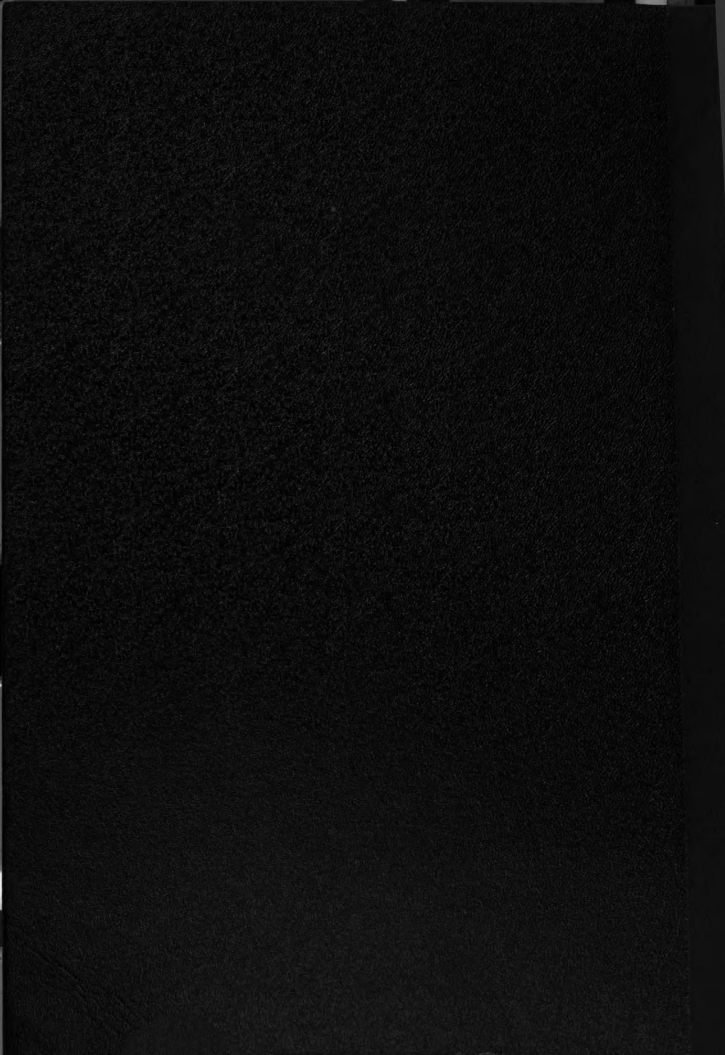




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RADIO FREQUENCY HEATING
APPLIED TO MAGNETIC AND NON MAGNETIC
CYLINDRICAL CONDUCTORS

THESIS FOR DEGREE OF M. S.
MICHIGAN STATE COLLEGE
ALDO A. CACAVELOS
1948



This is to certify that the
thesis entitled
Radio Frequency Heating
Applied to Magnetic and Non Magnetic
Cylindrical Conductors
presented by

Aldo A. Cacavelos

has been accepted towards fulfillment
of the requirements for

M.S. degree in E.E.


Major professor

Date May 14, 1948

THESIS

RADIO FREQUENCY HEATING APPLIED TO
MAGNETIC AND NON MAGNETIC CYLINDRICAL
CONDUCTORS.

By
ALDO A. CACAVELOS.

A THESIS

Submitted to the school of Graduate Studies
of Michigan State College of Agriculture and
Applied Science in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE.

Department of Electrical Eng.

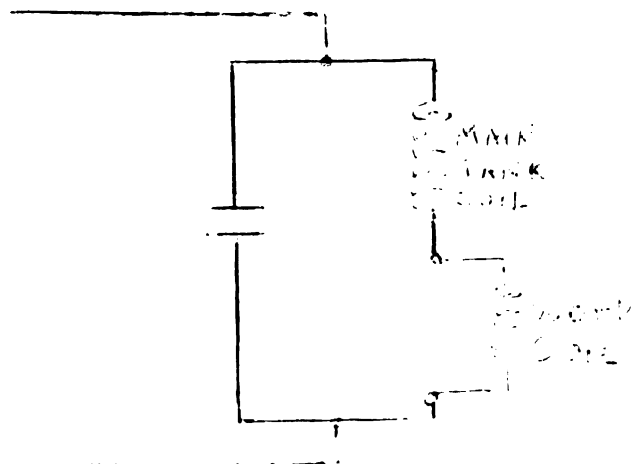
1948

THESIS

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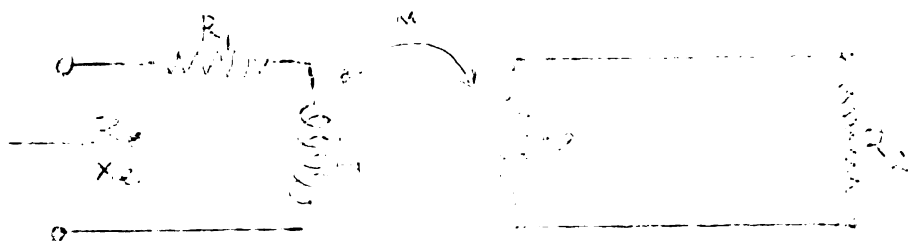
The objective of this thesis is the study of the application of induction heating principles to the heating of several metallic pieces to obtain the desired results. By means of the formulas that will be presented later, the circuit requirements are calculated and suitable coils designed to accomplish a determined purpose, namely, to heat the material up to T degrees Farenheit in t seconds.

One of the sources of trouble in induction heating is the variation of the resistivity of metals with temperature. This effect causes the load power to vary and therefore the reflected impedance due to the load, and the Q of the work coil. As a consequence, the Q of the tank circuit, the tank voltage, and current change too. This can be best understood by inspection of the circuit diagram.



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Considering the circuit shown as equivalent to the actual circuit, we can write



Work coil	Metal to be heated.
$R_e = R_1 + \frac{(WM)^2 R_2}{R_2^2 + (WL_2)^2}$	(1)
$X_e = X_1 - \frac{X_2 (WM)^2}{R_2^2 + (WL_2)^2}$	

Therefore, there is always an increase in resistance due to the secondary circuit and a decrease in reactance. It must be well understood that the original reactance, X_1 , to be considered, has the same magnetic circuit as the actual one with the only difference that the secondary circuit is open circuited.

Thus, in the case of heating a copper tubing, X_e is measured with the tubing inside the coil, and X_1 without the tubing. The experiment shows that X_e and R_e are 1.93 Ω and 0.161 Ω , X_1 and R_1 being 2.41 and 0.160 Ω .

The problems dealing with magnetic loads are somewhat more complicated, although the variation of R

follows the same behavior. In this case X_1 would be the coil with the magnetic core inside but not allowing any secondary current to flow. This is certainly not the same reactance as that measured with the coreless coil and can be thought of as the same coil with a laminated core of the same permeability. This way, starting from the coreless coil reactance X_0 we can obtain X_e in the following steps:

- 1) - Coreless coil X_0
- 2) - Same coil with ideal laminated core
 $X_1 = X_0 \mu$
- 3) - Same coil with actual core:

$$X_e = X_1 - \frac{X_2 (WM)^2}{R_2^2 + X_2^2} = X_0 \mu - \frac{X_2 (WM)^2}{R_2^2 + X_2^2}$$

The following experiments show that $X_e > X_0$ and of course that $R_e > R_1$.

In all the problems on induction heating, the variation of the resistivity of the load plays an important part. While the computations on ω - f - power deal with the resistivity that corresponds to the average temperature of the material to be heated, the design of the tank circuit must be made considering the minimum Q , that is the maximum resistance R_e of the circuit. Formula (1) says that this corresponds to the maximum resistivity of the core. During the operation, changes in R_2 due to the temperature, produce changes in R_e and therefore in the Q of the main tank. This, in turn,

causes the tank voltage and current to change and as a consequence the D.C. plate voltage must be adjusted continuously to keep a constant tank current and so a constant magnetizing force. All this will be illustrated later with the aid of vector diagrams.

CALCULATION OF REQUIRED MAGNETIZING FORCE

"Radio Frequency Heating" by Brown, Hoyles and Blerwith, on page 29, gives the following general formula for heating cylindrical conductors.

$$P = \frac{30 H_0^2 \sigma}{\pi \delta} F \quad \text{c.g.s. rationalized practical system of units.}$$

When: P = Watts per unit length

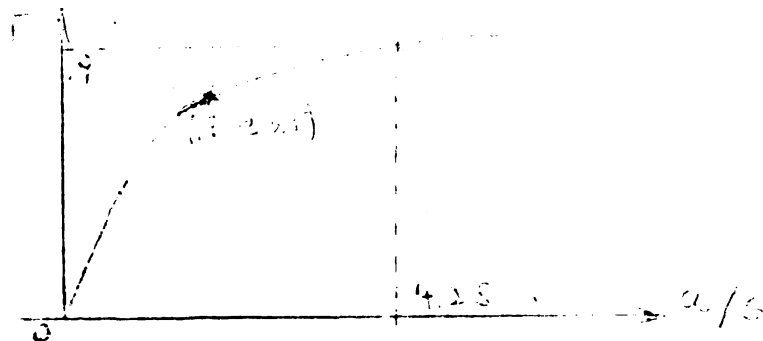
H_0 = magnetizing force of the coil without the core.

σ = conductivity.

a = radius of cylinder

δ = skin depth in the cylinder

F = a function of several Bessel's functions plotted in the following graph:



In all the experiments performed in connection with this thesis a/δ was much higher than 5 and so we can set

F equal to one.

$$P = \frac{8 \pi H_0^2}{G} \cdot \frac{a}{s} \quad \text{watts per cm length.}$$

The power density (watts per cm cube), becomes:

$$(1) \text{ PD} = \frac{8 \pi H_0^2}{G} \cdot \frac{a}{s} = \frac{8 H_0^2}{G a s} \quad \text{watts/cm}^3$$

$$(2) \text{ But } \frac{1}{S} = \frac{1}{2 \pi \sqrt{10^{-9} \mu_0 \mu_r}} \quad \text{cm (Brown's page 17)}$$

Therefore;

$$(3) \text{ P.D} = \frac{8 \pi H_0^2}{G} \cdot \frac{1}{2 \pi \sqrt{10^{-9} \mu_0 \mu_r}} = \frac{157 \cdot 10^{-9} H_0^2}{G \mu_r} \cdot \sqrt{\frac{1}{\mu_0 \mu_r}}$$

From here on we will analyze separately the magnetic and non-magnetic materials.

MAGNETIC MATERIALS

By definition

Therefore:

But since induction heating is accomplished under saturation conditions -

B = constant

and: $\mu_r = \frac{B}{\mu_0 H}$ Where $H = \frac{B}{\mu_0 \mu_r}$

$$\text{Therefore: P.D} = \frac{157 \cdot 10^{-9} H_0^2}{G \mu_r} \cdot \sqrt{\frac{1}{\mu_0 \mu_r}}$$

where ρ is the resistivity of the material

$$P.D = \frac{4 \times 10^{-15} \times 10^8}{2} = 2 \times 10^{-7}$$

Where

$$C = \frac{R H^2 \times 10^8}{2}$$

and

$$R = 1.5 \times 10^{-8} \times 10^8$$

The variation of P with the temperature causes the energy input to vary continuously so that the total energy input per cubic cm is:

$$E = \int_0^{T_{max}} P dT = C \int_0^{T_{max}} P dT$$

Assuming now that the temperature increases linearly with time and neglecting the initial value, we can write:

$$t^0 = K^1 t \text{ sec.}$$

Assuming also that the resistivity increases with temperature following a straight line through the origin, we can write:

$$\rho = K_1^1 t^0 = K_1 t \text{ sec}$$

$$\text{Where } K_1 = K_1^1 \times K^1$$

This assumption is not very far from the actual conditions as can be seen from the corresponding graph of $\rho = f(t^0)$ Fig. (1). Besides, as far as power computations are concerned, it yields acceptable results since the main contributions of energy are effected at higher values of ρ when it approaches the straight line closely enough.

Under these conditions we can write:

$$E = C \int_0^{T_{max}} P dT = C \int_0^{T_{max}} \frac{2}{T} \left(\frac{T}{T_{max}} \right)^{1/2} dT = C \int_0^{T_{max}} \frac{2}{T^{1/2}} dT = 4C \int_0^{T_{max}} \frac{1}{T^{1/2}} dT$$

But $\rho_{\max} = K_1 T_{\text{sec}}$. Therefore:

$$E = G \cdot \left(\rho_{\max} \frac{2}{3} \right) T_{\text{sec}}$$

If ρ is a linear function of temperature, as has been assumed, then:

$$\rho_{\max} = 2 \rho_{\text{average}}$$

Therefore:

$$E = G \times 0.945 \sqrt{\rho_{\text{ave}}} T_{\text{sec.}} = \frac{0.945 K H_0^{3/2}}{a} (\rho_{\text{ave}}) T_{\text{secs}}$$

However:

$$E = (PD)_{\text{ave}} \times T_{\text{secs.}}$$

So:

$$(P D)_{\text{ave}} = \frac{0.945 K H_0^{3/2}}{a} \sqrt{\rho_{\text{ave}}}$$

Hence:

$$H_0 = \left(\frac{(P.D)_{\text{ave}} a}{(0.945 \cdot K \cdot \sqrt{\rho_{\text{ave}}})} \right)^{2/3} \quad \text{cgs rationalized system of units}$$

The value of $K = 159 \times 10^{-5} \frac{B}{H_0}$ depends upon the magnetic induction of the material at saturation and, of course, it changes if we change the system of units.

For ferrous materials, "Electronic for Industry" by Bendz gives:

$$H_0 = \left(\frac{PD \times d}{0.438 \sqrt{\rho_{\text{ave}}}} \right)^{2/3} \quad \text{oersteds}$$

Where:

$P D$ = watts/cubic inch

d = diameter in inches

ρ = resistivity in Ω inches

H_0 = peak magnetizing force (oersteds)

μ = relative permeability

B = magnetic induction (Gausses)

The condition

$$\frac{a}{s} = \frac{d}{s} \geq 4.25 \quad (\text{to make } F \approx 1) \quad \text{expressed}$$

in these units becomes

$$\frac{d(\text{inches})}{s(\text{inches})} = \frac{d}{3170 \sqrt{\frac{\rho_{ave}}{\mu f}}} = \frac{d}{3170} \sqrt{\frac{\mu f}{\rho_{ave}}} \geq 4.25$$
$$d \sqrt{\frac{\mu f}{\rho_{ave}}} \geq 13400$$

The value of μ to be used in these formulas was found from experimentation (Bendz's, page 298) to be:

$$\mu = 1.8 \frac{B \text{ saturation}}{H_0} = 1.8 \times \frac{18000}{H_0} = \frac{32400}{H_0}$$

NON-MAGNETIC MATERIALS

Letting μ_r equal unity, equation (3) becomes:

$$P.D = \frac{159 \times 10^{-5} \times H_0^2}{a} \sqrt{\rho \times l}$$

Under the same assumptions done before, the following final formula can be obtained (Bendz's 304)

$$H_0 = \sqrt{\frac{P D \times d}{2.59 \times 10^{-3} \sqrt{l \rho}}} \quad \text{oersteds}$$

Where, as before:

d = diam. in inches

ρ = resistivity, $\sim$ inches

f = frequency, cpo.

The condition $\frac{a}{s} \geq 4.25$ becomes:

$$d \sqrt{\frac{f}{R_{\text{sol}}}} \geq 13.4 \text{ cm}$$

SELECTION OF FREQUENCY

The original formula

$$P = \frac{2\pi^2 f^2}{9} \left(\frac{a}{s} \right)^2 \quad (1)$$

and the plot of F as a function of $\frac{a}{s}$ shown before, show that increasing $\frac{a}{s}$ in the range 0-2.25 (by increasing frequency) causes a high increment of F and therefore P .

When $\frac{a}{s}$ reaches 2.25, F reaches 0.8 and approaches saturation. Therefore, we can define a minimum frequency (for $\frac{a}{s} = 2.25$) for which the coupling of energy is efficient.

In fact, let's analyze the variation of the ratio "power absorbed in the core to power lost in the exciting solenoid" as a function of F .

$$E = \frac{\text{Power core}}{I^2 R_{\text{solenoid}}}$$

But

$$R_{\text{solenoid}} = \frac{R_{dc}}{2} \frac{a_{\text{sol}}}{S_{\text{sol}}} \quad (\text{Brown's, page 22})$$

Besides from (2)

$$S = \frac{A_1}{f}$$

Where the A 's are constant for a given material

Therefore:

$$R_{\text{sole}} = A_2 \sqrt{f}$$

Similarly:

$$\frac{a}{s} \text{ core} = A_3 \sqrt{f}$$

So:

$$R_{\text{sol.}} = \frac{A_4 a \text{ core}}{s \text{ core}}$$

and

$$E = \frac{\text{Power core}}{I^2 A_4 \frac{a \text{ core}}{s \text{ core}}} = \frac{\text{Power core}}{A_5 \frac{a \text{ core}}{s \text{ core}} H_0^2}$$

substituting $\frac{P}{H_0^2}$

and from (4) gives:

$$E = K_1 F \quad \text{If } \frac{a}{s} > 2.25 \quad F \text{ is constant}$$

Therefore E is constant.

With higher values of frequency ($a/s > 2.25$) we couple, of course, more energy into the core (for same H_0) but the ratio E is very nearly constant and so is, of course, the efficiency.

The minimum frequency for efficient heating is, therefore:

$$\frac{a}{s} = 2.25$$

$$\text{So } \frac{a}{s} = a \cdot 2 \pi \sqrt{\frac{1}{4 \pi^2 \mu_0 \mu_r}} = 2.25 \text{ (cgs rationalized units)}$$

$$f_{\text{min}} = \frac{128.5 \times 10^6}{4 \pi^2 \mu_0 \mu_r}$$

In the specific case of the piece of iron that will be heated in the 1st experiment we have:

$$f_{\text{min}} = 26000 \frac{1}{\text{min}} \quad (\text{to obtain the higher } f_{\text{min}})$$

$$\mu_r = 938$$

$$d = 0.5" = 1.25 \text{ cm}$$

Therefore:

$$f_{\min} = \frac{128.5 \times 10^6}{26000 \times 938 \times 1.56} = 3.4 \text{ c/s}$$

The critical frequency to heat a 0.5" diam. copper cylinder is:

$$f_{\min} = \frac{1}{2\pi} \sqrt{\frac{\mu_r}{\epsilon_r}} \times \frac{1}{d} = \frac{1}{2\pi} \sqrt{\frac{938}{1}} \times \frac{1}{1.25 \times 10^{-2}} = 3.4 \text{ c/s}$$

The equipment used to conduct the experiments has a frequency of 350 KC, thus obtaining the highest possible efficiency for a given material and work coil. The object of using so high a frequency is to couple more power into the core for a given circuit.

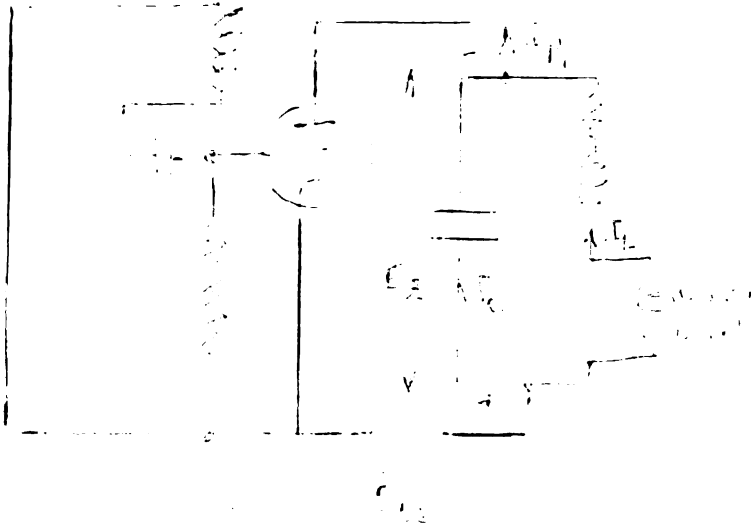
EQUIPMENT AND VECTORIAL DIAGRAMS

The equipment used during the experiments was a 1 KW, 20 amp. tank current, Westinghouse Generator. The equipment is so designed that we can obtain two different frequencies by changing the connections.

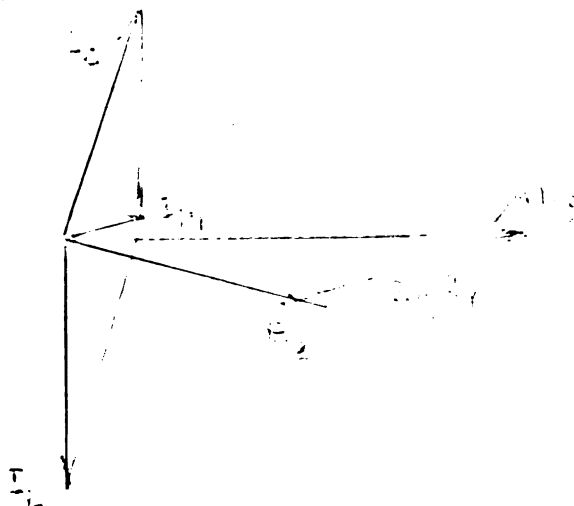
- a) Hartly circuit - For dielectric heating with a frequency of 10 M c/s.
- b) Feedback oscillator - For induction circuit with a rated frequency of 300 KC.

The experiments were run with the oscillator set in (b) and the frequency was checked to be 350 KC.

Essentially the circuit is as shown below:



The vectorial diagram can be drawn for the tank circuit as follows:



When the material to be heated is introduced in the work coil, it has been found that Q decreases due to the reflected resistance as has already been explained. This produces a slight shift in the vector diagram but the main effect is that the current I_L decreases.

In fact, the impedance of the tank circuit at resonance is:

$$R_T = \frac{1}{C \omega^2}$$

so, if R increases R_T decreases and, for the same plate current, E_T decreases too. This causes I_L and I_C to decrease.

When the material is being heated the reflected resistance changes continuously due to the variation of resistivity of the core with temperature which causes the above mentioned change to take place. As a result, if a constant magnetizing force (constant I_L) is desired, the anode supply voltage E_{bb} must be continuously adjusted.

The measurements of temperature were made with two iron constantan thermocouples whose calibration curves are attached, Fig.(2). The 1st couple was used during the 1st experiment and the 2nd one was used in the others.

HEATING SEVERAL SAMPLES OF LOW CARBON STEEL

The following specific heat and resistivity data was obtained from the "Handbook for Metallurgical Engineers".

<u>SWEDISH IRON</u>						
<u>°F</u>	<u>S HEAT</u>	<u>DENSITY</u>		<u>RESISTIVITY</u>		
68	.1075	70°F	- 7.85			
77	.108	600	- 7.78	°C	°F	ρ
104	.1097	1200	- 7.63	0	32	13.2
140	.112			100	212	20.1
212	.114			200	390	27.4
302	.121			300	570	36.
392	.128			400	750	46.2
482	.134			500	930	58.3
572	.140			600	1110	72.
752	.151					
932	.163					
1022	.172					
1112	.188					
1200	.208					

So the following average specific heat values were obtained for different ranges:

70°F - .1075 BTU/pound °F = small col/
 70 - 200 - .111
 70 - 600 - .124
 70 - 1200- .143

EXPERIMENT #I

Piece of iron (0.2% Carbon) 5.25" long,
0.5" diam. to be heated from 70°F up to
600°F in 1 minute.

1) Calculation of Thermal power required:

$TP = 17.6 MC \Delta T$ where:

M = rate of material to be heated per minute
(in pounds/minute).

C = average specific heat in BTU/pound °F

ΔT = temperature variation in °F

In this case it is:

$$Vol. = 1.03 \text{ cu. inch}$$

$$\text{Density at } 70^\circ\text{F} = 7.85 \frac{\text{gr}}{\text{cm}^3} = .284 \frac{\text{pound}}{\text{cub. inch}}$$

Hence:

$$M = 1.03 \times 0.284 = 0.292 \frac{\text{pound}}{\text{minute}}$$

Besides

$$C_{70-600} = 0.124$$

Therefore:

$$\begin{aligned} \text{Thermal power} &= 17.6 \times 0.292 \times 0.124 \times 530 \\ &= 338 \text{ watts.} \end{aligned}$$

2) Radiation, convection and conduction losses.

Conduction losses are very small because the piece is held by two 0.1" diam. pivots fixed one at each end.

The radiation and convection losses are less than 10 watts (from Bendz's, page 301) and therefore are negligible.

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3) Power density.

$$P.D = \frac{\text{Total input (watts)}}{\text{Volume of metal in coil}} = \frac{338}{1.03} = 328 \frac{\text{Watts}}{\text{Cub.inch}}$$

4) Peak magnetizing force:

The corresponding formula for a solid magnetic cylinder is:

$$H_{\text{peak}} = \left(\frac{PD \times d}{0.438} \right)^{2/3} \text{ valid where } d$$

Where $H =$

$d =$ diameter (inches)

$\mu =$ relative permeability

$\rho =$ resistivity at average temp (335°F) =

$f =$ frequency in C/S = 350,000 C/S

As already explained, the permeability to be used in these formulas is:

$$\mu = \frac{32400}{H}$$

The magnetizing force therefore becomes

$$H_{\text{peak}} = \left(\frac{328 \times 0.5}{0.438 \sqrt{35 \times 10^{-4} \times 10 \times 10^{-6}}} \right)^{2/3} = 200^{2/3} = 34.5$$

$$\mu = \frac{32400}{34.5} = 938$$

The condition

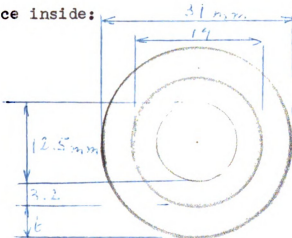
$$\frac{d}{\sqrt{H}} = \frac{0.5}{\sqrt{34.5}} = 0.084 \text{ inches} \leq 0.1 \text{ inches}$$

is satisfied.

5) Coil design:

The coil was designed to be 6.7" long so as to cover the material thoroughly. With a 19 min. interior diameter this allowed a clearance of 32 mm around the work piece. The coil was made of 19 turns of copper tubing 6 mm diameter. The outside diameter became 31

The sketch below shows the coil with the iron piece inside:



6) Coil current.

The values of H in oersteds and I in amperes are related by the following formula:

$$H = \frac{0.4 \pi N I}{l \text{ (cm)}} = \frac{0.4 \pi N I}{2.5 l \text{ (inch)}} = 0.503 \frac{N I}{l \text{ (inch)}}$$

If H is to represent the peak magnetizing force and I is expressed in terms of (rms) of a sine wave, then:

$$H_{\text{peak}} = \sqrt{2} \times 0.503 \frac{N I}{l} = 0.70 \frac{N I_{\text{rms}}}{l \text{ (inch)}}$$

Therefore:

$$I = \frac{H_{peak} \times l_{coil}}{10^8} = 1.45 \times \frac{10^2}{10^8}$$

To take account of the coil-core spacing the factor K_1 is added:

$$I = \frac{1.45 \times 10^2 \times K_1}{10^8} \quad (Bendz 312)$$

K_1 being a function of $\frac{\text{coil length}}{\text{spacing}}$

In this example the current will be:

$$I = \frac{1.45 \times 10^2 \times 1.02}{10^8} = 17.5 \text{ amp.}$$

Where for a $\frac{\text{length}}{\text{spacing}}$ ratio equal to 45, K_1 is very nearly 1.02. Hence:

$$I = \text{amp. } 18.0$$

As the rating of the equipment to be used is 1 KW, 20 amp., this experiment can be run without further complications.

The table shows the experimental results where the values of temp, I and V were measured, thus allowing the calculation of the impedance to be made:

TABLE I
Temp. (over
room temp.
Th. couple

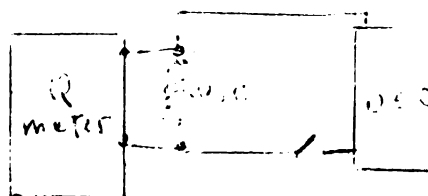
f		Secs.	I	°F	V	Z	
350	KC	10	2.5	95	61	3.3	
"	"	20	5	190	63	3.4	
"	"	30	7.5	285	65	3.51	Temp. in 1
"	"	40	9.4	360	66	3.57	minute =
"	"	50	11	420	66	3.57	515 + 70 =
"	"	60	13.5	515	66.3	3.59	585°F
"	"	90	18.2	700	69.	3.73	

To separate both, the resistive and reactive components of Z , measurements of the Q of the circuit were done by means of a Q meter. The material was heated up to a certain temperature and quickly connected to the Q meter and disconnected from the heating equipment. The same operation was repeated at different maximum temperatures.

The following data was obtained:

TABLE II

f	°F over room temp.	Q
350 KC	70	9
"	270	7
"	450	5
"	700	4
"	800	3.5
"	900	3.5



Plotting Z and Q as functions of temperatures in Fig. (4) provides a means of determining the values of R and X independently. The separation of R and X was made by means of:

$$\begin{cases} Z^2 = R^2 + X^2 \\ Q = \frac{X}{R} \end{cases}$$

Solving the above equations gives:

$$Z^2 = X^2 + \frac{X^2}{Q^2} = X^2 \left(1 + \frac{1}{Q^2}\right)$$

Hence

$$X^2 = \frac{Z^2}{1 + \frac{1}{Q^2}} \quad \begin{cases} X = \frac{Z}{1 + \frac{1}{Q^2}} = \frac{Z Q}{Q^2 + 1} \\ R = \frac{X}{Q} \end{cases}$$

The following table gives the results obtained for the first sample tested:

TABLE III

<u>°F over room temp.</u>	<u>Z</u>	<u>Q</u>	<u>X</u>	<u>R</u>
100	3.3	8.7	3.28	0.377
200	3.43	7.6	3.403	0.447
300	3.52	6.55	3.48	0.532
400	3.56	5.5	3.50	0.636
500	3.60	4.73	3.53	0.746
600	3.64	4.23	3.54	0.837
700	3.73	3.9	3.61	0.927

The same measurements were repeated for the coil alone over the range of temperature from room temperature up to the temperature that the coil attains when the material has been heated. It was found that Z and Q are constants, the values being:

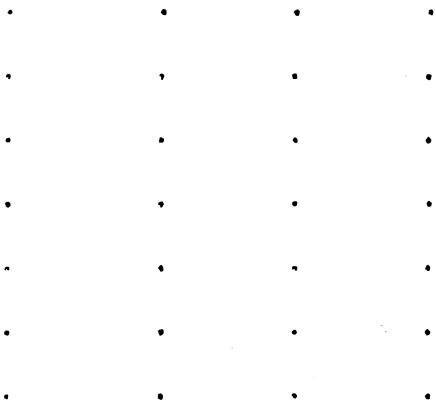


TABLE IV

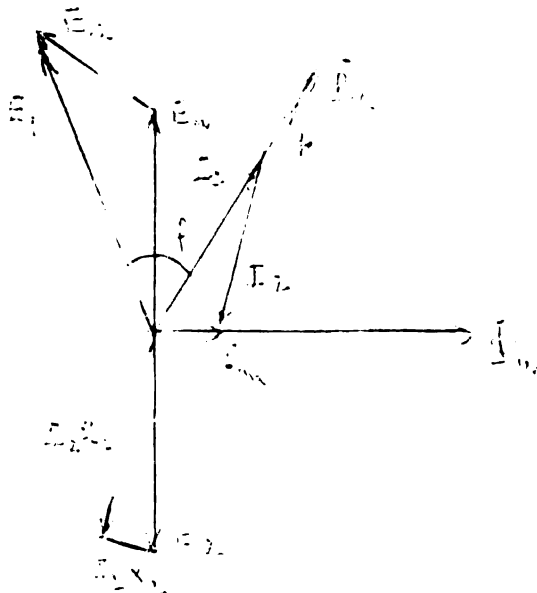
Coil Alone	Q	Z	X	R
The same range of variations of temper- ature	15	2.42	2.41	0.16

Where X and R have been calculated as before.

These curves are drawn on the same graph as the parameters of the cored coil (Fig. 4). The curves of Fig. 4 show to what extent the resistance and reactance of the coil increases when the core is set inside.

CALCULATION OF COIL VOLTAGE

The following vector diagram shows the core and coil currents and voltages and the distribution of fluxes through the core and air space:



Where:

Φ_w , E_w , flux through the work piece and corresponding emf in the coil -

Φ_A , E_A , flux through the air space and corresponding emf in the coil -

I_c = coil current

I_2 - core (secondary) current -

E_2 - secondary emf (core)

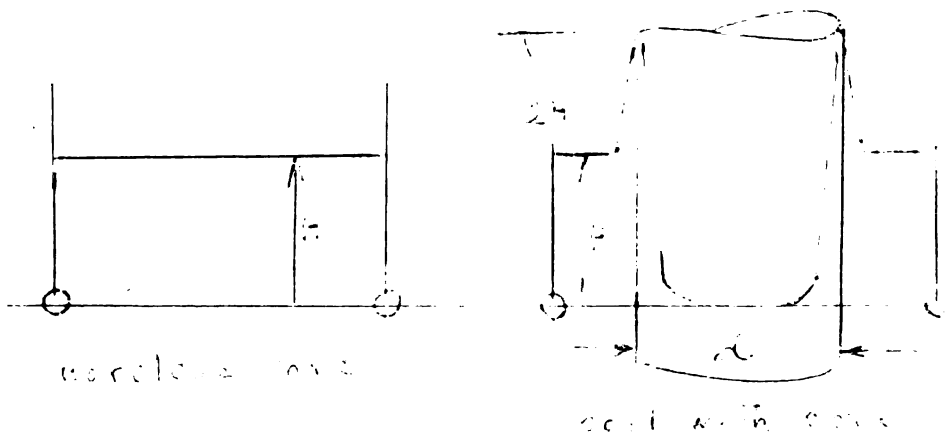
H - magnetizing force due to the coil current.

The coil current produces the magnetizing force H and the flux Φ_A in phase with it. The flux in the core Φ_w is in phase with the magnetizing current I_m .

The emf induced in the core E_2 is 90° lagging Φ_w and the core current I_2 is lagging due to the reactive characteristic of the circuit.

The primary emf E_1 is made up of two parts: E_A due to the flux in the air space, and E_w due to the flux in the work piece. Both these vectors are leading the corresponding fluxes.

The variation of H (peak magnetizing force) vs. the diameter of the coil and work piece, is shown to be (Brown, p. 28) roughly:



Therefore, the flux through the air space is

$$\bar{\Phi} = 6.45H (A_{\text{coil}} - A_w) \left(\frac{\Phi}{\text{cgs units}} \right) \quad (\Phi, B \text{ and } H)$$

Where

A_{coil} = cross sectional area coil in inches²

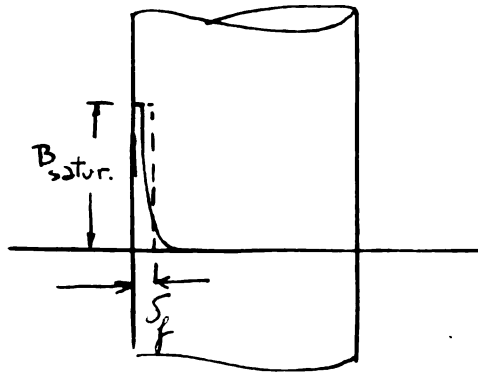
A_w = cross sectional area work piece

The flux through the work piece is calculated assuming that it penetrates the material at a constant value B (phase and magnitude constants) to a depth equal to δ below the surface. It is further assumed that the material is saturated and $B = 18000$. (See transactions AIEE Vol. 63, June 1944, p. 273).

On this basis the total flux through the material is approximately:

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$$\Phi_w = 18000 \pi \cdot d \cdot \frac{\delta_f}{f} \times 6.45 \left(\frac{\delta_f}{f} \text{ and } d \text{ in inches} \right)$$

Where

$$\delta_f = 17.6 \sqrt{\frac{H \rho_{max}}{f}} = 17.6 \sqrt{\frac{34.5 \times 14.6 \times 10^{-6}}{35 \times 10^4}} \text{ inches}$$

Where

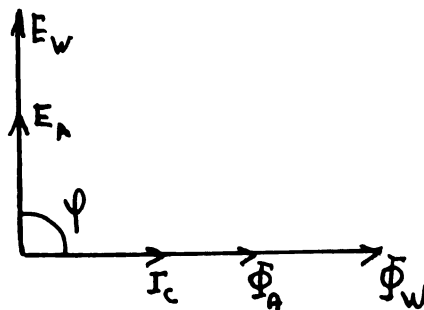
$$\rho_{max} = 37 \times 10^{-6} \Omega \text{ cm} = 14.6 \times 10^{-6} \Omega \text{ inch}$$

(Corresponds to 600°F)

So:

$$\delta_f = \frac{17.6 \times 3.8}{10^5} = 67 \times 10^{-5} \text{ inch.}$$

Under the assumptions made Φ_w is in phase with B in the surface which is, in turn, in phase with I coil. Therefore, the diagram becomes:



In this ideal diagram we are neglecting the in phase component of E_w that is small compared with the reactive component.

Now we can compute E_w and E_A .

$$E_w = j28.6 \times f \times T \times 18000 \pi d \delta_f \times 10^{-8} \quad \text{volts.}$$

$$= j 0.0162 \times f \times T \times d \times \delta_f = j 36 \text{ volts}$$

Where T = coil turns = 19. d = core diam = 0.5"

f = frequency.

The value of E_A must be calculated by means of the equivalent ideal coil. The same coil shall be discussed in connection with the heating of a non-magnetic material.

From there we get:

$$A \text{ coil} - A_w = 0.67 - 0.196 = 0.474 \text{ sq. inch.}$$

Therefore:

$$E_A = j 28.6 \times f \times T \times H \times 0.474 \times 10^{-8} = j31 \text{ volts}$$

Neglecting the internal resistance and reactance voltage drops we have:

$$E_T = j31 + j36 = j 67 \text{ volts.}$$

This value corresponds to 600°F and coincides with the one measured in the experiment.

$$\text{From there } Z = \frac{E}{I} = \frac{67}{18} = 3.73 \Omega (600^{\circ}\text{F})$$

When the core is taken out, all the voltage drop is due to the flux in the air and, assuming roughly the same current distribution in the coil, we get:

(A coil = 0.67) inch

$$\left(\begin{array}{l} \Phi_W = 0 \\ \Phi_A = 6.45H \times A_{\text{coil}} = H \times 0.67 \times 6.45 \end{array} \right.$$

Therefore; if H is kept constant (I = 18.0 amp) we get:

$$E_W = 0$$

$$E_A = j 28.6 \times f \times T \times H \times 0.67 \times 10^{-8} = j44 \text{ volts}$$

and the reactance of the coil would be:

$$X_{\text{coil alone}} = \frac{E}{I} = \frac{44}{18} = 2.44 \Omega$$

This coincides with the value obtained from the experiment.

Therefore, the introduction of the iron core increases the reactance of the coil from 2.44 Ω to 3.73 Ω at 600°F and also reflects some resistive component that can be calculated by means of the power factor:

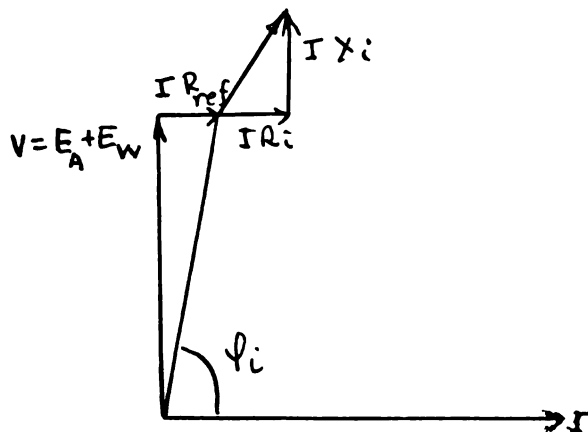
$$\text{Internal Power factor is } = \frac{\text{Input to the core (Watts)}}{VI \text{ (work coil)}}$$

Where V does not take account of the internal IR_i and IX_i drops.

$$\cos \phi_i = \frac{338 \text{ watts}}{67 \times 18} = 0.28$$

$$\cos \phi_i = 0.28$$

Where ϕ_i is the angle shown in the diagram



Therefore:

$$R_{\text{reflected}} = 3.73 \times 0.28 = 1.045 \, \Omega \quad (\text{at } 600^\circ\text{F})$$

The total resistance of the coil with the core inside is the sum of this term plus the coil resistance. This was measured and was found to be:

$$R_1 = 0.16 \, \Omega$$

Therefore:

$$R_{\text{Total}} = 0.16 + 1.045 = 1.205 \, \Omega \quad (\text{at } 600^\circ\text{F})$$

This figure differs from $0.837 \, \Omega$ found in the experiment by 30%. This is understandable if we consider how indirectly this experimental value was obtained.

The efficiency of the coil is:

$$\text{effy} = \frac{I^2 \cdot 1.045}{I^2 \cdot 1.205} \cdot 100 = 87\%.$$

and the total power factor

$$\cos \phi_T = \frac{1.205}{3.73} = 0.323$$

The above results have been plotted in graphs 2, 3 and 4.

EXPERIMENT #2

Piece of iron (0.2% carbon) 6" long, 0.37" diameter to be heated from 70°F up to 1000°F in one minute.

- 1) Calculation of required thermal power:

Again:

$$TP = 17.6 \times M \times C \times \Delta T \text{ (units as explained before)}$$

In this case:

$$\text{Volume} = 0.645 \text{ cub. inches}$$

$$M = 0.645 \times .284 = 0.183 \text{ pounds/minute.}$$

$$C = \text{average } 70 - 1000^\circ\text{F} = 0.137 \text{ BTU/pound } ^\circ\text{F}$$

Therefore:

$$TP = 17.6 \times 0.183 \times 0.137 \times 930 = 410 \text{ watts.}$$

- 2) Radiation, convection and conduction losses at maximum temperature are 17 watts (4%) and will be neglected during the calculations.

- 3) Power density

$$PD = \frac{410}{0.645} = 637 \frac{\text{watts}}{\text{cub. inch}}$$

• 1. The first step in the process of creating a new product is to identify a market need. This involves conducting market research to determine what consumers want and what problems they are trying to solve. Once a need is identified, the next step is to develop a concept for a product that addresses that need.

• 2. The second step is to create a prototype of the product. This involves designing and building a physical model of the product that can be used to test and refine the concept. The prototype is typically made from a material that is easy to work with, such as wood or plastic, and is used to demonstrate the basic functionality of the product.

• 3. The third step is to conduct a feasibility study. This involves evaluating the technical, financial, and market viability of the product. The study typically involves a detailed analysis of the costs of production, the potential revenue, and the competitive landscape. The results of the study are used to determine whether the product is worth pursuing and to identify any potential risks or challenges.

• 4. The fourth step is to develop a business plan. This involves creating a detailed document that outlines the business model, the marketing strategy, the financial projections, and the operational plan. The business plan is used to attract investors and to guide the development and launch of the product.

• 5. The fifth step is to launch the product. This involves manufacturing the product, distributing it to retailers or customers, and promoting it through marketing and advertising. The launch is typically followed by a period of monitoring and evaluation to determine how the product is performing in the market and to identify any areas for improvement.

• 6. The sixth step is to iterate and improve the product. This involves gathering feedback from customers and using it to make changes to the product. This process is typically ongoing, as the product is used and the market evolves. The goal is to create a product that is not only functional and useful but also meets the needs and expectations of the target market.

4) Peak magnetizing force:

The same formula used before applies in this problem:

$$H_{\text{peak}} = \left(\frac{PD \times d}{(0.438 \sqrt{f_p})} \right)^{2/3} \text{ valid when } d \sqrt{\frac{\mu f}{\rho}} \geq 13,400$$

The resistivity is:

$$\rho = \rho_{535^\circ\text{F}} = 34 \mu\Omega\text{cm} = 13.4 \times 10^{-6} \Omega \text{ inch}$$

Therefore:

$$H_{\text{peak}} = \left(\frac{637 \times 0.37}{0.438 \sqrt{35 \times 10^4 \times 13.4 \times 10^{-6}}} \right)^{2/3}$$

$$= (249)^{2/3} = 39.6$$

The condition

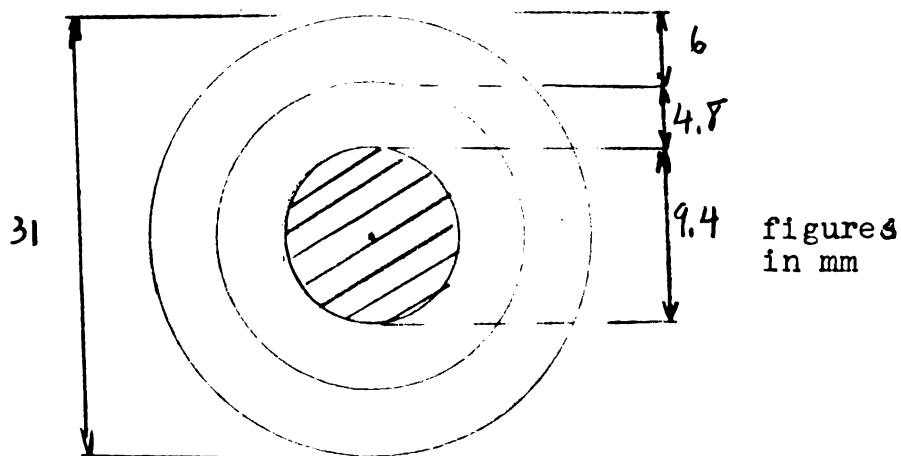
$$d \sqrt{\frac{\mu f}{\rho}} = 0.37 \sqrt{\frac{818 \times 35 \times 10^4}{13.4 \times 10^{-6}}} = 0.37 \times 10^5 \times 46$$

$$= 1,700,000 > 13,400$$

$$\text{Where: } \mu = \frac{32400}{39.6} = 818 \text{ is satisfied.}$$

5) Coil design.

The same work coil employed in the preceding problem was also used for this experiment. A sketch of the coil and core is shown below.



Coil length = 6.7", made of 19 turns of copper tubing 6 mm in diameter.

6) Coil current:

As in the preceding example:

$$I = \frac{1.43 \times H_{\text{peak}} \times l \text{ (inch)}}{N} K_1$$

Where K_1 for a ratio:

$$\frac{\text{Coil length}}{\text{spacing}} = \frac{164}{4.8} = 35$$

is:

$$K_1 = 1.03$$

Therefore:

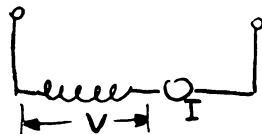
$$I = \frac{1.43 \times 39.6 \times 6.7}{19} 1.03 = 20.6 \text{ amp.}$$

The experiment was run at 20 amp, this being the maximum rating of the equipment used.

The following table gives the experimental results obtained:

TABLE V

f	secs	I	temp(over room temp) °C	°F	V	Z
350	10	20	3.5	150	63	3.15
350	20	20	6	250	66	3.3
350	30	20	9	375	68	3.4
350	40	20	12.2	520	70	3.5
350	50	20	16	660	75	3.75
350	60	20	19	790	78	3.9



Temperature in
1 minute = 790
+ 70 = 860°F

Voltage data has also been obtained to calculate the impedance of the cored-coil.

Following the same procedure as in the first experiment, the Q of the cored coil was measured at different temperatures, the following results being obtained:

TABLE VI

f	°F over room temp.	Q
350	700	9.5
350	300	7.
350	400	5.
350	500	5.
350	700	3.5

Both Q and Z were plotted on the same graph as a function of temperature (Fig. 5). Therefrom pairs of values at the same temperatures were obtained. As a next step X and R were calculated as before:

TABLE VII

°F over room temp.	Z	Q	X	R
100	3.05	9.3	3.035	0.327
200	3.25	8.1	3.22	0.397
300	3.35	6.8	3.32	0.488
400	3.4	5.6	3.35	0.6
500	3.5	4.7	3.43	0.73
600	3.63	4.2	3.53	0.84
700	3.8	3.7	3.68	0.995
800	3.95	3.4	3.79	1.11

As already stated the coil used in this experiment is the same as the one used before; its reactance and resistance being constant and of value:

$$Z = 2.42 \, \Omega$$

$$X = 2.41 \, \Omega$$

$$R = 0.16 \, \Omega$$

These curves have been plotted on the same graph as the curves for the cored coil. The curves indicate to what extent the resistance and reactance of the coil increased when the core is set inside.

All the above results have been plotted graphically in Figs. No. 5 and 6.

EXPERIMENT #3

Piece of iron 1.48" long, 0.75" diameter to be heated from 70°F up to 600°F in one minute.

The procedure is the same followed before.

- 1) Calculation of required thermal power:

$$T.P = 17.6 \times M \times C \times \Delta T$$

In this case:

$$\text{Volume} = 0.655 \text{ cub. inch.}$$

$$M = 0.655 \times 0.284 = 0.186 \text{ pounds/minute.}$$

$$C = \text{average } 70\text{-}600^\circ\text{F} = 0.124 \text{ BTU/pound } ^\circ\text{F.}$$

Therefore:

$$T.P = 17.6 \times 0.186 \times 0.124 \times 530 = 215 \text{ watts.}$$

2) Radiation, convection and conduction losses are negligible.

3) Power density.

$$P D = \frac{215}{0.655} = 329 \frac{\text{Watt}}{\text{cub. inch}}$$

4) Peak magnetizing force:

The formula to be applied is the same as in the preceding problems:

$$H_{\text{peak}} = \left(\frac{PD \times d}{(0.438 \sqrt{f \rho})} \right)^{2/3} \quad \text{valid when}$$

$$d \sqrt{\frac{\mu f}{\rho}} \geq 13400$$

When:

$$\rho = \rho_{335^{\circ}\text{F}} = 25 \mu\Omega\text{cm} = 10 \times 10^{-6} \Omega \text{ inch.}$$

Therefore:

$$H_{\text{peak}} = \left\{ \frac{329 \times 0.75}{0.438 \sqrt{35 \times 10^4 \times 10 \times 10^{-6}}} \right\}^{2/3} =$$

$$300^{2/3} = 45.$$

Hence:

$$\mu = \frac{32400}{45} = 720$$

The condition:

$$d \sqrt{\frac{\mu f}{\rho}} = 0.75 \sqrt{\frac{720 \times 35 \times 10^4}{10 \times 10^{-6}}} = 75000 \times 50.3 =$$

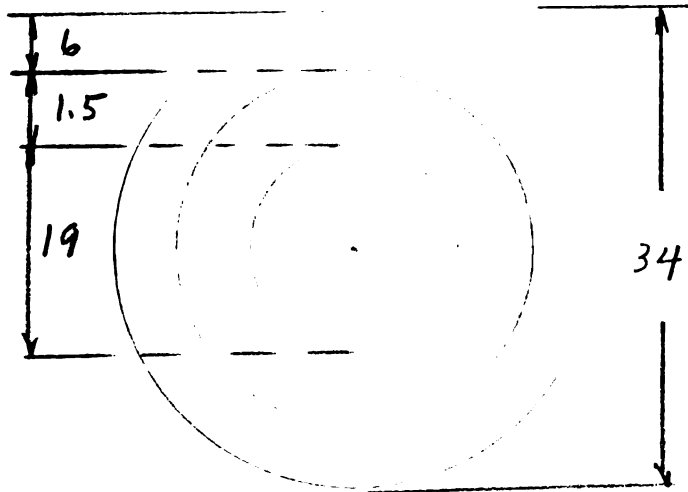
$$3,770,000 > 13400$$

is satisfied.

5) Coil design:

The coil was made of 6 turns of 6 mm diameter copper tubing and was designed 5.7 cm (2.24 inches)

in length and 34 mm outside diameter, thus allowing a clearance of 1.5 mm around the material.



Figures in mm.

6) Coil current:

$$I = \frac{1.43 \times H_{\text{peak}} \times l \text{ (inch)}}{N} K_1 =$$

$$\frac{1.43 \times 45 \times 2.24}{6} K_1$$

Where K_1 corresponds to a ratio:

$$\frac{\text{coil length}}{\text{spacing}} = \frac{57}{1.5} = 38 \quad \text{So } K_1 = 1.03.$$

Therefore:

$$I = 24.7$$

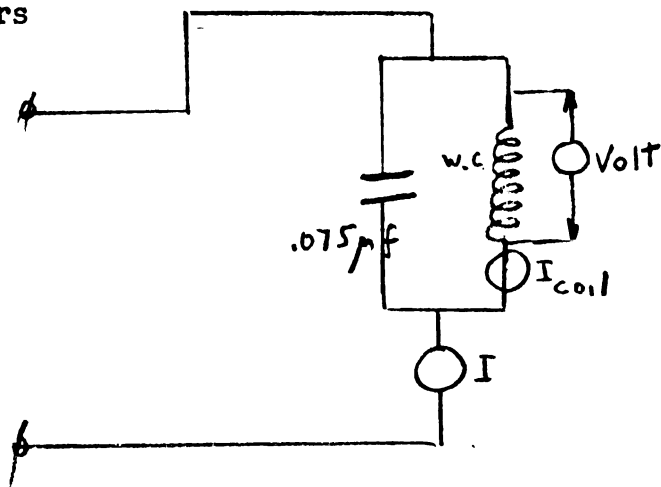
To get this current through the work coil with the 20 amps rated equipment, the work coil was shunted with a high voltage .075 μf mica condenser. The following data was obtained:

TABLE VIII

°F over
room temp.

<u>1</u>	secs	I_{coil}	μ amp.	°F	V	Z
350	10	25	2.5	105	22.3	0.893
350	20	25	4	170	23	0.92
350	30	25	5.5	230	23	0.92
350	40	25	7.5	310	23.8	0.953
350	50	25	9	375	23.8	0.953
350	60	25	10.2	430	24.1	0.964
350	80	25	14	580	25.	1.

The scheme shows
the parometers
measured.



Final temperature in 1 minute = $430 + 70 = 500^{\circ}F$

The Q readings gave the following results:

TABLE IX

<u>°F over room temp.</u>	<u>Q</u>
70	7
200	7
500	5
700	4
1000	4

Finally, computations were made for the reactance and resistance of the coil as before.

TABLE X

<u>°F over room temp.</u>	<u>Z</u>	<u>Q</u>	<u>X</u>	<u>R</u>
100	0.89	7.35	0.885	0.12
200	0.92	6.7	0.911	0.136
300	0.945	6.2	0.934	0.151
400	0.96	5.6	0.946	0.169
500	0.975	5	0.956	0.191
600	1.	4.4	0.975	0.221

1. The first part of the document is a letter from the author to the editor, dated 10/10/1910. The letter is written in a very formal and polite manner, and it discusses the author's recent work on the history of the city of New York. The author mentions that he has been working on this project for a long time, and that he has been able to gather a great deal of information about the city's past. He also mentions that he has been able to find some very interesting facts about the city's early history, and that he is very pleased to be able to share this information with the public.

2. The second part of the document is a letter from the editor to the author, dated 10/10/1910. The editor's letter is also very formal and polite, and it discusses the author's letter and the work that he has been doing. The editor mentions that he is very impressed with the author's work, and that he is very pleased to be able to publish it. He also mentions that he is very interested in the author's findings, and that he is looking forward to reading the book.

3. The third part of the document is a letter from the author to the editor, dated 10/10/1910. The author's letter is also very formal and polite, and it discusses the editor's letter and the work that he has been doing. The author mentions that he is very pleased to hear from the editor, and that he is very grateful for the editor's interest in his work. He also mentions that he is very happy to be able to publish his work, and that he is looking forward to seeing it in print.

1	2	3	4
5	6	7	8
9	10	11	12
13	14	15	16
17	18	19	20
21	22	23	24
25	26	27	28
29	30	31	32

The corresponding readings for the coil alone are:

TABLE XI

<u>t</u> <u>over room</u>	<u>Q</u>	<u>Z</u>	<u>X</u>	<u>R</u>
70°	10	0.8	0.796	0.0796
600	10	0.8	0.796	0.0796

Measurements of the temperature were made at both the surface and the center of the piece under identical conditions and running the experiment with 20 amp. The following results were obtained:

TABLE XII

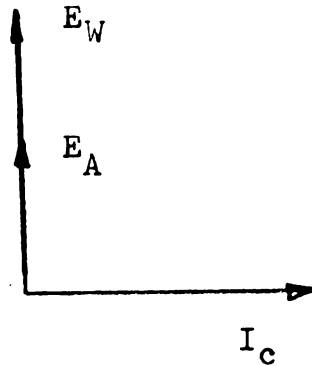
<u>I_{coil}</u>	<u>°F over room temperature</u>		<u>Secs</u>
	<u>Center</u>	<u>Surface</u>	
20 amp.	130	130	20
"	170	170	30
"	210	228	40
"	263	278	50
"	317	333	60
"	470	490	90

It can be seen that the temperature is fairly uniform due to the small size of the piece and the fact that the heating was rather slow.

All of the above results have been plotted graphically in Figs. 7, 8 and 9.

COIL VOLTAGE COMPUTATIONS

Following the same procedure as in the first experiment and neglecting the in phase component:



$$E_W = j 0.016 \cdot d \times f \times T \times \delta_f \quad \text{volts}$$

(δ and d in inches)

Where:

$$\delta_f = 17.6 \sqrt{\frac{H \times \rho_{\max.}}{f}} = 17.6 \sqrt{\frac{45 \times 15 \times 10^{-6}}{35 \times 10^4}} \text{ inches}$$

Where

$$\rho_{\max} = \rho_{600^\circ\text{F}} = 15 \times 10^{-6} \quad \Omega \text{ inch}$$

Hence -

$$\delta_f (600^\circ) = 77.4 \times 10^{-5} \text{ inches.}$$

Therefore:

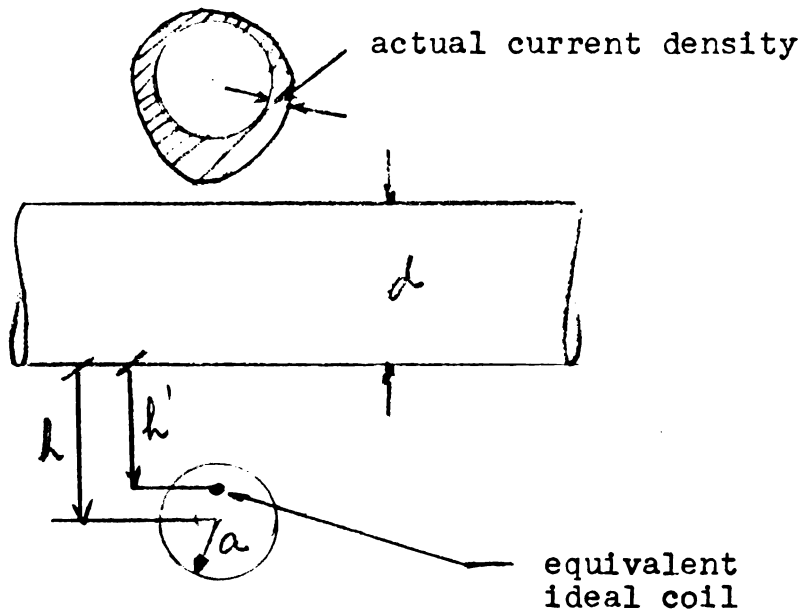
$$E_W (600^\circ) = j 0.0162 \times 0.75 \times 35 \times 10^4 \times 6 \times 77.4 \times 10^{-5} = j 19.75 \text{ volts}$$

Besides:

$$E_A = j 28.6 \times f \times T \times H (A_c - A_w) \times 10^{-8} \text{ volts.}$$

A_c is the cross sectional area of the equivalent ideal coil. As will be explained later in connection with the heating of a copper tubing, the spacing h' of

this fictitious coil would be: (Brown's Chapter VIII)



$$h^1 = h \sqrt{1 - \left(\frac{a}{h}\right)^2} \quad \text{Where } a = 3 \text{ mm}$$

$$h = 4.5 \text{ mm}$$

$$h^1 = 4.5 \sqrt{1 - 0.445} = 3.33 \text{ mm.}$$

Therefore the diameter of the ideal coil is:

$$d_c = 1.01" \text{ and the area: } A_c = 0.8 \text{ sq. inch.}$$

Hence:

$$\begin{aligned} E_A &= j 28.6 \times 35 \times 10^4 \times 6 \times 45 \times 0.358 \times 10^{-8} = \\ &= j 9.66 \text{ volts} \end{aligned}$$

Therefore

$$V = E_A + E_W = j 9.66 + j 19.75 = j 29.41 \text{ volts}(600^\circ\text{F})$$

$$\text{And: } X = \frac{29.41}{24.7} = 1.19 \sim$$

Actually E_W has an "in-phase component" that provides the power input to the load.

We can thus calculate the internal power factor (not including the IR_i , IX_i voltage drops in the coil):

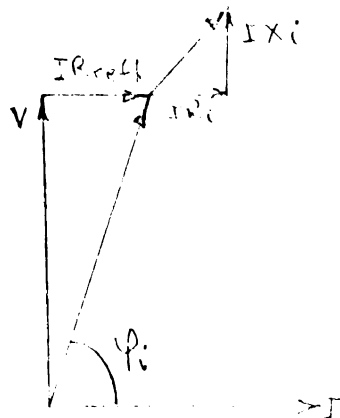
$$\text{internal power factor} \approx \cos \phi_i = \frac{\text{Input to the core (watts)}}{V I (\text{work coil})}$$

Where $V = E_A + E_W$.

$$\cos \phi_i \approx \frac{215}{24.7 \times 29.41} = 0.296$$

Therefore:

$$R_{\text{reflejada}} = 1.19 \times 0.296 = 0.35352$$



The total resistance of the coil with the core inside is the sum of this plus the coil resistance. This was measured and was found to be:

$$R_1 = 0.0796$$

So:

$$R_{\text{total}} = 0.0796 + 0.353 = 0.4326 \Omega (600^\circ\text{F})$$

This value is high compared with that found in the experiment (0.221). This disagreement is due partially

to the fact that the power was less than 215 watts as can be observed by looking at the heating curve. However the power could not be measured directly to check this.

Besides, the value of R from the experiment was found through a very indirect way basing our computations on the measurements of Q done with an inadequate instrument and for this reason it cannot be considered accurate.

The total power factor:

$$\cos \phi_T = \frac{0.4326}{1.19} = 0.363$$

And the efficiency of the coil:

$$\text{efficiency} = \frac{I^2 \times 0.353}{I^2 \times 0.4326} \times 100 = 87.8\%$$

Condenser computations.

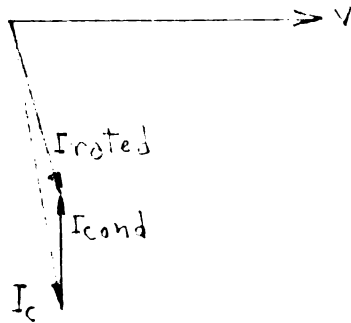
In the last experiment of this paper there is a complete discussion about the application of condensers in parallel with the work coil.

Starting from V = 29.41 volts and selecting I condenser so that:

$$I_{\text{cond}} = I_{\text{coil}} - I_{\text{rated}} = 24.7 - 20 = 4.7 \text{ amp}$$

equip

Even though this formula is not estriactly **correct** it can be applied successfully due to the fact that i_c is almost an entirely resistive current.



We can write

$$I_{\text{cond}} = V \cdot C \cdot W.$$

$$C = \frac{I_{\text{cond}}}{V \cdot W} = \frac{4.7 \times 10^6}{29.41 \times 211 \times 35 \times 10^4} \text{ } \mu\text{f.}$$

$$C = 0.073 \text{ } \mu\text{f.}$$

EXPERIMENT # 4

From tubing 3.22" long, 0.11" thick and 0.84" external diameter to be heated from 70°F up to 600°F in one minute.

The calculations follow the same procedure as before

1) Thermal power:

$$TP = 17.6 \times M \times C \times \Delta T$$

Where

$$\text{Volume} = \frac{\pi \times 0.84^2}{4} - \frac{0.62^2}{4} \times 3.22 = 0.805 \text{ Cub. inch}$$

$$M = 0.805 \times 0.284 = 0.229 \text{ pounds/minute}$$

$$C = \text{average } 70 - 600^{\circ}\text{F} = .124$$

$$= 530$$

Thence:

$$TP = 17.6 \times 0.229 \times 0.124 \times 530 = 265 \text{ watts.}$$

2) Radiation, correction, and conduction losses are negligible.

3) Power density.

$$PD = \frac{265}{\text{total volume}} = \frac{265}{1.78} = 149 \frac{\text{watts}}{\text{cub. inch}}$$

4) Peak magnetizing force. The same equation for solid magnetic cylinders applies for the hollow ones if the wall thickness is greater than the depth of current penetration or:

$$\text{Wall thickness} \geq 3170 \sqrt{\frac{\rho}{\mu f}}$$

Therefore:

$$H = \left(\frac{PD \times d}{0.438 \sqrt{f \times \rho}} \right)^{2/3} = \left(\frac{149 \times 0.87}{0.438 \sqrt{35 \times 10^4 \times 10 \times 10^6}} \right)^{2/3}$$

$$\rho (335^{\circ}\text{F}) = 10 \times 10^{-6} \text{ ohm-inch}$$

$$H = \left(\frac{285}{1.87} \right)^{2/3} = 28.6$$

So:

$$\mu = \frac{32400}{28.6} = 1130$$

The maximum skin depth takes place at maximum temperature. It is:

$$\rho (600^{\circ}\text{F}) = 38 \mu\Omega\text{-cm} = 15 \times 10^{-6} \text{ ohm-inch}$$

$$\text{Skin depth} = 3170 \sqrt{\frac{15 \times 10^{-6}}{1130 \times 34 \times 10^4}} = \frac{3170 \times 1.95}{10^7}$$

$$= 6.18 \times 10^{-4} \text{ inches}$$

The condition

Wall thickness = $0.11" > 6.18 \times 10^{-4}$ inch
is satisfied.

5) Coil design.

The coil was made of 10 turns of 6 ~~mm~~
diameter copper tubing and was designed
3.5" (8.9cm) long and 38 ~~mm~~ outside diam-
eter thus allowing a clearance of 2 ~~mm~~
around the core.

6) Coil current

For $\frac{\text{coil length}}{\text{spacing}} = \frac{89}{2} = 45$ $K_1 = 1.02$
(Bendz page 312)

Therefore:

$$I_{\text{coil}} = \frac{1.43 \times 28.6 \times 3.5}{10} \times 1.02 = 14.5 \text{ amp.}$$

The following data was obtained:

TABLE XIII

t secs.	I coil	°F over room Temp.		V	Z
10	15.5	1.3	60	36	2.32
20	"	3.2	140	38	2.45
30	"	5.4	230	42	2.7
40	"	7.	290	42	2.7
50	"	8.7	360	42	2.7
60	"	10.5	435	42	2.7
90	"	15	620	42	2.7

Final temp. in 1 minute = $435 + 70 = 505^{\circ}\text{F.}$

Following the same procedure as before the Q's
were measured at different temperature.

TABLE XIV

Temp	Q
70	7.5
350	6
600	4
800	4

From the graph No. 11 the following table can be constructed:

TABLE XV

°F over room temp.	Z	Q	X	R
100	2.4	7.6	2.38	0.313
200	2.6	6.8	2.57	0.378
300	2.7	6.	2.665	0.444
400	2.7	5.2	2.65	0.51
500	2.7	4.5	2.64	0.587
600	2.7	4.2	2.63	0.603

The following readings were obtained taking the core out of the coil:

TABLE XVI

Coil alone	Temp. over room	Z	Q	X	R
	70	1.75	15	1.715	0.114
	450	"	"	"	"
	700	"	"	"	"

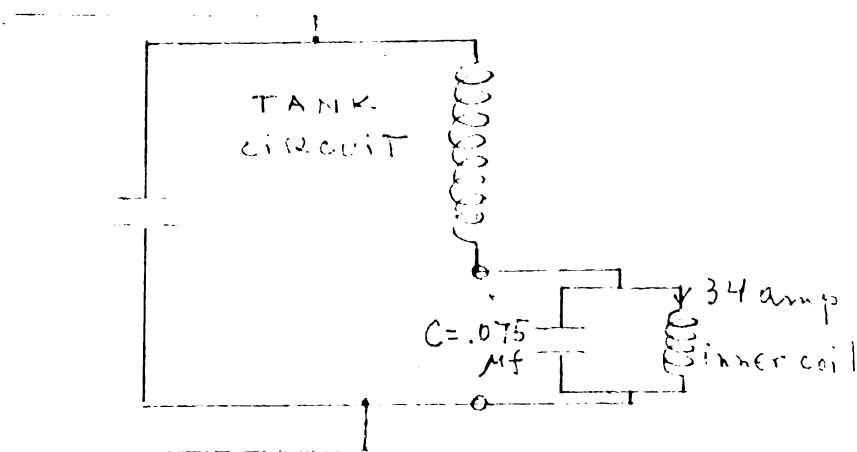
All these results are plotted in figs. 10 and 11. Conclusions are similar to those drawn from experiment No. 1.

EXPERIMENT # 5

The same iron tubing was heated with a coil inside, and a higher current using a condenser in parallel.

TABLE XVII

Coil current I	secs.	Temp over room	
		M. amp	°F
34	10		
"	20	1	40
"	30	1.5	65
"	40	1.7	72
"	50	2.	85
"	60	2.7	115
"	90	4.5	190



The coil had the following characteristics:

external diameter = 13 inches
 internal diameter = 5 inches
 length = 8.5 = 3.35 inches
 no. of turns = 15

The final ΔT in one minute was only 115°F . To get a temperature of 600°F in one minute ($\Delta T = 530$) the current should have been I_2 , and the peak magnetizing force H_2 .

But:

$$H = K_1(P.D)^{2/3} = K_2 \times (\text{Thermal power})^{2/3} = K_3 \times \Delta T^{2/3}.$$

The ratio between the actual H_1 and H_2 is:

$$\frac{H_2^{3/2}}{H_1^{3/2}} = \frac{530}{115} = 4.61 = \frac{I_2^{3/2}}{I_1^{3/2}}$$

Therefore:

$$\begin{aligned} I_2^{3/2} &= I_1^{3/2} \times 4.61 = \\ I_2^{3/2} &= (34.0)^{3/2} \times 4.61 = 198 \times 4.61 = 915 \end{aligned}$$

Hence:

$I_2 = 94.5$ amp and the value of H_2 peak magnetizing force for such a coil to **heat** the **material** up to 600°F in one minute, becomes:

$$H_{2\text{peak}} = \frac{0.70 \times 15 \times 94.5}{3.35} = 296.$$

Therefore in this case, the ratio of $\frac{H_{\text{inner}}}{H_{\text{outer}}}$

to accomplish the same purpose is:

$$\frac{H_{\text{inner}}}{H_{\text{outer}}} = \frac{296}{28.6} = 10.35$$

The results are shown in graph No. 10.

EXPERIMENT # 6

Copper tubing to be heated from 70 to 320°F in two minutes.

The dimensions of the copper tubing are:

outer diameter = 0.5 inches

length = 6.2 inches

thickness = 0.018 inches

weight = 0.056 pounds

external volume = 1.215 cub. inches

The specific heat and resistivity are for copper:

TABLE XVIII

°F	S. heat	$\rho_{\mu cm}$
	-	1.72
70	0.09	-
400	0.096	3.1
600	0.099	-
800	0.101	4.8
1200	0.106	6.6

Hence, average s. heat (70-320) = 0.093

- 1) Thermal power

$$TP = 17.6 \times 0.056 \times 0.093 \times \frac{250}{2} = 11.5 \text{ watts}$$

- 2) Radiation, convection and conduction losses are negligible.

- 3) Power density

$$PD = \frac{11.5}{\text{External volume}} = \frac{11.5}{1.215} = 9.46 \frac{\text{watts}}{\text{cub. inch}}$$

- 4) Peak magnetizing force:

For this hollow cylinder to be considered

equivalent to a thick-walled one, the following condition must be satisfied:

Wall thickness $\geq$ skin depth

That is:

$$\text{Wall thickness} \geq 3170 \sqrt{\frac{\rho_{\max}}{f}} = \quad (\text{Bendz's p.305})$$

When

$$\rho_{\max} = \rho_{320} = 2.8 \times 10^6 \Omega \cdot \text{cm} = 1.1 \times 10^6 \Omega \cdot \text{inch}$$

So:

$$\text{Wall thickness} \geq 3170 \sqrt{\frac{1.1 \times 10^6}{35 \times 10^4}} = \frac{3170}{106} 1.77 = 5.6 \times 10^{-3} \text{ in.}$$

The required condition is satisfied.

Under these conditions we can apply the following formula developed in this paper previously:

$$H = \frac{PD \times d}{\sqrt{2.59 \times 10^3} \sqrt{f \rho_{\text{ave}}}} \quad \text{valid if } d \sqrt{\frac{f}{\rho_{\text{ave}}}} > 13400$$

$$\text{Where } \rho_{\text{ave}} = \rho_{145} = 2.35 \times 10^6 \Omega \cdot \text{cm} = 0.93 \times 10^6 \Omega \cdot \text{inch}$$

The condition

$$d \sqrt{\frac{f}{\rho_{\text{ave}}}} = 0.5 \sqrt{\frac{35 \times 10^4}{0.93 \times 10^6}} = 0.5 \times 10^5 \times 6.14 = 3.07 \times 10^4 > 13400$$

is also satisfied.

Therefore:

$$H = \sqrt{\frac{9.46 \times 0.5}{2.59 \times 10^3 \sqrt{35 \times 10^4 \times 0.93 \times 10^6}}} = \sqrt{3.2 \times 10^3} = 56.5$$

5) Coil design.

The same coil used in experiment No. 1, was used for this experiment, its characteristics being:

19 turns of copper tubing 6 inches in diameter

6.7" long

31 ~~inches~~ outside diameter

19 ~~inches~~ inside diameter

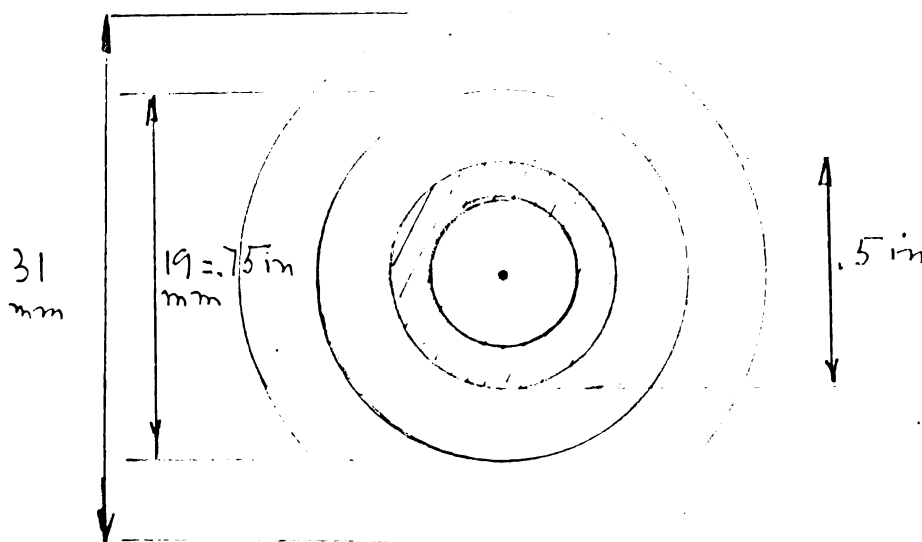
The clearance was 3.2 ~~inches~~ and the factor K_1 nearly unity.

6) Coil current

$$I = \frac{1.43 \times 56.5 \times 6.7}{19} = 28.5 \text{ amp.}$$

Coil voltage

The diagram shows the relative sizes of coil and core:



It is easily seen that we have to consider two different fluxes, the one through the work piece Φ_w and the one through the air space surrounding it, Φ_A .

Let a vector diagram be constructed. The coil current I_c produces the flux Φ_A in phase with it. The

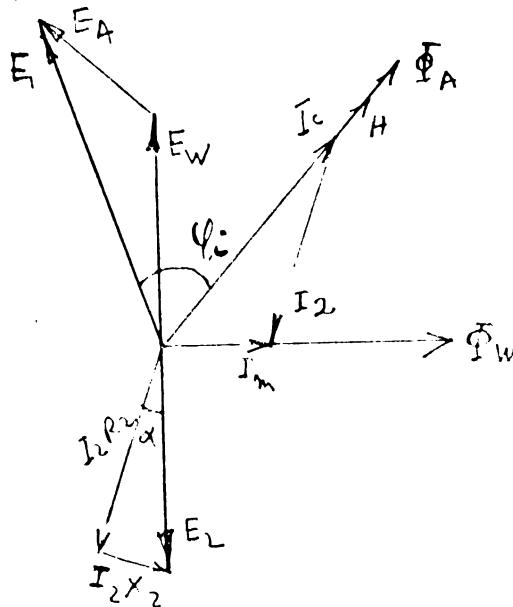
• The first step in the process of creating a new product is to identify a market need. This is often done through market research, which involves gathering information about the target market and its needs. Once a market need has been identified, the next step is to develop a concept for a new product that meets this need. This is often done through brainstorming and prototyping. Once a concept has been developed, the next step is to create a business plan for the new product. This plan should outline the costs of production, the pricing strategy, and the marketing strategy. Once a business plan has been created, the next step is to secure funding for the new product. This can be done through a variety of methods, including venture capital, angel investors, and crowdfunding. Once funding has been secured, the next step is to manufacture the new product. This is often done through a combination of in-house production and outsourcing to third-party manufacturers. Once the product has been manufactured, the final step is to launch the product into the market. This is often done through a combination of direct sales and indirect sales through retailers.

• The second step in the process of creating a new product is to develop a concept for a new product that meets this need. This is often done through brainstorming and prototyping. Brainstorming is a process of generating ideas for a new product. It is often done in a group setting, where individuals are encouraged to share their ideas and build on each other's ideas. Prototyping is the process of creating a small-scale model of a new product. This is often done to test the feasibility of a new product and to gather feedback from potential customers. Once a concept has been developed, the next step is to create a business plan for the new product. This plan should outline the costs of production, the pricing strategy, and the marketing strategy. Once a business plan has been created, the next step is to secure funding for the new product. This can be done through a variety of methods, including venture capital, angel investors, and crowdfunding. Once funding has been secured, the next step is to manufacture the new product. This is often done through a combination of in-house production and outsourcing to third-party manufacturers. Once the product has been manufactured, the final step is to launch the product into the market. This is often done through a combination of direct sales and indirect sales through retailers.

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flux Φ_w is lagging due to the secondary current ($I_2 = I_{work}$), I_2 is yet to be found.

As a second step let's find the emf's. The emf induced in the core E_2 is 90° lagging Φ_w and the core current is lagging α° due to the resistive and inductive characteristic of it, considered as a secondary circuit short circuited. Thus, E_2 is made up of $I_2 R_2$ and $I_2 X_2$. Now adding up I_c and I_2 referred to the primary, we obtain the total core magnetizing current I_m . The primary emf E_1 is made up of 2 parts: E_a due to the flux in the air and E_w due to the flux in the work piece. Each of these vectors is leading 90° the corresponding flux.



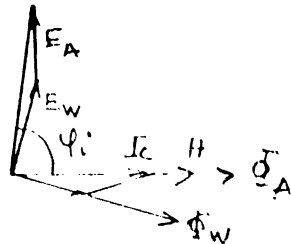
$\cos \phi_i$ is the internal power factor.

Shifting the diagram so as to make I_c be in the X axes we can write:

$$\Phi_A = H \times \text{Area air space}$$

$$\Phi_A = H (A_{\text{coil}} - A_w)$$

$$\Phi_w = A_w \cdot H(P - jQ)$$



Where A_{coil} and A_w represent the area of the coil and work piece and H the peak magnetizing force of the coil above; that is, the air space. P and Q therefore, take care of any change in the magnitude and phase of H while coming into the core.

The emf's core then, can be written:

$$E_a = j28.6 \times f \times T \times H (A_{\text{coil}} - A_w) 10^8 \text{ volts.}$$

$$E_w = j28.6 \times f \times T \times A_w \cdot H (P - jQ) \times 10^8 \text{ volts.}$$

T represents the number of coil turns.

In the present experiment at a temperature of 320°F we have:

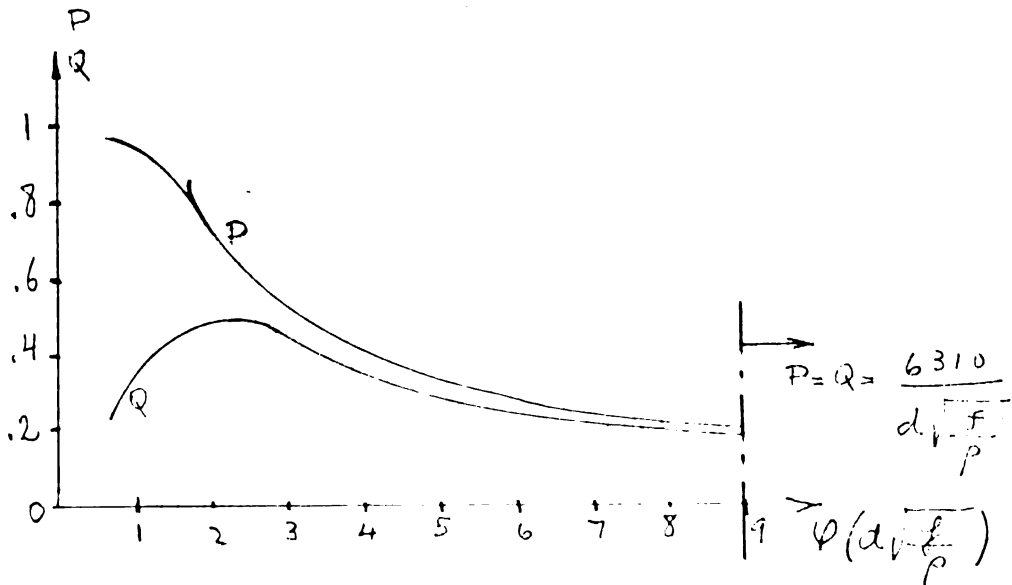
$$P_{\text{max}} = P_{320} = 1.1 \times 10^{-6} \text{ inch.}$$

$$d = \text{diameter} = 0.5 \text{ inch.}$$

Hence:

$$d \sqrt{\frac{f}{P}} = 0.5 \sqrt{\frac{35 \times 10^4}{1.1 \times 10^{-6}}} = 0.5 \times 10^5 \times 5.63 = 282,000$$

The parameters P and Q vary as shown in the following graph. Taken from AIEE transactions Vol. 63, June 1944, p. 273.



The value $\varphi(d\sqrt{\frac{f}{\rho}}) = 9$ on the X axes corresponds to
 $d\sqrt{\frac{f}{\rho}} = 13400$

Hence in the present case we are beyond that
 point and:

$$P = Q = \frac{6310}{282000} = 2.24 \times 10^{-2}$$

Therefore:

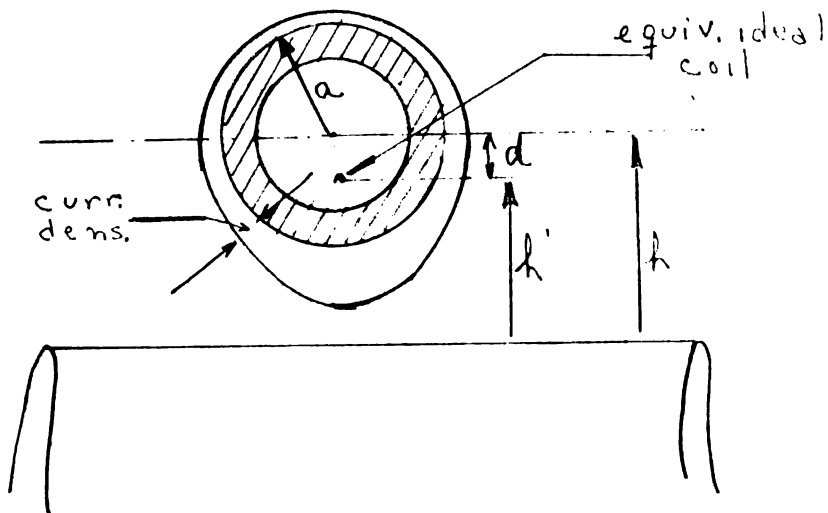
$$E_w = j 28.6 \times 35 \times 10^4 \times 19 \times 0.19 \times 56.5 (2.24 - j2.24) 10^{-10} \text{ volts}$$

$$E_w = j (471 - j471) 10^{-3} = 0.471 + j0.471 \text{ volts} = 0.665 \angle 45^\circ$$

We can see that, in all the theoretical cases very
 small and the flux Φ_A can be neglected, the internal
 power factor angle is 45° .

The value of E_a is analyzed by considering an
 equivalent ideal coil.

Due to the currents flowing in the cylinder the
 current density in the coil increases at the inner
 boundary and decreases at the outer one as the diagram
 shows:



In Brown S. Hoiler's Chapter VIII there is a complete analysis of the matter where for a single turn coil they conclude that for the equivalent ideal coil the following equation applies:

$$h' = h \sqrt{1 - \left(\frac{a}{h}\right)^2}$$

In this case:

$$h = 6 \text{ inches}$$

$$a = 3 \text{ inches}$$

Therefore:

$$h' = 6 \sqrt{1 - 0.25} = 6 \times 0.865 = 5.2 \text{ inches}$$

and the diameter of this fictitious coil

$$d_c = 23.4 \text{ inches} = 0.923 \text{ inches.}$$

So:

$$A_c = 0.67 \text{ sq. inch.}$$

$$E_a = j28.6 \times 35 \times 10^4 \times 19 \times 565 \times (0.67 - 0.196) \times 10^{-8}$$

$$= j 51 \text{ volts} = 51 \angle 90^\circ \text{ volts.}$$

We must add to this internal voltage (emf) the voltage drops in the coil itself due to its internal impedance.

From (Brown's page 22)

$$R_1 = X_1 = \frac{1}{\sqrt{\pi} a^2} \times \frac{a}{23}$$

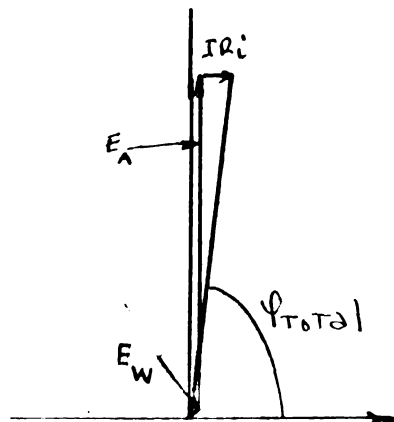
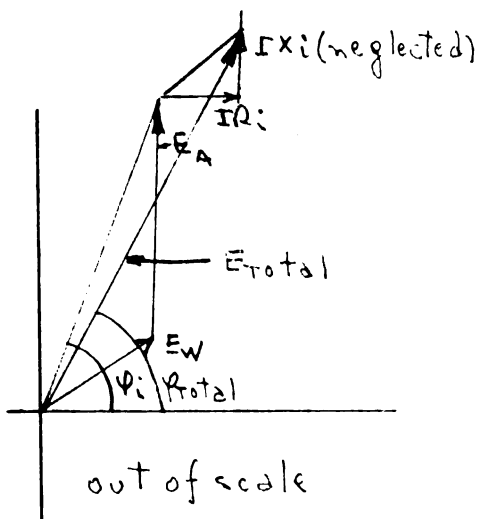
Theoretical calculations are not accurate, whereas a simple reading in the experiment gives (neglecting X_1)

$$R_1 = 0.16 \Omega$$

Hence

$$IR_1 = 28.5 \times 0.16 = 4.5 \text{ volts}$$

We can see that in this case the total voltage is very nearly the same as E_a and our ϕ becomes nearly 90° . The total coil voltage is shown in the following diagram:



1. The first part of the paper is devoted to the study of the properties of the function $f(x)$ defined by the equation $f(x) = \int_0^x f(t) dt$. It is shown that $f(x)$ is a constant function, and its value is determined by the initial condition $f(0) = 1$.

2. In the second part, we consider the function $g(x)$ defined by the equation $g(x) = \int_0^x g(t) dt$. It is shown that $g(x)$ is a constant function, and its value is determined by the initial condition $g(0) = 1$.

3. The third part of the paper is devoted to the study of the properties of the function $h(x)$ defined by the equation $h(x) = \int_0^x h(t) dt$. It is shown that $h(x)$ is a constant function, and its value is determined by the initial condition $h(0) = 1$.

4. In the fourth part, we consider the function $k(x)$ defined by the equation $k(x) = \int_0^x k(t) dt$. It is shown that $k(x)$ is a constant function, and its value is determined by the initial condition $k(0) = 1$.

5. The fifth part of the paper is devoted to the study of the properties of the function $l(x)$ defined by the equation $l(x) = \int_0^x l(t) dt$. It is shown that $l(x)$ is a constant function, and its value is determined by the initial condition $l(0) = 1$.

Hence:

Total coil voltage: 52 volts $\angle 84^\circ$

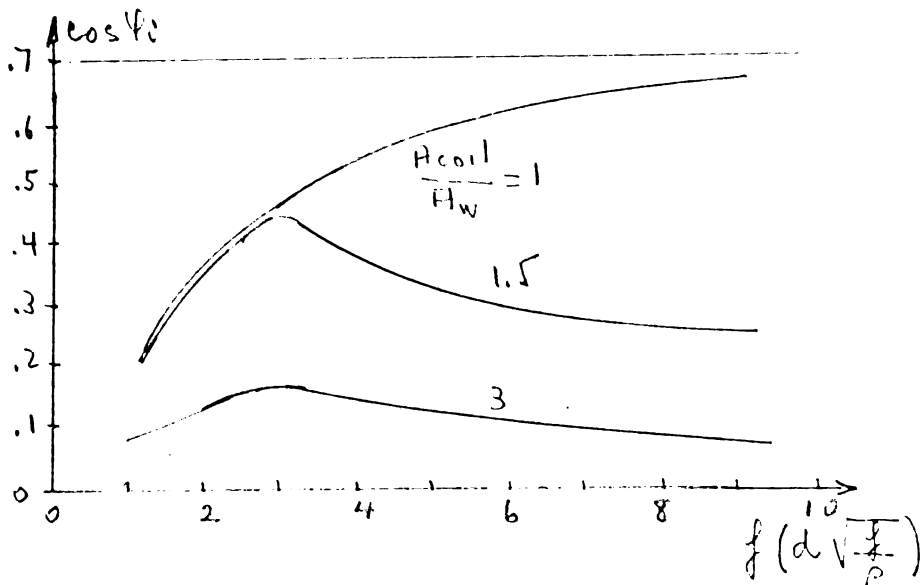
Where 84° is the total ϕ since it comprises also the IR_1 , IX_1 , drops on the coil. The efficiency of the coil is:

$$\begin{aligned} \text{Effy} &= \frac{E_1 \text{ (in phase component)} I}{I^2 R_1 + E_1 I} = \frac{E_w}{E_w + IR_1} 100 \\ &= \frac{0.471}{0.471 + 4.5} 100 = \frac{0.471}{4.971} 100 = 9.6\%. \end{aligned}$$

Total power factor = $\cos \phi_T = 0.1$

In the experiment the voltage through the coil was 7% higher than this value, due to the fact that a slight difference in the measure of the coil diameter increases greatly the area ($A_{\text{coil}} - A_w$) and as the coil was made by hand its diameter was not very uniform.

The variation of the internal power factor with the ratio $\frac{A_{\text{coil}}}{A_{\text{work}}}$ has been shown to be (AIEE transactions Vol. 63, June, 1944, page 273)



1. The first step in the process of the scientific method is to ask a question. This question should be based on observation and should be something that can be tested. For example, a scientist might observe that plants grow better in sunlight than in shade and ask the question, "Does sunlight affect plant growth?"

2. The next step is to form a hypothesis. A hypothesis is a statement that can be tested. It is often written in the form of an "if-then" statement. For example, a scientist might hypothesize, "If a plant receives more sunlight, then it will grow taller."

3. The third step is to design an experiment. The experiment should be designed to test the hypothesis. It should include a control group and an experimental group. The control group is the group that does not receive the treatment being tested. The experimental group is the group that does receive the treatment. In this example, the control group would be plants that receive no sunlight, and the experimental group would be plants that receive sunlight. The scientist would then measure the height of the plants in each group over a period of time.

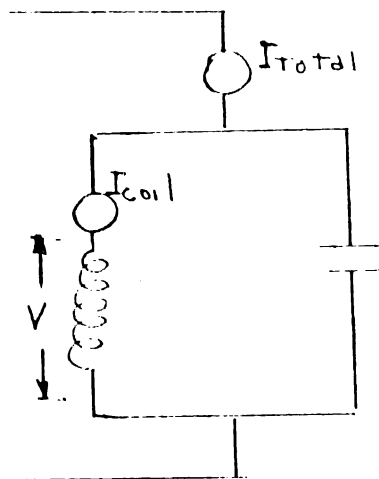
4. The fourth step is to collect data. The scientist would record the height of the plants in each group at regular intervals. This data would then be used to analyze the results of the experiment.

5. The fifth step is to analyze the data. The scientist would compare the height of the plants in the control group to the height of the plants in the experimental group. If the plants in the experimental group are significantly taller than the plants in the control group, then the hypothesis is supported. If the plants in the experimental group are not significantly taller, then the hypothesis is not supported.

6. The final step is to draw a conclusion. The scientist would write a conclusion based on the results of the experiment. This conclusion would state whether the hypothesis was supported or not supported and what the implications of the results are.

The experiment was run by connecting a condenser in parallel with the work coil as shown. The table gives the results obtained.

TABLE XIX						
I_{total}	I_{coil}	secs.	over room temp	V	Z	
20	29	10	1.8	75	56	1.935
"	"	20	2.5	105	"	"
"	"	30	3.	130	"	"
"	"	40	3.5	150	"	"
"	"	50	3.8	160	"	"
"	"	60	4.2	175	"	"
"	"	90	5.2	220	"	"
"	"	120	5.7	240	"	"



Final temperature in 2 minutes = 240 + 70 = 310°F

The value of Q was found to be constant through this temperature range and equal to Q = 11.

• The first step in the process of creating a new product is to identify a market need. This can be done through market research, which involves gathering information about the target market and its needs. Once a market need has been identified, the next step is to develop a product concept that addresses this need.

• The product concept is then developed into a detailed product specification, which outlines the features and benefits of the product. This specification is used to guide the design and development of the product. The next step is to create a prototype of the product, which allows the company to test the product and gather feedback from potential customers. Once the prototype has been tested and feedback has been gathered, the company can then proceed to develop the final product.

• The final product is then manufactured and distributed to the market. The company then monitors the product's performance in the market and makes any necessary adjustments to the product or the marketing strategy.

• The process of creating a new product is a complex one, but it is essential for companies that want to stay competitive in the market. By following these steps, companies can ensure that they are developing products that meet the needs of their target market and that are profitable for the company.

• The second step in the process of creating a new product is to develop a product concept that addresses the market need. This can be done through brainstorming, which involves generating ideas for the product. Once a product concept has been developed, the next step is to create a prototype of the product, which allows the company to test the product and gather feedback from potential customers.

Therefore, R and X were calculated with the result listed below:

TABLE XX

Coil with hollow cop- per core.	temp. over room	Q	Z	X	R
	0-240	11	1.935	1.93	0.175

For the coil alone the corresponding parameters are also constants over the same range of temperature.

TABLE XXI

Coil alone same range temperature	Q	Z	X	R
	15	2.42	2.41	0.16

It is seen that the copper core acts as an inductive secondary circuit increasing the total resistance and decreasing the reactance.

The fact that the resistance of the secondary is very small compared with the reactance causes the total reactance and resistance to be fairly constant.

In fact, the total impedance is:

$$R_1 + \frac{(WM)^2 R_2}{R_2^2 + (WL_2)^2} + jw(l_1 - \frac{(WM)^2 L_2}{R_2^2 + (WL_2)^2})$$

That in this case reduces to:

$$R_1 + \frac{M^2 R_2}{L_2^2} + jw(L_1 - \frac{M^2}{L_2}) \quad \text{where } \frac{M^2 R_2}{L_2^2} \text{ is small.}$$

Condenser Computations

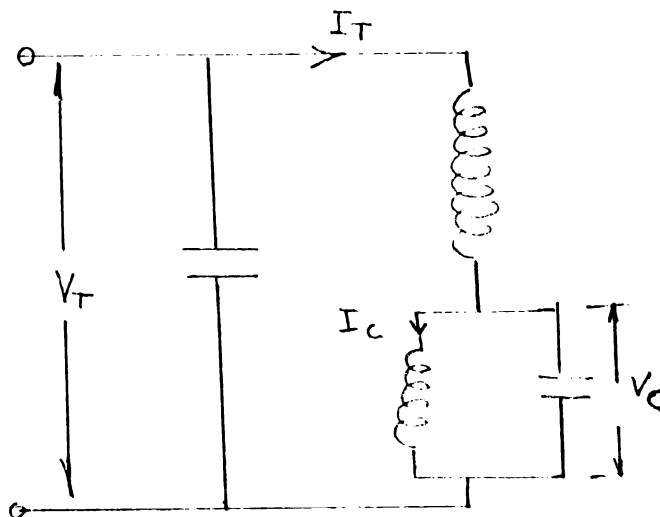
In applying a condenser in parallel with the work coil care must be taken to insure that this combination

will not form a tank circuit that can take control of the frequency of oscillation.

To help avoid this undesired possibility the following condition will be imposed.

$$Q_{\text{load}} \leq 80\% \text{ } Q_{\text{main tank circuit with work coil}}$$

This can be written as: (Bendz's p.319)



$$\frac{\text{Coil voltage} \times \text{coil current}}{\text{load watts}} \leq 80\%$$

$$\leq 80\% \frac{\text{generator rated volt-amp}}{\text{load watts}}$$

or $V_C \times I_C \leq 80\% V_T I_T$

In addition, the Westinghouse Mfg. Co. recommends (1kw generator catalogue) that: $I_{\text{coil}} \leq 2I_T$ to keep the load tank circuit away from resonance.

In this range the condenser current is to be chosen

- 1990年，在《中国大百科全书》中，首次提出“中国人口老龄化”的概念。
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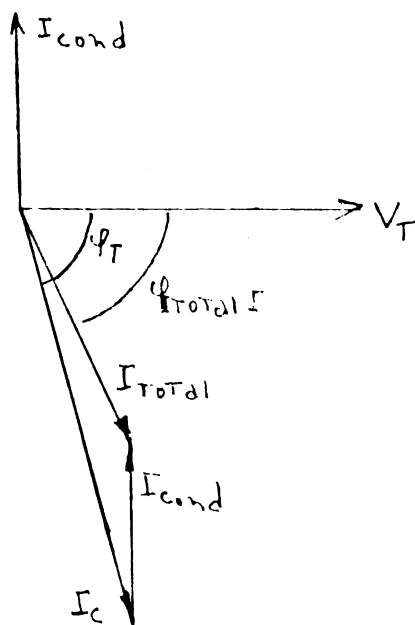
so that

$$I_{\text{cond}} = I_{\text{coil}} - I_{\text{t rated}}$$

In this case:

$$I_{\text{cond}} = 29 - 20 = 9 \text{ amp}$$

This formula is only correct in the total absence of power in the circuit but in most practical problems it yields approximate results because ϕ_T is very nearly 90° as analyzed before.



Finally:

$$C = \frac{I}{V_{\text{CW}}} = \frac{9 \times 10^6}{56 \times 2\pi \times 35 \times 10^4} = .073 \mu f$$

The results of this experiment are shown in graphs 12 and 13.

0.001

$$1000 \times 10^{-6} = 10^{-3}$$

0.001

$$1000 \times 10^{-6} = 10^{-3}$$

The following table shows the results of the analysis of the data obtained from the experiments. The values in parentheses are the standard deviations of the means. The values in brackets are the standard deviations of the individual measurements. The values in the last column are the standard deviations of the means of the individual measurements.

• The standard deviation of the means of the individual measurements

$$1000 \times 10^{-6}$$

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0.001

0.001

0.001

0.001

0.001

0.001

0.001

0.001

0.001

$$1000 \times 10^{-6} = 10^{-3}$$

• The standard deviation of the means of the individual measurements

Conclusions

Developing the expression for 'E' found at the beginning of this paper we get:

For $F \approx 1$

$$E = \frac{P(\text{power core})}{I^2 R_{\text{solenoid}}} = \frac{8 \pi H_0^2}{\mu_{\text{core}}} \frac{A_{\text{core}}}{S_{\text{core}}} \frac{1}{I^2} \frac{2 S_{\text{sol}}}{R_{\text{dc sol.}} A_{\text{sol}}}$$

For a given solenoid this becomes:

$$E = K \frac{A_{\text{core}} S_{\text{sol}}}{\mu_{\text{core}} S_{\text{core}}} = K \frac{A_{\text{core}}}{\mu_{\text{core}}} \sqrt{\frac{\mu_{\text{core}} \mu_{\text{core}}}{\mu_{\text{sol}}}}$$

$$E = K A_{\text{core}} \sqrt{\mu_{\text{core}}} P_{\text{core}} \text{ independent of freq.}$$

This formula shows that for a given solenoid, E is much smaller when heating a piece of non magnetic material than heating a magnetic one, no matter what the frequency is, as long, of course, that we are over $\frac{a}{s} = 2.25$.

Assuming for instance:

$$A_{\text{mag core}} = A_{\text{non mag core}}$$

$$\mu_{\text{r mag}} = 800$$

$$P_{\text{mag core}} = 10 P_{\text{non mag core}}$$

there results:

$$\frac{E_{\text{mag}}}{E_{\text{non mag}}} = \sqrt{800 \times 10} = 90$$

If we also assume an efficiency of 85% for the heating of the magnetic core we can write:

$$\text{effy}_{\text{mag}} = \frac{85}{85+15} = 85\% \text{ where } \begin{matrix} \text{Power} = 85 \\ \text{core} \\ I^2 R_{\text{sol}} = 15 \end{matrix}$$

For the same $I^2 R_{sol}$, the power that gets to the load for non magnetic material would be:

$$\text{Power}_{\text{non mag}} = \frac{85}{90} = 0.95$$

and the effy:

$$\text{effy}_{\text{non mag}} = \frac{0.95}{0.95+15} = 6\%.$$

We can conclude, therefore, that to keep the efficiency of this method between reasonable values while heating non magnetic materials much larger coils must be used.

High frequency heating, then, is especially convenient to heat magnetic materials but in spite of its low efficiency is used many times to heat non magnetic ones due to its outstanding characteristics such as:

- 1) Heating can be accomplished faster than with other methods for most metal pieces.
- 2) Heating can be confined to the desired area which may be a small fraction of the total.
- 3) Heating starts instantly when radio frequency power is applied and stops instantly when radio frequency power is removed.

These features frequently outweigh the relatively high cost of the necessary equipment.

List of the equipment used in these experiments

-Westinghouse industrial radio-frequency generator;

EE V 020, Style No. 867692, 1KW, 300 M c/s low frequency, and 10 M c/s high frequency.

-Radio frequency 'Q' meter; Type 160 A, Serial

No. 2632, Boonton Radio Corp.

-Vacuum tube voltmeter; Type 726A, Serial No. 3091

General Radio Co.

-Iron constantan thermocouple with galvanometer

Weston model 301, EE 2504, 30 micro amp

-Ammeters. GE Type CG 22037, 200 amps (rf)

EEAA124

GE Type CG 22041, 50 amps (rf)

EEAA125

-High voltage condensers (rf)

Cornell - Dubilier GD 48449-5

EE 2819-0.03 mf

Cornell - Dubilier GD 48996-5

EE 2818 - 0.045 mf

1. The first step in the process of the scientific method is to ask a question.

2. The second step is to do background research on the topic.

3. The third step is to form a hypothesis, which is a prediction about the outcome of the experiment.

4. The fourth step is to design and conduct the experiment.

5. The fifth step is to analyze the data and draw conclusions.

6. The sixth step is to communicate the results of the experiment.

7. The seventh step is to repeat the experiment to verify the results.

8. The eighth step is to apply the results to other situations.

9. The ninth step is to use the results to develop new questions.

10. The tenth step is to use the results to develop new hypotheses.

11. The eleventh step is to use the results to develop new experiments.

12. The twelfth step is to use the results to develop new theories.

13. The thirteenth step is to use the results to develop new models.

14. The fourteenth step is to use the results to develop new laws.

15. The fifteenth step is to use the results to develop new principles.

16. The sixteenth step is to use the results to develop new concepts.

17. The seventeenth step is to use the results to develop new ideas.

18. The eighteenth step is to use the results to develop new theories.

19. The nineteenth step is to use the results to develop new models.

20. The twentieth step is to use the results to develop new laws.

21. The twenty-first step is to use the results to develop new principles.

22. The twenty-second step is to use the results to develop new concepts.

23. The twenty-third step is to use the results to develop new ideas.

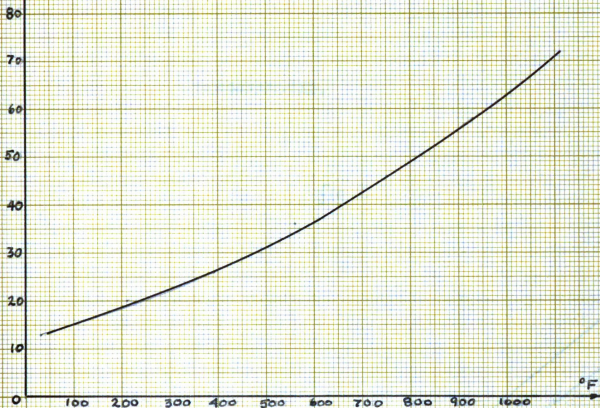
24. The twenty-fourth step is to use the results to develop new theories.

25. The twenty-fifth step is to use the results to develop new models.

RESISTIVITY OF SWEDISH IRON.

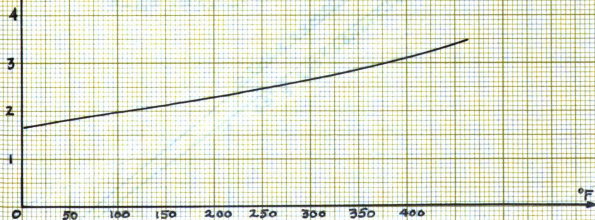
fig. 1.

ρ in $\Omega \text{ cm}$



RESISTIVITY OF COPPER.

ρ in $\Omega \text{ cm}$



THERMOCOUPLES.

fig.2

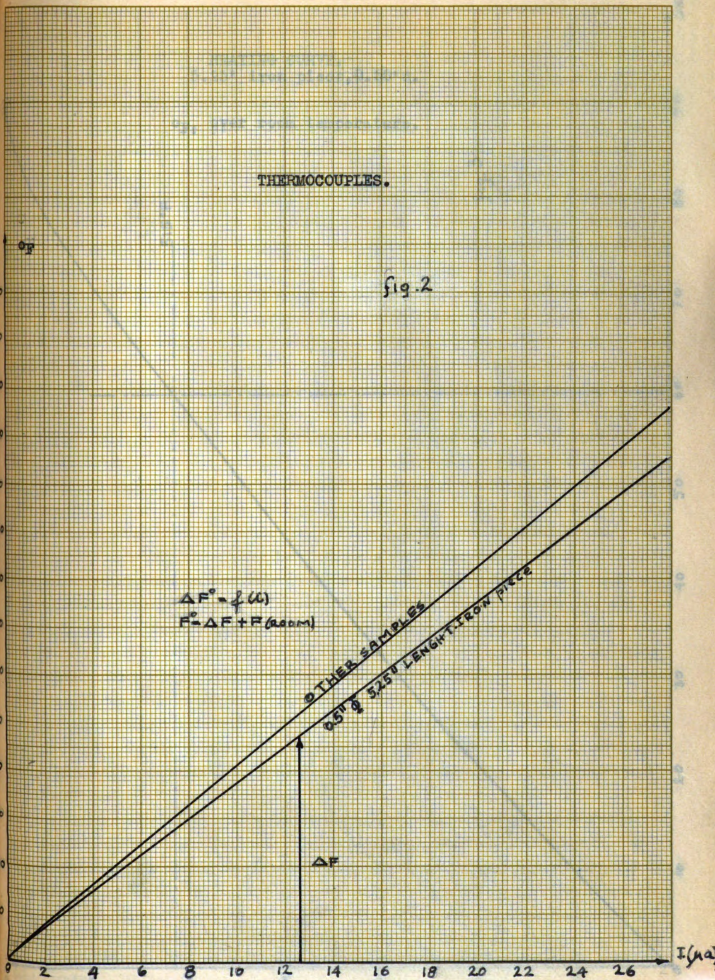
$$\Delta F^\circ = f(\omega)$$

$$F^\circ = \Delta F + F(\text{room})$$

OTHER SAMPLES
0.5" & 5.25" LENGTH IRON PIECE

ΔF

$I(\text{na})$

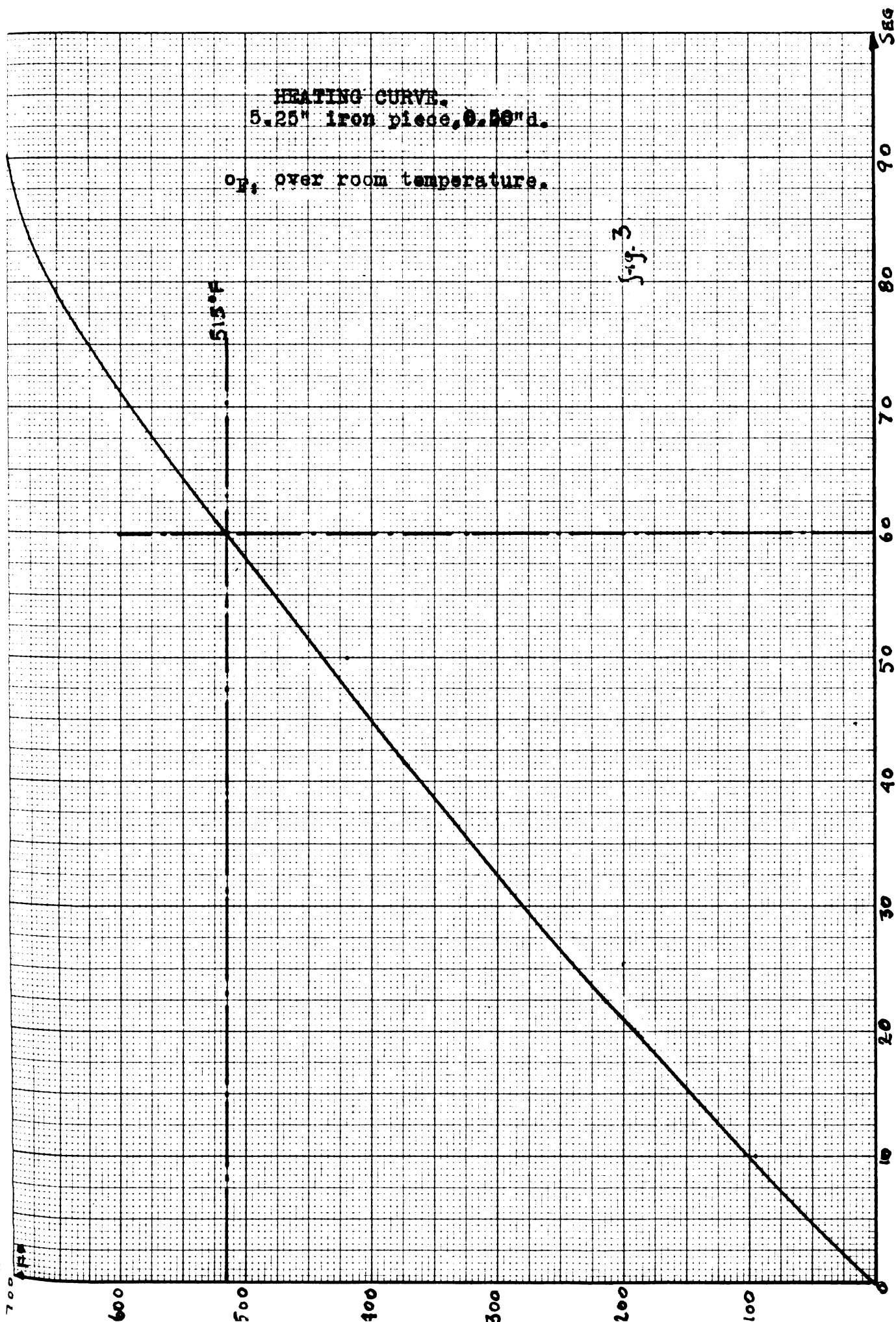


HEATING CURVE.
5.25" iron pipe, 0.50" d.

op. over room temperature.

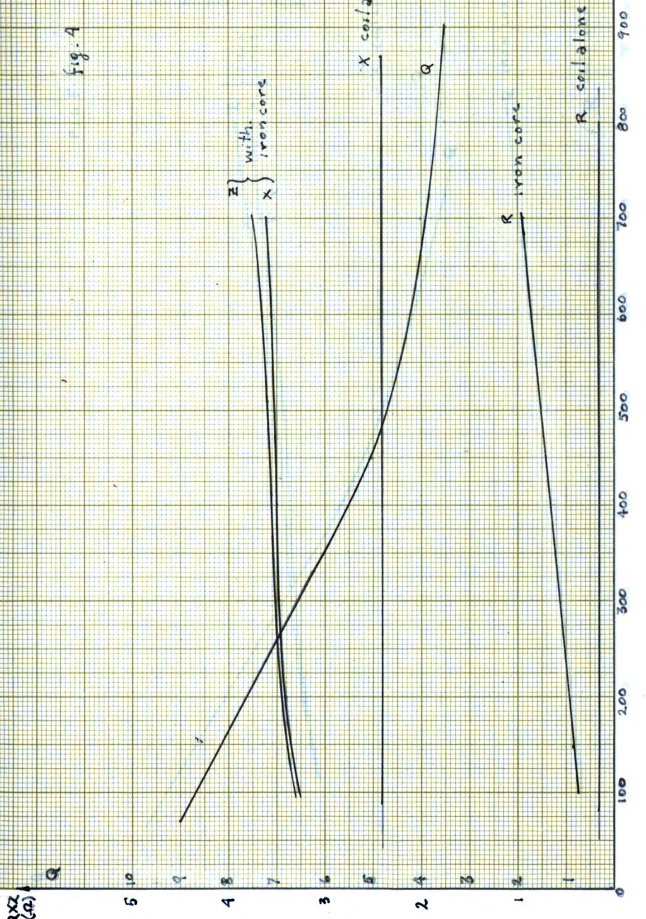
Fig. 3

515°F



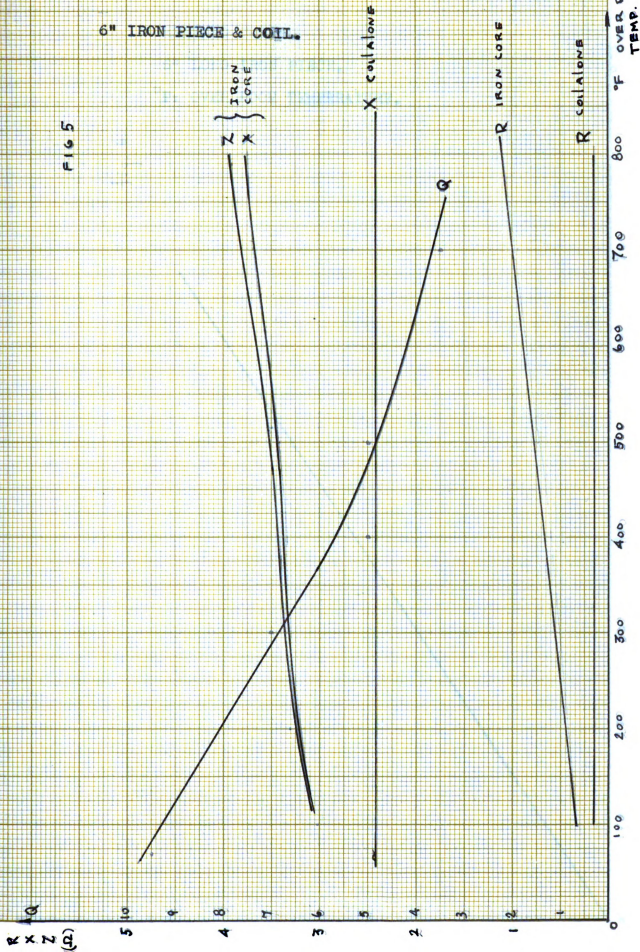
5.25" IRON PIECE & COIL.

Fig. A



6" IRON PIECE & COIL.

FIG 5

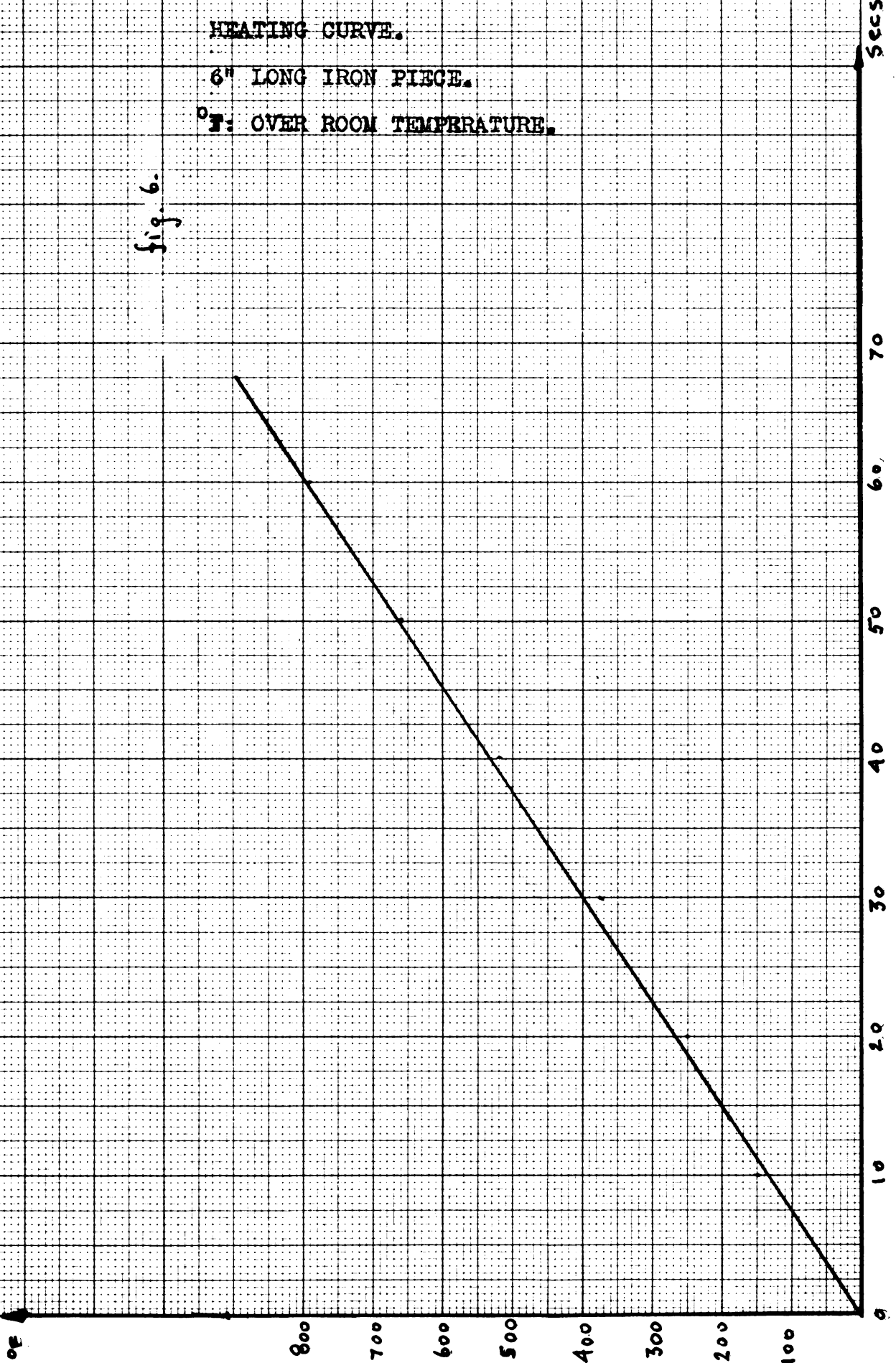


HEATING CURVE.

6" LONG IRON PIECE.

$^{\circ}\text{F}$: OVER ROOM TEMPERATURE.

fig. 6.

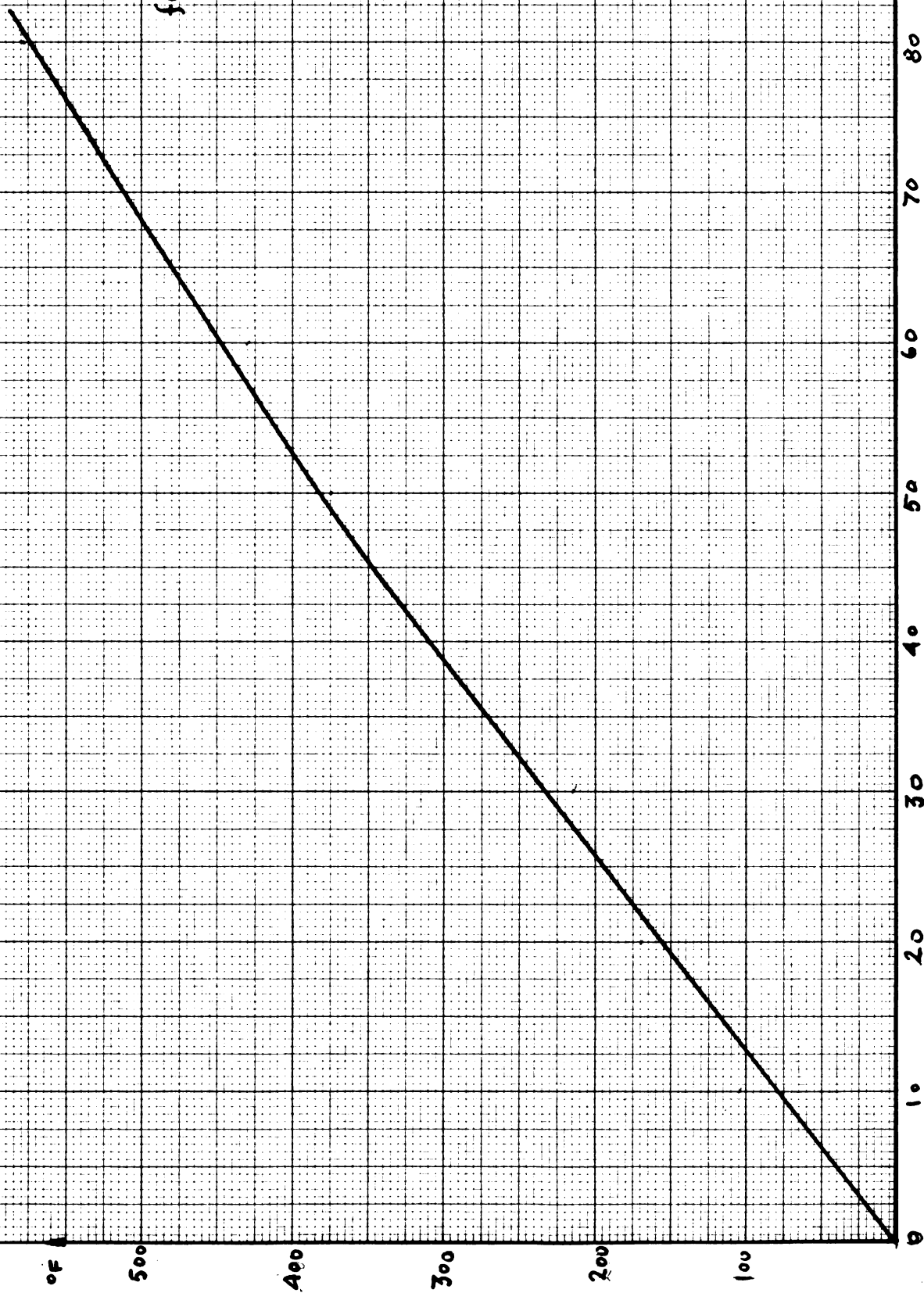


HEATING CURVE.

1.48" LONG IRON PIECE.

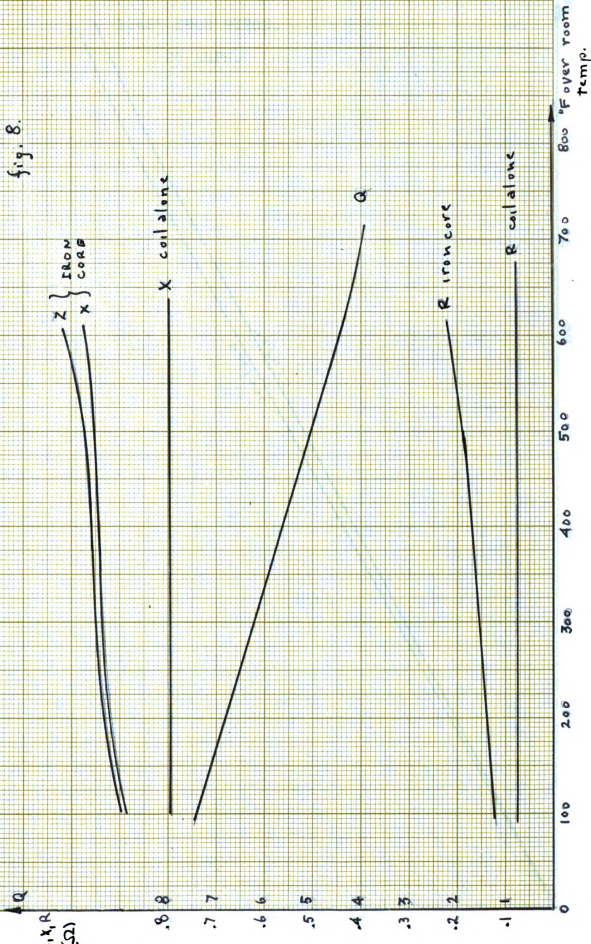
♦ F: OVER ROOM TEMP.

fig. 7.



1.48" IRON PIECE & COIL.

fig. 8.



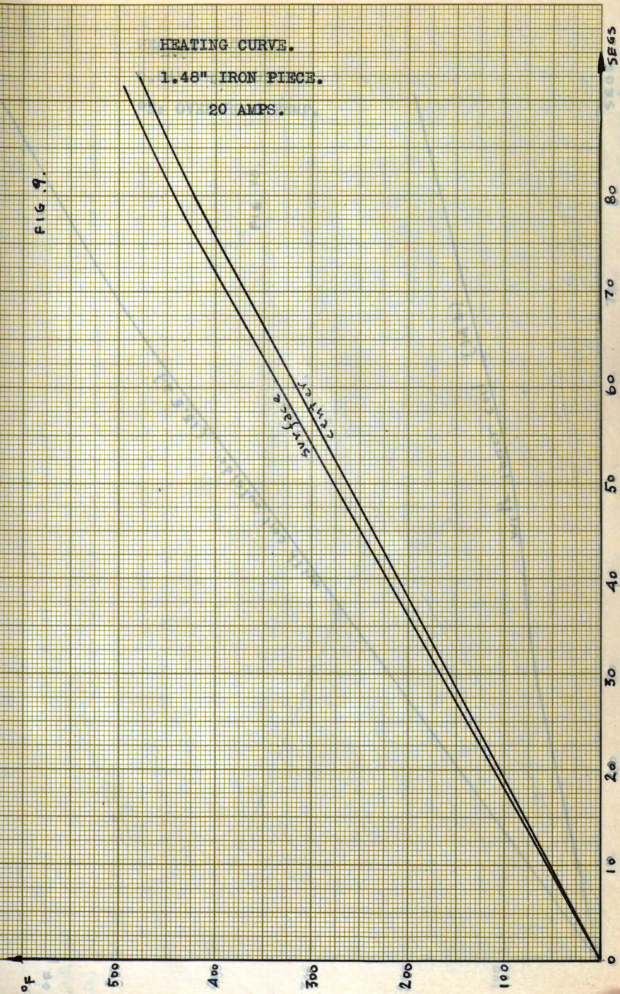
HEATING CURVE.

1.48" IRON PIECE.

20 AMPS.

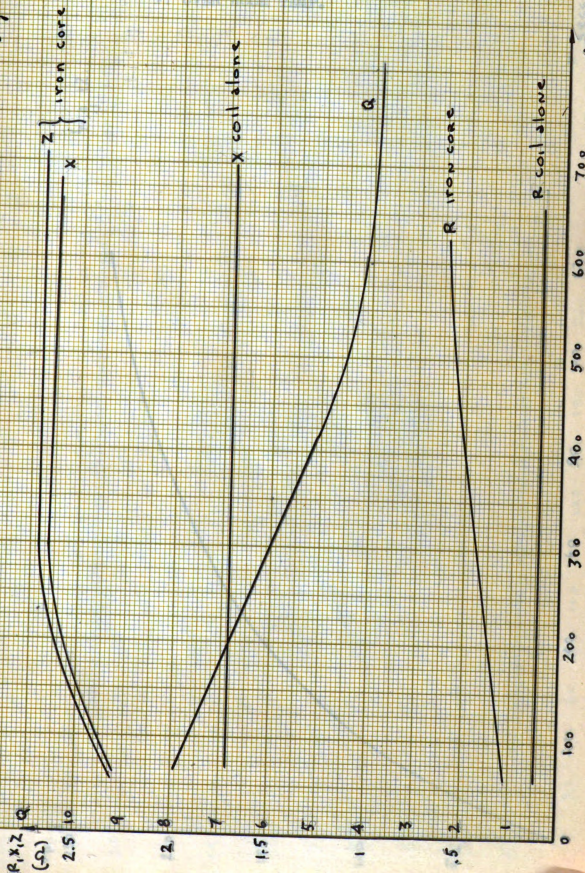
FIG. 9.

surface
center



0.24" IRON TUBING & OUTER COIL.

fig 11.



OF OVER ROOM
t. n

HEATING CURVE.

COPPER TUBING.

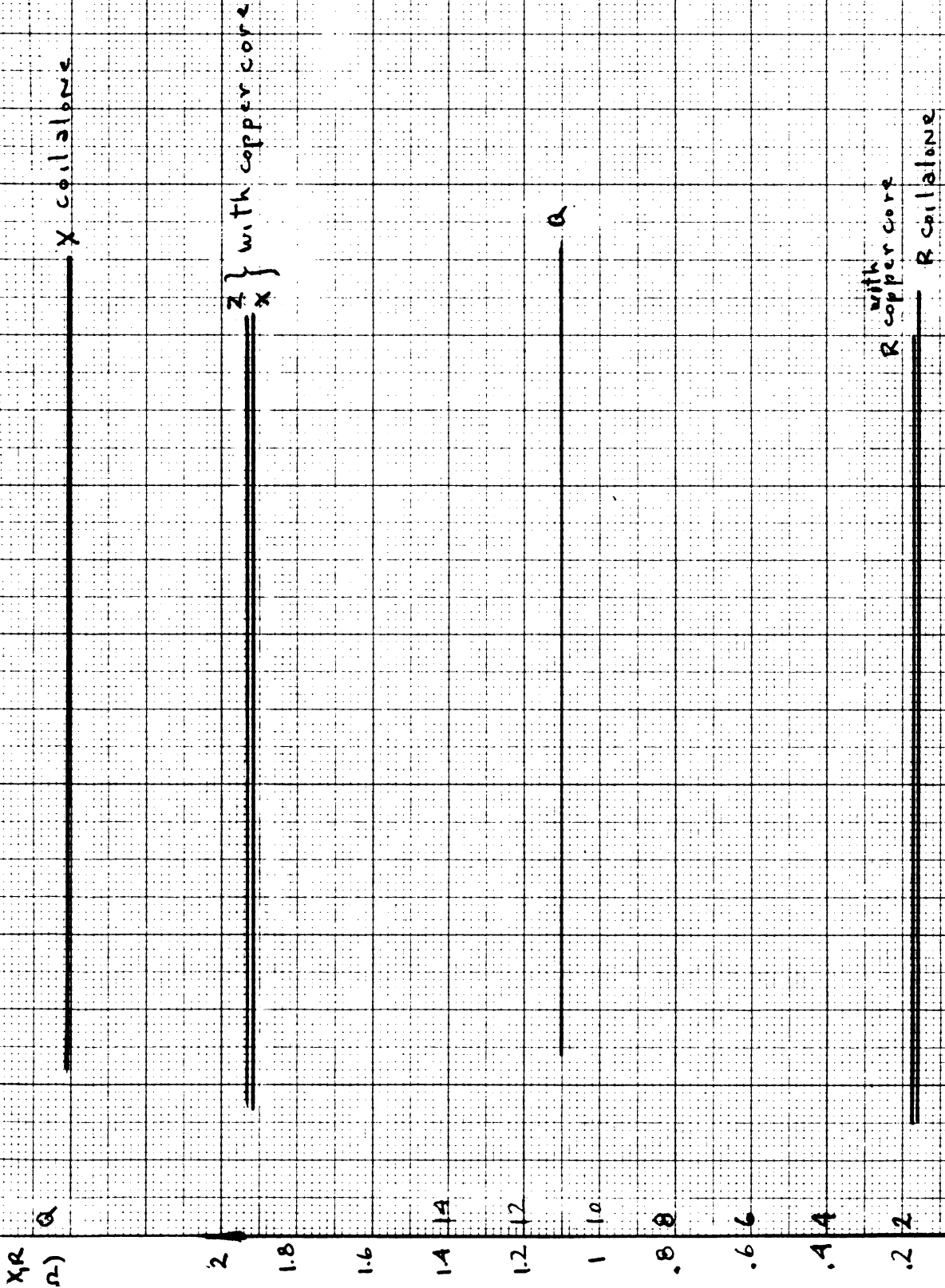
°F: OVER ROOM TEMP.

Fig 12.



COPPER TUBING & COIL.

fig 13.

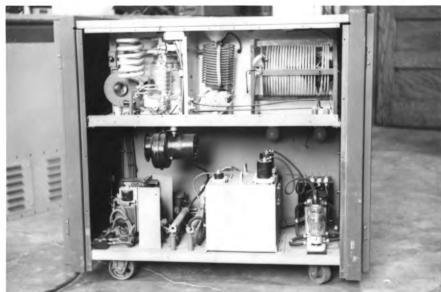


of over room temp.

0 20 40 60 80 100 120 140 160 180 200 220 240



FRONT VIEW OF THE EQUIPMENT USED



REAR VIEW



COILS AND CYLINDRICAL CONDUCTORS TO BE HEATED.

References

- Brown, Hoyler, Blerwith, "Radio Frequency Heating"
Van Nostrand Company, 1947.
- Bendz, W. I. "Electronics for Industry" (Wiley &
Sons), 1947.
- Ramo & Whinnery "Fields and Waves in Modern Radio"
Wiley & Sons, 1944.
- M-I-T Staff "Applied Electronics". Wiley & Sons,
1943.
- Markus & Feluff "Electronics for Engineers" McGraw
Hill, 1945.
- H. B. Dwight "Electric Coils and Conductors", McGraw
Hill, 1945.
- Terman, F. E. "Radio Engineers' Handbook" McGraw Hill,
1943.
- Baker, R. M. "Heating of non magnetic electric con-
ductors by magnetic induction - longitudinal flux"
AIEE Transactions, Vol. 63, June, 1944, P. 273.
- Baker, R. M. "Induction heating of moving magnetic
strip" AIEE Transactions, Vol. 64, April, 1945,
P. 184.
- Stancel, N. R. "Induction Heating - Selection of
Frequency" AIEE Transactions, Vol. 63, October,
1944, P. 755.

QUESTION

1. The following table shows the number of people who attended the 2010 World Cup in South Africa.

Country	Number of people (in millions)
South Africa	1.2
France	1.1
Germany	1.0
Italy	0.9
Spain	0.8
England	0.7
United States	0.6
Sweden	0.5
Denmark	0.4
Netherlands	0.3
Portugal	0.2
Switzerland	0.1
Other countries	0.1

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Sweden	0.5
Denmark	0.4
Netherlands	0.3
Portugal	0.2
Switzerland	0.1
Other countries	0.1

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