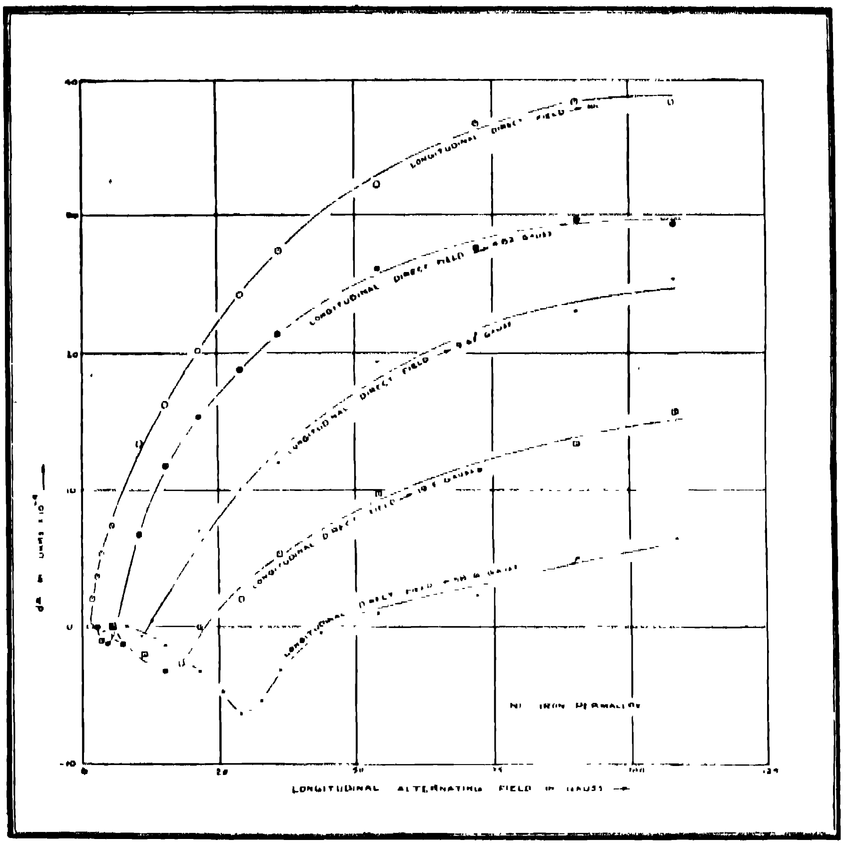

FIGURE 2.

the corresponding direct fields given in table IV. The tables III and IV are merely analysis of the data given in tables I and II and the curves of figures 1 and 2. So far concerning resistance change under the effect of alternating field alone.

Now let us consider the resistance change under a simultaneous effect of direct and alternating fields. When a direct field is at first applied, there is a consequent increase in the resistance of the specimen, as given in the tops of columns 4, 6, 8 and 10 of tables I and II. If now an alternating field be superimposed on the direct field, a decrease of resistance first takes place and then after reaching a minimum value, the resistance again increases, passing through the value it had at zero alternating field and finally reaches nearly the same values as it did under the effect of the alternating field alone. For the purpose of neatness and clarity no account is taken in figures 1 and 2 of the resistance change of the specimen due to the direct field, but this is taken into account in the columns 4, 6, 8 and 10 of tables I and II.

TABLE III.

Specimen.	H_d in Gauss.	H_m in Gauss	H_d/H_m.	H_o in Gauss.	H_c in Gauss	$H_d + H_c$ in Gauss.
Ni-Iron Permalloy	0	...	...	1.50	1·40	1·40
Do	4·82	4·00	1·21	6·00	1·40	6·82
Do	9·65	7·45	1·30	12·00	1·40	11·05
Do	19·50	15·00	1.30	21·50	1·40	20·90
Do	38·60	29·50	1·31	44·50	1·40	40·00
Nickel	0	..	...	6·50	7·80	7·80
Do.	19·30	...	...	25·00	7·80	27·10
Do.	39·60	30·00	1·32	44·50	7·80	47·40

TABLE IV.

Specimen.	Field value Alternating or Direct in Gauss.	dR in Alternating Field Ohms × 10⁻⁴.	dR in Direct Field Ohms × 10⁻⁴.
Ni-Iron Permalloy	4·82	6·30	5·36
Do.	9·65	12·00	15·41
Do.	19·50	19·50	22·11
Do.	38·60	29·00	32·16
Nickel	19·30	3·80	5·14
Do.	39·60	8·00	8·40

DISCUSSION OF THE RESULTS

If,

H_m = the alternating field at which the resistance has a minimum value,

H_d = the direct field,

H_o = the alternating field after which the resistance finally begins to increase,

then two very remarkable results can be noticed from table III.

$$H_o = H_d + H_c \qquad \dots (1)$$

$H_d/H_m =$ 1·30 nearly = constant (2)

The relation (2) has a very significant meaning in the light of the following observations. The alternating field that is created by the passage of an alternating current through a solenoid is a fluctuating field passing through a maximum in one direction 50 times per second just like the current. Now as it is the root mean square value of the current which is read by an A.C. ammeter, it is the root mean square value of the alternating field that is obtained when calculated from the alternating current and not the maximum value. If it is supposed that the resistance is minimum when the maximum value of the alternating field is equal to the direct field, the relation H_d/H_m = 1·30, shows that the crest factor of the current used is 1·30 which is near the correct value.

The relation (1) again points to the fact that the direct field applied behaves just like the coercive field in this case and unless the alternating field is more than the sum of the coercive field and the direct field, no increase in resistance takes place.

Another important observation should be made in this connection. The magnitude of the maximum decrease in the resistance of a ferromagnetic wire due to the superimposition of an alternating field over a direct field increases with the value of the direct field applied.

The above remarkable observations are capable of being explained on the general theories of magneto-resistance change. It is known that there is always an increase of resistance, whatever be the direction of the magnetic field applied. The increase in resistance, therefore, in an altering magnetic field similar to that in a direct longitudinal field is quite expected, and is a sort of average of the varying resistance changes during a cycle. The fact that the resistance does not begin to increase until the coercive field is overcome by the alternating field has also a parallel in the case of the direct field if we consider a full resistance-hysteresis cycle.

The effects of the superimposition of alternating and direct fields can be similarly explained. An alternating field helps the direct field during one half of the cycle and opposes it during the other half. There is an increase of resistance, therefore, in half the cycle when the two fields are helping each other and a decrease in the other half ; but the increase of resistance is necessarily less than the decrease as is clear from the nature of the magneto-resistance curves. The net result therefore in a complete cycle is that there is a decrease of resistance. This goes on till the peak value of the alternating field equals the direct field and then the maximum decrease in the resistance takes place. It is clear that the maximum decrease in the resistance will be greater, the greater the value of the direct field applied. After this point is passed, an increase in the alternating field increases the resistance of the wire and the usual form of the magneto-resistance curve is obtained.

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