FIAT FINAL REPORT NO. 792

IRON CORES

OFFICE OF MILITARY GOVERNMENT FOR GERMANY (US)

FIELD INFORMATION AGENCY, TECHNICAL

OFFICE OF MILITARY GOVERNMENT FOR GERMANY (US)

FIAT FINAL REPORT NO. 792 4 April 1946

IRON CORES

BY

F. R. HENSEL

Joint Intelligence Objectives Agency

FIELD INFORMATION AGENCY, TECHNICAL

ABSTRACT

German methods for the manufacture of low hysteresis iron and iron-nickel powder cores are given.Special emphasis is placed on insulation and bonding. Manufacturing details and theoretical considerations of hysteresis are given in tabular form at the end of the report.

TABLE OF CONTENTS

1. INTRODUCTION

A search was made for information on German developments in the manufacture of high frequency iron cores of the following eight known producers. The first three account for most of the production and for practically all of the important developmental work.

1. Siemens, Berlin
2. AEG, Berlin
3. Vogt and Company, Metallpulverwerkstoffe, Berlin and Erlau-Passau, Bavaria
4. Neosid, Berlin
5. Dralowid, Steatit-Magnesia, Teltow, Berlin
6. Gösler, Berlin
7. Bosch, Stuttgart
8. Felten and Guillaume, Köln

German practice generally parallels that in the United States. The mixing methods used at AEG and the extrusion process developed by Siemens are of special interest. A short description of the practices followed by each of the three leading firms is given. The five other small producers do not have any special methods or unusual practices.

2. SIEMENS AND HALSKE A. G., WERNERWERK

Materials. - - The raw material for iron Pupin cores at Siemens was exclusively iron carbonyl powder purchased from I. G. Farben. The preferred grades were E. H. and C powder. Siemens had the following designations for the I. G. grades:

I. G. Designation	Siemens Designation
C normal	F
C Stabil	A
E	D
H	K

The grain size of the powder ranges from 5—10 microns. The H powder was of particular fine grain size and the average particle size was 1—3 microns.

To a smaller extent Siemens employed iron-nickel powders. This powder was produced by reducing nickel iron oxides. This oxide was supplied by the "Saechsiche Blaufarbenwerke", Leipzig.

Iron cores produced from iron-nickel powders were utilized for Pupin cores of small dimensions for sea and river cables. Further applications were in the field of ceramic condensers where iron-nickel mixtures are employed for temperature coefficient compensation. In this case the iron-nickel powders are mixed with E powder.

Insulation. - - The technique of insulating iron powders is as follows:

1. Sodium silicate and sugar sodium silicate mixtures are compounded of technical sodium silicate (40° Be) and finegrained commercial sugar. The mixer is started cold and the vanes are initially run toward the inside. When using two grades of powder it is necessary to mix these for half an hour while dry. It is then moistened with about one-half liter of water for 60 kgs. After one-quarter hour, sodium silicate solution diluted with about 3 liters of water is added, or it is undiluted when using a 1 percent solution. In the second case, 2 liters of water are added later. Four and one-half to 5 liters of water are finally added. The heating is started and the mixture is diluted sufficiently to prevent the powder sticking to the vanes. Too much dilution will cause the mixture to drain through the stuffing box. The temperature of mixing is 60—65° C; the exhaust fan is used; and the mixing time is about 4½ to 5 hours. During the first hour, the vanes should be rotated alternately toward the inside and outside for onequarter hour periods. Finally, they are rotated toward the outside only. The powder adhering to the vanes and walls is scraped off to prevent the formation of lumps. The operation is completed when the powder feels dry and will not smear when rubbed between the fingers. The heat and exhaust are then switched off, the powder is poured into an iron pan, and the mixer, especially the vanes, is cleaned. The powder is distributed in thin layers over three plates and well raked to crush the large lumps. Each plate is provided with an identification tag to indicate the mixture number and grade. Drying is done in a recirculating air oven at about 90° C for 7 hours. It is raked thoroughly after 3 hours so that the lower layers will dry well. It is then crushed in a roller mixer or a ball mill (see Table I). It is then stored in a dry place. Subsequent processes should follow within the next few days. It should be redried if storage time is too long. In the case where several sodium silicate and/or sugar sodium silicate insulations are necessary, one must proceed carefully in the third and fourth stages of insulation. When the final water is added, a loss through the stuffing boxes may occur as the powder decreased in its power to absorb water. Preinsulation powder is stored for 3 days prior to main insulation.

2. Bakelite Mixtures. - - The material used is bakelite and 50 percent ethyl alcohol solution. Porcelain powder is added for "y." The mixture is run cold. When making additions "y," these powders and second-grade powders are to be mixed in while dry. The mixer is started; the bakelite solution in ethyl alcohol is added. For 5 percent bakelite mixtures, the additions are made in two portions; the second half after about 25 minutes of agitation. The bottle is washed out with about onehalf a liter of ethyl alcohol. The mixer is not heated but the exhaust is started at about 30 percent capacity to prevent too fast drying. The mixing time is 30 to 40 minutes. The longer mixing time produces a doughy powder due to heat

generated. At the time of renewal, the powder must be loose, as described for the sodium silicate insulation. Emptying is done in the same manner as described above.

The powder is dried in a recirculating air oven at 45° C. The crushing procedure is described in Table I.

If "y" insulation bakes into lumps during grinding, the drying has not been sufficient. In this case, further drying for 3 hours is required. The materials are stored at room temperature. The powder must be processed in 5 days or otherwise stored in barrels sealed with rubber and placed in a cold room.

Production Methods. - - Pupin cores are produced on hydraulic presses. The pressure which is applied ranges from 10,000 to 15,000 kg. per cm². In special cases pressures as high as 20,000 kg. per cm² are applied. The press capacities varied from 100 to 2,500 tons.

The life of the dies was between 6,000 to 10,000 cores per die. The die construction was quite important in order to avoid breakage and rapid wear. Usually the main die body was reinforced by a ring of special steel to take up the enormous forces exerted due to pressure and friction. The actual working part of the die is a tapered insert into the main body. This insert is split three ways. After the core has been pressed and is ready for ejection, both core and insert are ejected.

Usually a dial feed arrangement was available for each press and several operators took care of the operations at the various stations such as inserting the tapered inserts, filling the die cavities with powder, removing the finished cores, etc.

High-Frequency Cores. - - Siemens produced a large number of iron cores by means of specially designed extrusion presses applying the techniques developed for pressure moulding of plastics. The materials used were the same as the Pupin core materials. Manufacturing specifications for pre-insulation and main insulation are given in Table II.

The binder as well as the insulating material was Trolitul which is a Polystyrene. Trolitul is the trade name of a plastic produced by the firm Dynamit A. G., Troisdorf, Köln.

The extrusion presses which were in use at Siemens were "Isoma-Maschinen" built by Fa. Braun in Zerbst/Anhalt. These presses operate with a total pressure of 10 tons. Split moulds are used the life of which is 200,000 extrusions. In one split die frequently as many as 8 to 12 cores were extruded in one stroke. This extrusion process permits the production of complicated cores and it was therefore utilised extensively by Siemens for cores in radio receivers as well as transmitters. In transmitters a special high temperature brand of Trolitul was employed which was stable up to 130° C.

The extrusion process was commercially developed during the war and it assisted greatly in speeding up production and maintaining a high standard of quality.

Specifications. - - The ring permeability of high-frequency iron cores, most of which are made by extrusion, is about 6. The specific gravity is 4 grams per cubic centimter.

The properties of typical iron core mixtures produced on hydraulic presses are shown in Table III.

3. AEG, Berlin

Materials. - - The AEG used carbonyl iron for Pupin cores and high-frequency cores.

Insulation of Powders. - - - AEG uses extensively sodium silicate (water-glass) and synthetic resins for insulating the iron powder particles. They pre-mix iron powders with various insulators and then use certain percentages of these pre-mixed materials in the preparation of their final iron cores. For certain applications kaolin is employed in addition to sodium silicate and synthetic resins.

Their technique of insulating the powders is best illustrated by a number of typical mixtures which they have developed for cores used at different frequencies.

(1) Pupin core - - for uses up to 3,000 cycles: (mixture NFA₂)
  (a) Carbonyl iron — "C — Stabil"
    2% sodium silicate
    7% distilled water

(2) Pupin core - - for uses up to 15,000 cycles: (mixture NFB₁)
  (a) Iron mixture as follows:
    50% carbonyl iron P - - medium hard
    30% carbonyl iron H - - hard
    20% carbonyl iron E - - soft
  (b) The mixture (a) was treated with 3.2% sodium silicate; 6% distilled water.

(3) High-frequency cores for uses up to 150,000 cycles:
  (a) Mix 95% iron carbonyl — "C — Stabil" (hard)
    5% iron carbonyl A.
  (b) Treat mixture (a) with .5% sodium silicate and 7% distilled water.
  (c) Treat mixture (b) with 1.25% bakelite and 6% acetone.
  (d) Press to a specific gravity of 6.9 grams per cubic centimeter. After adding the sodium silicate, mixing is continued for 8 hours. Mixture is sieved through 1 mm. mesh.

(4) **High-frequency cores for uses up to 1 megacycle: (mixture HFC$_3$)**
- (a) 100% carbonyl iron A (soft).
- (b) Treat (a) with .5% sodium silicate and 7% distilled water.
- (c) Take 70% of mixture (b) and add 30% of carbonyl iron powder.
- (d) Treat mixture (c) with 5% "Neoresit" and 6% acetone.
- (e) Press to an approximate density of 5 grams per cubic centimeter.
- (f) Resulting ring permeability 15.

(5) High-frequency iron cores for uses up to 150 megacycles (mixture HFD$_3$)
- (a) 100% carbonyl iron powder A.
- (b) Treat (a) with 1% sodium silicate and 7% distilled water.
- (c) Add to (b) 5.5% Kaolin and mix intimately.
- (d) Treat mixture (c) with 8.5% Neoresit and 7% Acetone.
- (e) Press to an approximate density of 5 grams per cubic centimeter.
- (f) Resulting ring permeability 9.

Production Methods. - - AEG uses mechanical presses of 4—5 ton capacity with pressure applied from the top only. For larger cores hydraulic presses up to 1500 ton capacity were employed.

Most of the iron cores are pressed cold and subjected to a subsequent heat treatment. The types of heat treatment are as follows:

V = Pre-hardening
  6 hours to bring to temperature
  10 hours at 120° C
  Air cooling
V$_{80}$ = Pre-hardening at 80° C
H = Hardening
  4 hours to bring to temperature
  12 hours at 140° C
  Air cooling
A = Ageing
  4 hours to bring to temperature
  6 hours at 140° C
  Oven cooling (about 12 hours)
NA = Supplementary hardening and aging
  4 hours to bring to temperature
  6 hours at 150° C
  Oven cooling
T = Impregnation
  15 minutes in bakelite-solution 1 to 10

Iron cores with threads in the bore are pressed hot (about 120° C). The core rod is screwed out after the pressed part is removed from the die.

Highly polished dies are used, made either from special steel or tungsten carbide. The dies are lubricated with tallow after each pressing operation.

The production of iron cores at AEG consumed about 55 tons of carbonyl iron per month.

Specifications. - - The specifications for high-frequency and low-frequency cores are collected in Tables IV and V and the formulae for calculating hysteresis are collected in Table VI.

4. VOGT AND COMPANY, Berlin

Materials. - - Vogt uses exclusively carbonyl iron for his cores. The grain size variations range from 2—10 micron. The finest grain size of 2—3 micron is used for very high frequencies. The iron powder is not only classified according to grain size but also according to hardness. Hard powders are generally used for cores which have low permeabilities and must operate at high frequencies while soft powders are used for cores operating at lower frequencies and requiring high permeability values.

The hard iron particles retain their globular shape in pressing, thereby making contact with each other only on a few points and retaining a high Q value. The softer iron particles press together much more readily, thereby having many points of contact. With this type of powder, high densities and permeabilities are obtainable; on the other hand, the Q value is low.

Cores from soft iron powders are used up to frequencies of 100,000 cycles with ring permeability values of 15—55. Cores from hard iron powders are used from 100,000 cycles to 15 megacycles with ring permeability values varying from 5—15.

Insulation of Powders. - - For insulation of the iron powder particles phenol resins are employed, the percentage of solid resins in the mixture amounting to 5 percent. In certain cases a lower percentage is used and it may be as low as 1 percent for cores where highest densities are desired. Solvents for resins are acetone, methanol, or similar liquids. Iron cores bonded with phenol resins will stand temperatures up to 150° C.

Production Methods. - - Both mechanical and hydraulic presses are used. Pressure was applied from one side only. Pressing is carried out either hot or cold. Hot pressing is frequently employed for complicated shapes since a better powder flow can be obtained.

For cores which have threads on the circumference a double pressing operation is applied. In the first operation small slugs are pre-pressed on a mechanical press (rotary or tablet press). This pressing is carried out cold. These slugs are inserted into a small foot-operated hot press into collapsible dies where they obtain the final shape as well as the threads. One or several of the pre-pressed slugs may be used for the hot re-pressing operation depending on the length of the desired iron core. The several slugs are automatically bonded together with the phenol resin at the elevated temperature during re-pressing.

The use of iron powder for cores amounted to about 7,000—8,000 kilos per month.

Specifications. - - The specific gravity values of the finished cores are about 4.8—4.9 grams per cubic centimeter for ring permeabilities of 40 to 50.

Vogt's method of obtaining cores of consistent quality and uniformity was by selection of cores from production runs into a number of specific groups showing only minute deviations from each other.

TABLE I

Compilation of the Most Common Mixing Processes for Iron Core Manufacture

	1. Pre-insulation				2, 3, and 4. Pre-insulation		%	Main-insulation (Ring cores)					
Core-material	% Solid sodium silicate or sugar sodium silicate	Time temp. water addition	Drying	Milling (Minutes)		Milling	Bakelite solid ingredients	% Porcelain powder	Ethyl Alcohol Addition	Time temp.	Drying	Milling	Time of storage until pressing
Fs 55 Fks 55 67/33 Ak 49	¼% Sodium silicate	About 4 1/2 - 5 hours at 60-65° C; water addition, total about 8 liters	About 7 hours at 90° C raked thoroughly after 3 hours calm air or circulating air	In Ball Mill			1/4	-	3-4 Ltr.	At room temperature about 30-45 min.	About 7 hours at 45°, 1x thoroughly raked through after about 3 hours	Alexander Mill	Storage at room temperature up to 5 days
As 39	¼ Sod. sil.						7/8	-	3 Ltr.				
Fs 30	¼ " "						3	-	1/2 Ltr.				
JDs 21 50/50	¼ " "						3 1/4	-					
Ds 18	1/6 " "						3 1/4	-					
Ks 14	1/6 " "						3 1/4						
Krs 12	¼ " "		circulating air, if possible	Roller Mill 10 to 15'	Insulation like 1. careful water addition at 3 & 4, insulation. Prior to main insulation store for 3 days in dry room.	Milling of 3 and 4 insulation each 30 min.	4	-				Roller Mill 30-40 min.	
Ky 7	Sugar sod. sil. 1%			20'		Milling for 30 min.	5% 5% At first for 30 min. only porcelain chips then for 20-30' with 2% bakelite 5% 20%						
Ky 4	1% "			20'									
DPe 6 ca 75/25	Sod. sil. ¼%						After addition of 15% Trolitul III clear as glass, extruded in Isoma machine.						

A liquid resin "Durophen" is lately used instead of bakelite for cores. "Durophen" is no solution, can therefore be regarded as solid ingredient. Fv 30: Durophen 330 v, 4%, Kv 14: Durophen 309 w. No oven drying.

TABLE II

A. Mixing specification for pre-insulation of D-powder

Composition: 100 parts of weight of D-powder
$^{1}/_{2}$ part of weight of technical sodium silicate in solid ingredients (Na-silicate about 40° baume)

Mixing sequence:

Sodium silicate (dilution: 1 part sodium silicate, 3 parts of water) is added to the D-powder in the cold mixer. As required (about 3—5 liters) water is added during the mixing process until a thin solution is obtained. The mixture is kneaded for 3.5 hours at a temperature of about 70° C. The heating is to be discontinued after 3 hours. After mixing and kneading the material is dried for 12 hours without interruption in a recirculatingair-oven at 70° C admitting fresh air continuously.

The material after drying is crushed for about 30 minutes or it is ball milled to a fine powder and sieved. (Sieve 160—200 meshes per inch.)

Storage

The pre-insulated D-powder thus obtained is to be kept at about 30—50° C.

Marking

The barrels containing pre-insulated powder are to be marked with "01".

Mixture example:

60 kg. iron powder "D"
750 gm. sodium silicate

B. Mixing specification for manufacture of Sirufer 4 (main insulation)

Composition: 100 parts of weight pre-insulated D-powder according to Table 2, A.
15 parts of weight Troliful III (clear)
1 part of weight transformer - or spindle oil
20 parts of weight old material Sirufer 4

Mixing sequence:

The pre-insulated D-powder must be dry and be prepared according to Table 2, A. The commercial Troliful III is ground prior to its use and sieved to a maximum of 1 mm. granular size. 100 parts of weight of preinsulated D-powder are to be mixed at first with 15 parts of weight of Troliful in the cold mixer for $^{3}/_{4}$ of an hour. Following, one part of weight of transformer or spindle oil is added and mixed for another $^{3}/_{4}$ of an hour. 20 parts of weight of old material are finally added to this mixture and mixed for $^{1}/_{4}$ of an hour.

Storage:

The powder ready to be extruded is to be stored at 30—50° C.

Marking:

The barrels are marked with "Sirufer 4".

First mixture example:

(without old material)
36 kg of pre-insulated D-powder
5.4 kg. of Troliful III
.36 kg. of transformer or spindle oil

Second mixture example:

(with old material)
30 kg. of pre-insulated D-powder
4.5 kg of Troliful III
.30 kg. of transformer or spindle oil
6 kg. of old material Sirufer 4

TABLE III

Mixture Siemens Designation	μ	Mean TK* (°/₀₀/°C 15 to 45°)	TK* Curve	Time Const. Drop °/₀₀		Loss Values 800 Hertz		Spec. Gravity	Heat resisting up to
					h	n	w	g/cc	
Fz 55 a)	53 to 57	+4	Curved	2 to 5	40 to 60	6 to 9	0.15	7.5	130°
Az 49 b)	47 to 50	+3.5	Curved	ca 3	25 to 40	5 to 8	0.1	7.3	130°
JDz 21 c)	20 to 22	—0.1 to 0	Sharply curved	2	4.5	4			130°
Dz 18 d)	16.5 to 18	—0.15	Curved	2	3	1	0.03	5.6	130°
Kz 14 e)	14 to 15	—0.1	Curved	2	1.5	0.7	0.015	5.6	130°
Krz 12 (Krv 12)	11.5 to 12.5	+0.10 to +0.18	Straight		2 to 5	1.5	0.015		130°
Ky 7	ca 7	—0.05	Curved	0.5				4.8	130°
Kz 7	ca 7	—0.02 to —0.05	Straight		0.65	0.5	0.005		70°
D Po 6	ca 6	—0.02 to —0.05	Straight	0.2					70°
D 6	ca 6	—0.10 to —0.15	Straight						70°

---

* TK temperature coefficient. The symbol ‰ means per thousand

a) Corresponds to I. G. powder C normal.

b) " " " " C stabil.

c) " " " " PE.

d) " " " " E.

e) " " " " H.

TABLE IV

GRADES OF IRON CORES

1. High-frequency iron

Designation	Ring µ	Spec. Gravity	Manufacturing Method		Heat Treatment (See below)
			Ring Cores	Form Cores	
HF — A 1	40	7.1	Hydraulic	—	H—T—A
HF — A 2	55	7.4	Hydraulic	—	V_{80} (x 2)
HF — B 1	20	5.6	—	Mech.	V (x 2)
HF — B 3	22	6.1	Hydraulic	—	V—H—T—A
HF — C 1	12	5.5	Hydraulic	—	V—H—T—A
HF — C 2	12	4.9	—	Mech.	V (x 2)
HF — C 3	15	5.3	—	Hydr. Mech.	V—H—NA
HF — C 4	18	5.8	—	Mech.	V—H—A
HF — C 6	12	5.4	Hydraulic	—	V—H—T—A
HF — D 3	9		—	Mech.	V—H—A
HF — Z 1	12	5.3	Hydraulic	—	V—H—T—A
HF — Z 2	12	5.3	Hydraulic	—	V—H—T—A

2. Low-frequency iron

Designation	Ring µ	Spec. Gravity	Ring Cores	Form Cores	Heat Treatment (See below)
NF — a 1	25	6.2	—	Hydr. Mech.	V—H—A
NF — a 2	48	7.2	Hydraulic	—	H—T—A
NF — a 3	60	7.5	Hydraulic	—	H—T—A

HEAT TREATMENT OF IRON CORES

V = Pre-hardening: 6 hrs. warming up; 10 hrs. temperature 120° C.; air cooling.

V_{80} = Pre-hardening at 80° C.

H = Hardening. 4 hrs. warming up; 12 hrs. temperature 140° C.; air cooling.

A = Aging: 4 hrs. warming up; 6 hrs. temperature 140° C.; furnace cooling (about 12 hrs.).

NA = Reheating and Aging: 4 hrs. warming up; 6 hrs. temperature 150° C.; furnace cooling (about 14 hrs.).

T = Insulating Mixture: 15 min. in Bakelite solution 1:10.

TABLE V

MAGNETIC MATERIALS

(a) Iron Cores

Designation	μ	h cm/kA¹)	n ⁰/₀₀	w μ s	TK²) $10^{-3}/1^{0}$ C.	Spec. Gravity g/cc
HF/A_1	40—50	40	8	0.07	+ 0.4	6.9
HF/A_2	55—69	60	12	0.06	+ 0.35	7.1
NF/a_2	48—60	55	11	1.20	+ 0.5	7.0
NF/a_3	60—75	65	18	4.20	+ 0.6	7.2
HF/B_2	22—27.5	8.1	5	0.07	+ 0.07	6.1
HF/C_1	12—15	1.4	1.0	0.015	— 0.05	5.2
HF/C_6	12—15	2.5	1.2	0.02	— 0.05	5.2
HF/D_2	8—10	0.5	0.7	0.01	— 0.02	4.7

(b) Band iron cores of 40% nickel iron

Isoperm Cu 0.06 mm.	55—69	45	12	2.4	+ 0.8
Isoperm Cf 0.045 mm.	80—100	45	12	1.2	+ 0.8
Nicalloy 0.10 mm.	90—150	300	40	6	+ 1.0

1) Mean values ± 15%.

2) Temperature coefficient measured on ring-core coils.

Reference equations: $r_h = h.\,f.\,L.\ \gamma\, i$ . . . . Ohm

$r_h = n.\,f.\,L.$: . . . . Ohm

$r_w = w.\,f.^2\,L.$: . . . . Ohm

in which f = frequency in kiloherts

L = inductivity in H

γ i = field strength in A $_{eff}$/per centim

TABLE VI

Hysteresis

1. Hysteresis-numeral

$$H = \frac{h}{\sqrt{\mu}} \cdot \frac{L^{3/2}}{V^{1/2}} \cdot 8910 \quad \dots\dots \quad \Omega/A$$

2. Hysterisis-measure

$$H_0 = K \cdot \sqrt{L} \quad \dots\dots \quad \frac{\Omega/H}{mAw/cm}$$

$$K = 8.91 \cdot \frac{h}{\sqrt{\mu}} \cdot \frac{1}{\sqrt{V}}$$

h = hysteresis constant . . . . $\frac{\Omega/H}{Aw/cm}$

μ = permeability

L = inductivity . . . . H

V = volume of core . . . . cm^3

3. Conversion

$$H_0 = K \cdot \sqrt{L} = \frac{H}{L} \cdot 10^{-3} \quad \dots\dots \quad \frac{\Omega/H}{mAw/cm}$$

$$H = H_0 \cdot L \cdot 10^3 = K \sqrt{L} \cdot L \cdot 10^3 \quad \dots\dots \quad \Omega/A$$

$$K = \frac{H \cdot 10^{-3}}{\sqrt{L} \cdot L}$$

4. Hysteresis constant

$$h = \frac{H \cdot l_m}{L \cdot n} = \frac{H \cdot V^{1/2} \cdot \sqrt{\mu}}{L^{3/2} \cdot 8910} \quad \dots\dots \quad \frac{\Omega H}{Aw/cm}$$

l_m = mean distance of lines of force

n = number of windings

5. Hysteresis factor

$$h_0 = \frac{h}{\sqrt{\mu}} \quad \dots\dots \quad \frac{\Omega/H}{Aw/cm}$$

6. Hysteresis measurements

a. Measured at the Dekaden bridge

$$h = \frac{\Delta R_w \cdot 10^3 \cdot l_m}{\Delta i \cdot L \cdot n} \quad \dots\dots \quad \frac{\Omega/H}{Aw/cm}$$

$$H = \frac{\Delta R_w \cdot 10^3}{\Delta i} \quad \dots\dots \quad \Omega/A$$

$$H_0 = \frac{\Delta R_w}{\Delta i \cdot \sqrt{L}} \cdot L \cdot \sqrt{L} \quad \dots\dots \quad \frac{\Omega/H}{mAw/cm}$$

ΔR_w (r_h) = Resistance-difference

Δi = Current-difference

TABLE VI (Continued)

b. Measurement of the Busch-compensator

$$h = \frac{(\triangle m \, . \, \Omega/mm) \, . \, 1m}{2 \quad L \, . \, n} \dots\dots \quad \frac{\Omega/H}{Aw/cm}$$

$$H = \frac{(\triangle m \, . \, \Omega/mm)}{2} \dots\dots \quad \Omega/A$$

$$H_0 = \frac{(\triangle m \, . \, \Omega/mm) \, . \, 10^{-3}}{2 \, . \, \sqrt{L} \, . \, L} \dots\dots \quad \frac{\Omega/H}{mAw/cm}$$

$\triangle m$ = distance of the sliding wire in millimeter at current-change of 2mA

Ω/mm = resistance of the sliding wire per mm ($\triangle m \, . \, \Omega/mm = r_h$)

7. Calculations

$$H = \frac{h \, . \, n \, . \, L}{1m} \dots\dots \quad \Omega/A$$

$$\left.\begin{aligned} h &= \frac{H \, . \, 1m}{L \, . \, n} \dots\dots \\ h &= \frac{H_0 \, . \, 1_m \, . \, 10^3}{n} \dots\dots \end{aligned}\right| \quad \frac{\Omega/H}{Aw/cm}$$

$$K = \frac{h \, . \, n}{\sqrt{L} \, . \, 1m \, . \, 10^3}$$

$$\frac{H1}{H2} = \sqrt{\frac{L_1^3}{L_2^3}} = \sqrt{\frac{V_2}{V_1}}$$

Amount of coil-loss r_h at $i = 0.5$ mA from H resp. H_0

$$\left.\begin{aligned} rh &= \frac{H}{1000} \cdot 0.5 = \frac{H \, . \, 10^{-3}}{2} \dots\dots \\ r_h &= H_0 \, . \, L \, . \, 0.5 = \frac{K \, . \, \sqrt{L} \, . \, L}{2} \dots\dots \end{aligned}\right| . \quad \Omega$$

Hysteresis numeral H, resp. hysteresis measure H_0 from r_h

$$H = \frac{r_h \, . \, 10^3}{i} \dots\dots \quad \Omega/A$$

$$H_0 = \frac{rh}{L \, . \, i} \dots\dots \quad \frac{\Omega/H}{mAw/cm}$$

$$K = \frac{rh}{L \, . \, \sqrt{L} \, . \, i}$$

Angle of hysteresis loss:

$$tg = \frac{r_h}{\omega L} \cdot \frac{h}{\xi i \, . \, \omega_i} \, . \, \xi$$

ξ_1 = relative field strength = 1 Aw per cm

ω_1 = relative frequency = 5000

ξ = measuring field strength = $\frac{n}{1_m} \, . \, i \dots$ Aw/cm

ω = measuring frequency