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The Wiedemann Effect of the Magnetostriction Alloy "Alfer"*

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Synopsis

The Wiedemann effect of "Alfer" (12.91 per cent Al-Fe alloy) was measured at room temperature up to 820 Oe in longitudinal magnetic field and to 8 A in current through the specimens, 3 mm, in diameter and 150 mm in length (the circular magnetic field at the surface of the cylindrical specimen was about 10.7 Oe). It was found that the Wiedemann effect, that is, the angle of twist increased with increasing longitudinal field and after attaining a maximum value decreased gradually at the constant current through the specimen, and that the maximum value as well as the corresponding field increased with increasing current through the specimen. In a weak field, the effect increased at first at a constant rate, and then reaches a saturation value with increasing current, and in higher fields, the effect became proportional to the current. The effect of "Alfer" had the opposite sign to that of Ni, though the absolute magnitudes were nearly equal to each other.

I. Introduction

When a ferromagnetic bar, one end being fixed, is longitudinally magnetized by an external field after being magnetized circularly by a current through it, it will be subjected to torque. This phenomenon was first discovered by G. Wiedemann in 1858 and is now called "Wiedemann Effect" after the discoverer(1). A few reports have been published on this effect. After the discovery, C. G. Knott(2) studied the temperature dependence of the twist with Ni-wire. Nagaoka and Honda(3) took up this problem for the first time in our country: they studied the effect on Ni and Fe-Ni alloys. Next, Honda and Shimizu(4) reported their study of the effect on Co first without load and then under the influence of load. Later on, Shimizu and Tanakadate(5) made their research on Fe-Ni alloy and W steel chiefly under the influence of high temperature, S. R. Williams(6) on Fe tube, Howard A. Pidgeon(7), and Paul McCorkle(8) on Fe, Ni and Co. Recently, Kimura(9) reported a theoretical study on Fe single crystal. He also studied with his

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* The 876th report of the Research Institute for Iron, Steel and Other Metals. Published in the Journal of the Japan Institute of Metals, **16** (1952), 239.

(1) G. Wiedemann, Electricität, **3** (1858), 797.

(2) C. G. Knott, Trans. Roy. Soc. Edin., **32** (1883), 193.

(3) H. Nagaoka and K. Honda, Phil. Mag., **4** (1902), 45.

(4) K. Honda and S. Shimizu, Phil. Mag., **5** (1903), 650.

(5) S. Shimizu and T. Tanakadate, Tokyo Sûgaku Buturi Kiji, **3** (1906), 142.

(6) S. R. Williams, Phys. Rev., **10** (1917), 129.

(7) H. A. Pidgeon, Phys Rev., **13** (1919), 209.

(8) Paul McCorkle, Phys. Rev., **22** (1923), 271.

(9) R. Kimura, Proc. Phys. Math. Soc. Japan, **22** (1940), 224.

coworker(10) the inverse Wiedemann effect and obtained an important result.

Now, it seems to be reasonable, as H. A. Pidgeon discussed, that the Wiedemann effect is chiefly connected with the amount of the longitudinal magnetostriction. Recently, the magnetostriction alloy "Alfer" having a high value of magnetostrictive constant has been discovered, and then it becomes interesting to observe the Wiedemann effect of this alloy which is applicable to practical use by its high magnetostriction and, therefore, based on this idea, the present study was performed.

Further, this magnetostriction alloy "Alfer" belongs to the Fe-Al binary alloys and has been discovered by Honda, Masumoto, Kobayashi and one of the present authors(11). The characteristic property of this alloy has the static magnetostriction of 40×10^6 at 1200 Oe and its absolute value is equal to that of Ni. This alloy is practically used in large quantities as the ultrasonic oscillator.

In the present experiment, the Wiedemann effect of "Alfer" was measured not only at room temperature but also at higher temperatures. At the same time, the experiment was extended on the other Fe-Al alloys. Here, only the results obtained from the study of Alfer at room temperature will be reported.

II. Specimen, apparatus and method of observation

The materials from which the specimens were made were electrolytic iron prepared at Nippon Denki Seitetsu-sho and aluminium provided by Alcoc Co. The results of chemical analysis of these metals are given in Table 1.

Table 1. Results of chemical analysis of materials used.

Elements	Fe(%)	Co(%)	C(%)	Mn(%)	Si(%)	P(%)	S(%)	Cu(%)	Al(%)	Zn(%)
Electrolytic Iron	—	—	0.05	0.00_4	0.00_8	0.000_5	0.00_3	None	0.02	—
Aluminum (Alcoc)	0.48	—	0.02	0.00_8	0.01_0	Trace	0.00_2	None	—	0.02
Electrolytic Nickel	0.01	0.23	0.05	0.00_0	0.00_5	—	0.00_4	—	—	—

The process of obtaining the specimens was as follows: First, electrolytic iron was melted in the high frequency induction furnace, then Al was added, taking a great care not to be oxidized and then the melt was cast into an ingot of 6 kg. By the chemical analysis the amount of aluminium contained was 12.91 per cent. This ingot was forged and rolled at the high temperature and then ground to a cylindrical rod, 3 mm in diameter and 150 mm in length. Next, this rod was annealed for an hour at 1000°C in the non-inductive electric heating vacuum furnace and was furnace-cooled to 700°C, and then it was cooled slowly from 700°C to room temperature at the rate of 30°C per hour before the observation. This cooling rate was necessary to produce a superlattice of Fe_3Al in the specimen.

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(10) K. Kimura and Yoshimura, Rikoken Hokoku, **2** (1948), No. 12, 4.

(11) K. Honda, H. Masumoto, Y. Shirakawa and T. Kobayashi, J. Japan Inst. Met., **12** (1948), No. 1, p. 1., Sci. Rep. RITU, **A1** (1949), 341.

The apparatus is shown in Fig. 1. As seen from the figure, to both ends of the specimen S, non-magnetic rods, N and N′, (Fe = 40 per cent, Ni = 30 per cent, Cr = 30 per cent) are connected with the binders made of the same material and this specimen is suspended at the center of the silica tube. The upper end of N was fixed so that the specimen is arranged vertically against the brass block B, which is connected to silica tube T, and a mirror M was attached to the central part of N′. To the lower end of T, a glass tube G was connected through the vacuum joint of frosted glass parts of both tightly, the latter being provided with a peep-window to read the scale with the telescope. The lower end of G was closed and filled with Hg, in which the end of N′ was dipped. The upper end of N was connected electrically to the mercury pot which formed a part of the vacuum-cap. Thus, through the lead wires from the both pots, the electric current could be applied to the specimen in vacuum. The specimen was placed in the middle part of the magnetic field produced by magnetizing coil C which is sufficiently uniform. The coil constant $4\pi n/10$ is equal to 58.64/A. The vertical component of the earth field was eliminated by Helmholtz coil H, placed at the upper and lower parts of the apparatus. The specimen was heated in the electric furnace F of Ni–Cr wire wound non-inductively. A water jacket was attached between the magnetization coil and the electric furnace to prevent the coil from the heating by the latter.

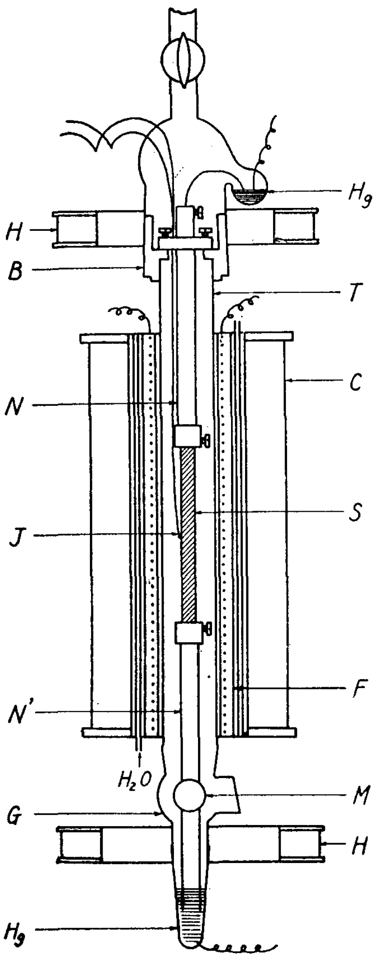

Fig. 1. Main portion of measuring apparatus for wiedemann effect.

B: Brass block
C: Magnetizing coil
F: Electric furnace
G: Glass tube
H: Helmholz coil
J: Junction
M: Mirror
N, N′: Non magnetic rod
S: Specimen
T: Silica tube

In performing the experiment, first, the electric current for the circular magnetic field, that is, the current through the specimen was kept at constant (0.5, 1, 2, 3, 4, 6, 8 A) and, then, the various intensities of current were applied through the magnetizing coil to observe the rotations of the mirror at various longitudinal fields (the maximum value was equal to 820 Oe) with scale and telescope. The deflection of 0.1 mm on the scale corresponded to the torsion of $0.3''$/cm. Before every experiment, the specimen was demagnetized by the alternating current.

III. Results of measurements

The Results of measurements are shown in Fig. 2. In the figure, the abscissa is the external longitudinal magnetic field H in logarithmicscale, and the ordinate is the angle of torsion θ per unit length, i being the value of electric current for the circular-field, that is, the current through the specimen. The current density in the case of $i = 8$ A corresponds to 1.13 A/mm^2, and the circular field is about 10.7 Oe on the surface of the specimen. As shown in the figure, the curves resemble one another in the tendency: as the external longitudinal magnetic field increases, the angle of the twist increases, first gradually and then rapidly until it reaches the maximum. The weaker the circular-field current, the smaller is the magnetic field where the maximum value of the twisted angle (θ_m) is observed. As shown in Table 2 the relation between the maximum value of the twisted angle and the corresponding field is nearly linear.

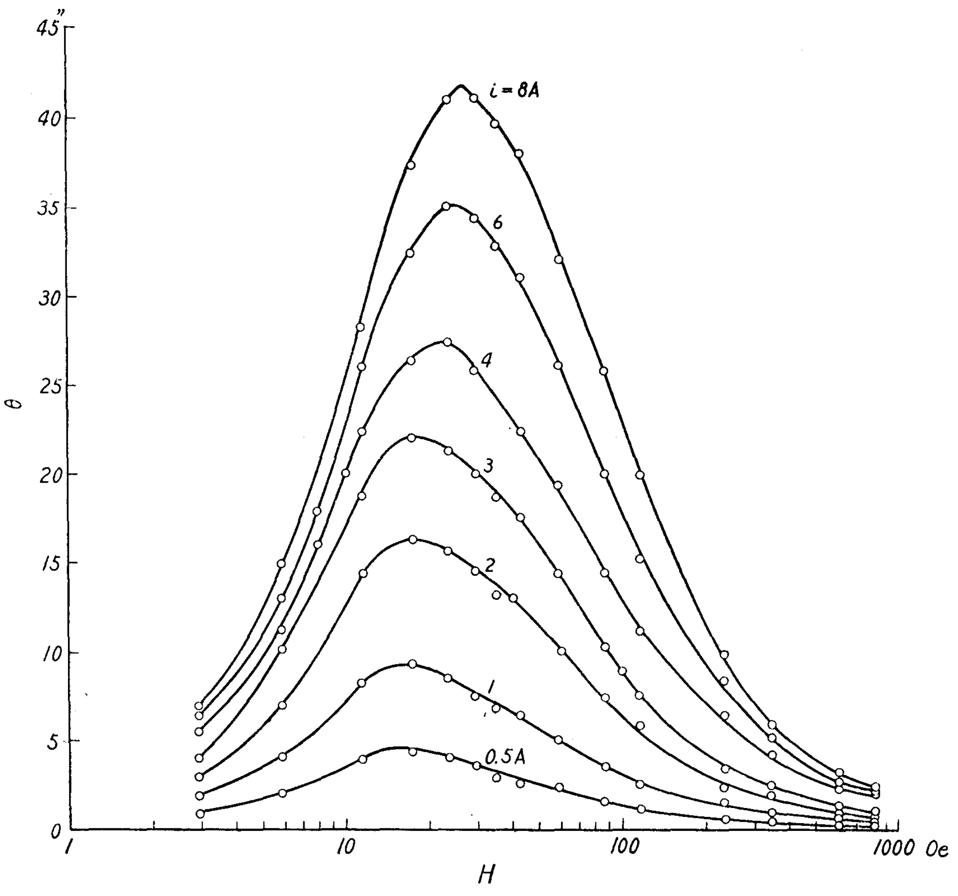

Fig. 2. Relation between twisted angle and longitudinal external field for Alfer.

Fig. 3 shows the relation between the circular-field current and the twisted angle obtained from Fig. 2 in the constant longitudinal magnetic field. This figure shows that in lower longitudinal field, θ tends to rise almost linearly and gradually reaches the saturation value. In higher magnetic field, θ increases in proportion to the circular field. The behaviours of the above-mentioned curves can be qualitatively explained by the following formula derived by Pidgeon⁽⁷⁾.

$$\theta = \lambda H_c / \gamma \sqrt{H_c^2 + H^2},$$

where θ is the twisted angle, λ the magnetostriction, H_c the circular field, γ the radius of the specimen and H the longitudinal magnetic field. In this equation θ ought to show a maximum value against the magnetic field when H_c is constant.

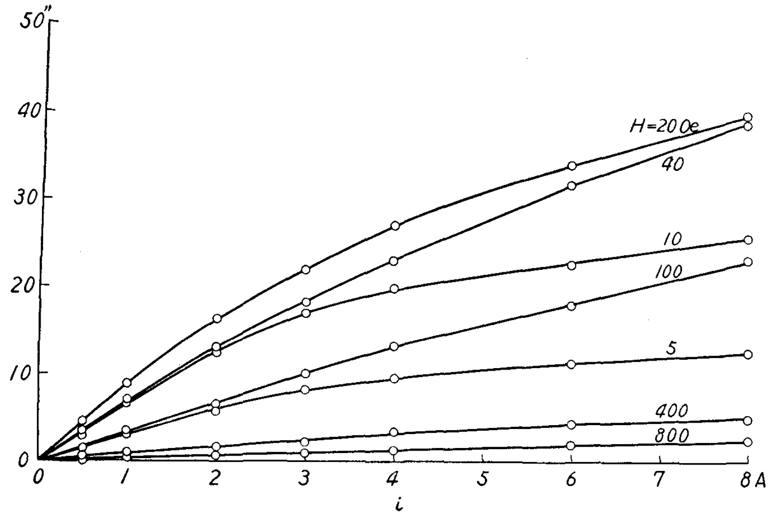

Fig. 3. Relation between twisted angle and current through specimen for Alfer.

This fact seems to explain the tendency of the curves in Fig. 2. When H is very large compared with H_c, θ will be given by the following equation:

$$\theta = \lambda H_c / \gamma H \ ,$$

that is, θ is proportional to H_c when H is constant. This also explains qualitatively the tendency of the curves in Fig. 3.

Though the Wiedemann effect of Ni and Fe had been reported long before, it was re-measured to compare with that of Alfer. The results for Ni are given in Figs. 4 and 5. The direction of the twist for Ni was reverse to that of Alfer. This may be understood from the different signs of magnetostriction of them. The tendency of the curves is similar completely to that of Alfer. The maximum value of the twist (θ_m) and the magnetic field (H) in Fig. 4 are in Table 2.

Table 2. Maximum twisted angle (θ_m) and longitudinal external magnetic field (H) at the constant circularly magnetizing current (i)

Materials	Alfer		Ni		Fe	
(A)	θ_m (″)	H (Oe)	θ_m (″)	H (Oe)	θ_m (″)	H (Oe)
0.5	4.5	15.0	4.8	13.0	7.2	15.0
1.0	9.3	16.5	9.4	14.0	10.4	16.5
2.0	16.3	17.5	17.3	14.0	11.8	17.5
3.0	22.1	18.5	24.8	14.5	12.1	19.5
4.0	27.5	22.5	31.0	15.0	12.3	20.5
6.0	35.2	24.5	38.5	16.5	13.3	23.5
8.0	41.8	27.0	42.4	18.0	14.3	25.0

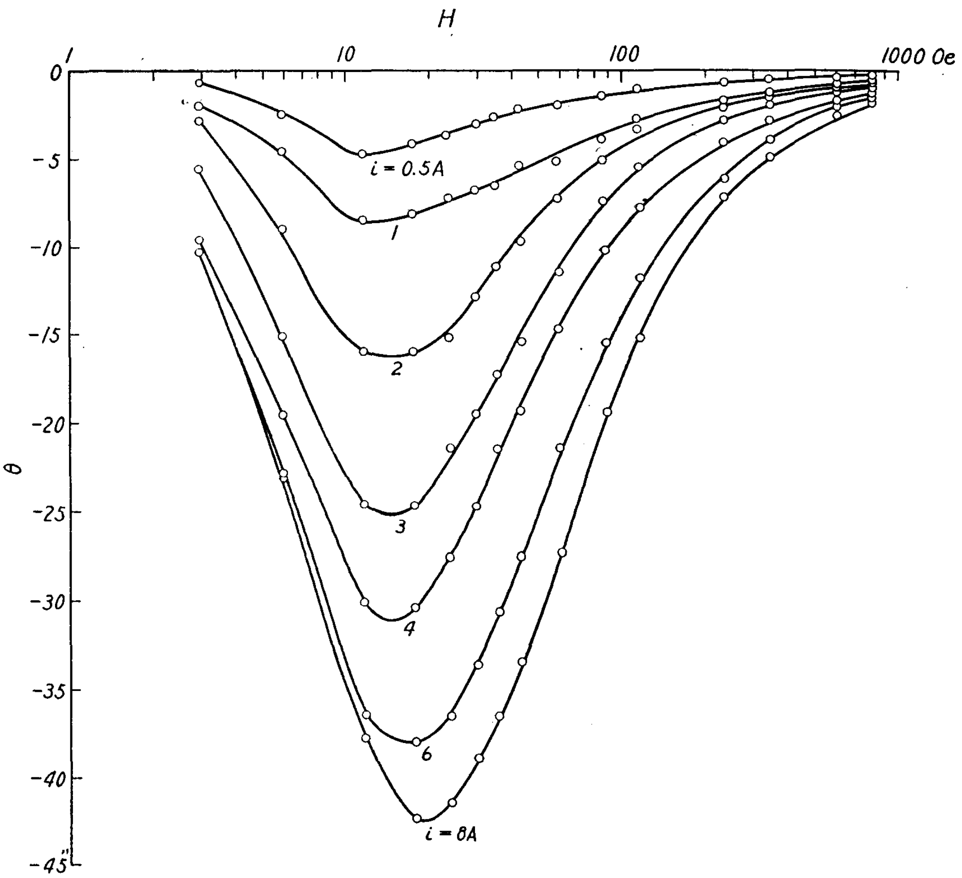

Fig. 4. Relation between twisted angle and longitudinal external field for Ni.

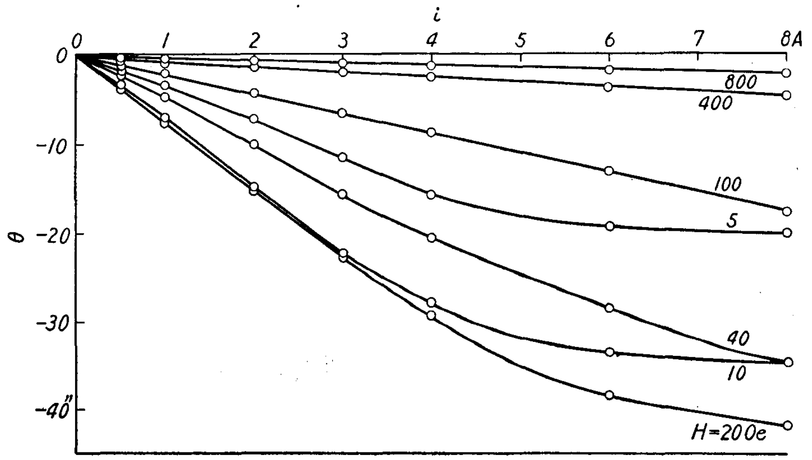

Fig. 5. Relation between twisted angle and current through specimen for Ni.

The results of measurement for Blogen iron are shown in Figs. 6 and 7. Generally, the twisted angle of Fe is very small compared with that of Alfer or Ni. As shown in Fig. 6, when the current is below 4 A, the twists increase similarly as the longitudinal magnetic field increases, while after becoming zero in a certain intermediate magnetic field, the twists increase in the reverse direction in the magnetic field of 800 Oe. As seen from Fig. 7, differing from the case of

Alfer or Ni, the twist caused by the circular-field current in the constant longitudinal magnetic field is markedly small. A maximum is shown on the twist vs. circular field current curve at the longitudinal field lower than about 10 Oe.

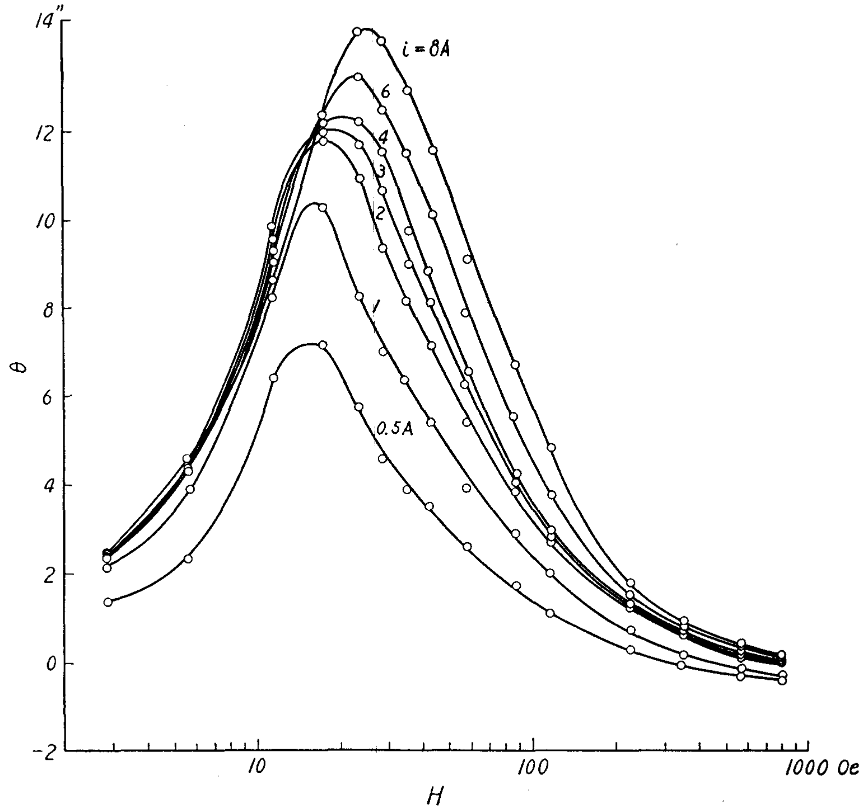

Fig. 6. Relation between twisted angle and longitudinal external field for Fe.

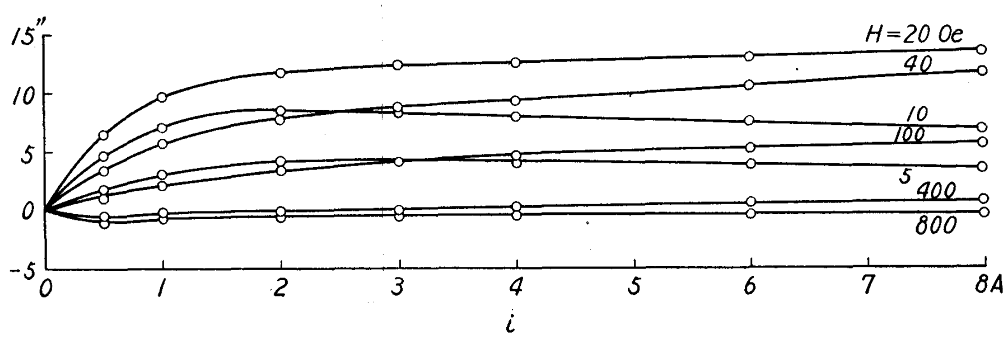

Fig. 7. Relation between twisted angle and current through specimen for Blogen inon.

Next, the relation between the effect and the intensity of magnetization in the longitudinal field is shown in Fig. 8, which has been obtained with the circular field current of 8 A. The sign of the twisted angle of Ni is negative against that of Alfer or Fe, so in the figure the absolute value is given. As shown in the figure, the maximum value of the twist of Alfer or Fe is seen at about 1/2 of the saturation magnetization. But in the case of Ni the corresponding magnetization is smaller than the above and is about $1/\sqrt{3}$ of the saturation magnetization.

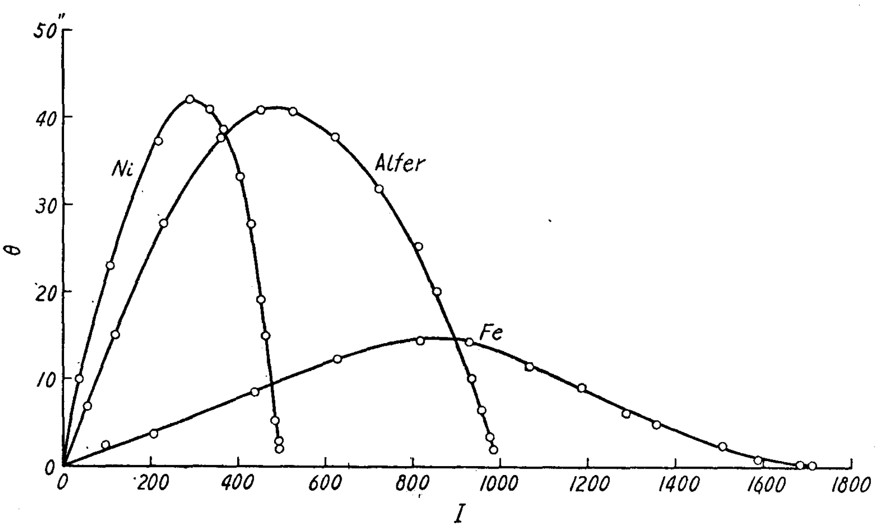

Fig. 8. Relation between twisted angle and intensity of magnetization.

Summary

The Wiedemann effect of the new magnetostriction alloy "Alfer" was measured at room temperature and the following results were obtained:

(1) In the constant circular magnetic field, the effect increased rapidly as the longitudinal magnetic field increased, and reached a maximum, and then decreased gradually. The value of the longitudinal magnetic field at which the maximum was observed became higher as the circular magnetic field increased.

(2) In the constant longitudinal magnetic field, excepting the weak field, the effect increased almost linearly as the circular magnetic field increased.

(3) The same measurements were carried out on Fe and Ni to compare with Alfer, and the following relations were obtained: The sign of the effect of Alfer was contrary to that of Ni, while the amount of these effects was nearly the same order. The maximum value of the effect for Ni in the constant circular field was almost equal to that for Alfer and the maximum of Fe about 1/3 of those for both metals. The longitudinal magnetic fields where the maximum value of the effect was obtained were nearly equal to each other in the cases of Alfer and Fe, which that for Ni was a little lower than those for Alfer and Fe.

In conclusion, the present authors express their hearty thanks to Dr. Hakaru Masumoto, the president, under whose guidance and encouragement this study was performed. They also thank to Mr. Yoshiyuki Satô for his aid in making the measuring apparatus.

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