DESIGN AND STUDY OF A SMALL DISTRIBUTION TRANSFORMER

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PREFACE

This thesis is a detailed account of the design, construction, test, and operation of a constant potential transformer. It was written with the aim of clarifying many of the problems of transformer design and operation, and should be studied by the engineer with the hope of a clearer understanding of the subject. It has been assumed by the authors that the reader has an elementary knowledge of both alternating and direct current phenomena.

Chapter 1

GENERAL SURVEY OF THE FIELD

In 1830, Faraday discovered that an e.m.f. is generated in a conductor when the conductor is cut by magnetic lines of force. This was a discovery of very great importance. He found that voltage could be generated in the conductor by moving either the conductor or the flux, or both. In present day practice this principle is applied in various ways. In direct-current generators and motors, revolving conductors cut the stationary flux in the air gap under the field poles; in large alternating-current generators, the flux from revolving field poles cuts stationary armature conductors; while in transformers, stationary windings cut a periodically varying flux produced by an alternating m.m.f. in a stationary winding.

In the modern electrical age the transformer is of vital importance. It is the connecting link between economical and uneconomical power transmission; without it electricity would be of little use to the world. Thus it is seen that proper transformer design and operation go hand in hand with proper electrification.

Chapter 2

TRANSFORMER DESIGN

Given:- Output----------5 K.V.A.
Primary Voltage-----110
Secondary Voltage---110
Frequency----------60 cycles per second

In order to determine the number of turns necessary on each winding, the volts per turn are calculated as follows:

$$V_t = \frac{1}{c} \times \sqrt{\text{volt-ampere output}}$$ [1]

Assuming c=55 (distributing type transformer)

$$V_t = \frac{1}{55} \sqrt{5000} = 1.29$$

Primary turns = $\frac{110}{1.29}$ = 85 approximately

Try 84 turns, using 6 coils of 14 turns each for the primary and also for the secondary as the ratio is 1 to 1.

Rated primary current = $\frac{5000}{110}$ = 45.4 Amps.

Rated secondary current = 45.4 Amps.

In order to get the total flux, the following equation is used:

$$E_p = 4.44 f \phi T_p \times 10^{-8}$$

where E_p = Primary voltage

f = Frequency

ϕ = Total flux

T_p = Primary turns

$$\Phi = \frac{E_p \times 10^8}{4.44 f T_p} = \frac{110 \times 10^8}{4.44 \times 60 \times 84}$$

$$\Phi = 492{,}000 \text{ Lines}$$

[1] Still, Elements of Electrical Design

Assuming 70,000 lines per sq. inch as an allowable flux density,

$$\text{Core Area} = \frac{492000}{70,000} = 7.04 \text{ Sq. Inches}$$

Using a stacking factor of 0.8, the final necessary area of the core is

$$\frac{7.04}{0.8} = 8.75 \text{ Sq. Inches}$$

Having this final area, the respective dimensions can be chosen arbitrarily. For a small distributing transformer of this type a rectangular cross section is generally used. The length of the leg is usually from 1.5 to 2.5 times the width, these two dimensions forming the cross sectional area. The height of the leg is made to accommodate the coils. At the ends, however, the thickness of the core is usually increased in order to cut down the core loss.

The size of wire to be used is determined by assuming a safe current density and calculating the cross sectional area necessary.

As this thesis is primarily a study of leakage reactance, the further intricate phases of transformer design will be omitted.

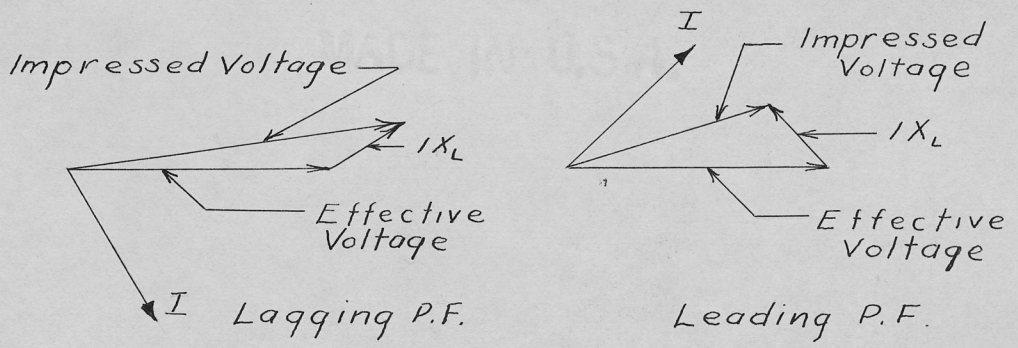
Chapter 3

STATE OF PURPOSE

The purpose of this thesis is to make a study of the leakage reactance of a transformer and the effect of coil arrangements upon it.

In any arrangement, all of the flux which links with the primary does not link with the secondary. A part of it completes its path by linking with the primary only or with the secondary only, as shown by figures 1 and 2. Some of the lines enclose only a few turns of the winding, while others include more. These lines complete their path through the air, and are known as "leakage flux". That flux linking with only the primary is known as "primary leakage flux", and similarily that linking only with the secondary is known as "secondary leakage flux".

These leakage fluxes vary with time as the currents in the respective windings producing them. They, therefore, induce in the corresponding windings voltages lagging the currents by 90 degrees. Hence they have the effect of a reactive coil in series with the primary and one in series with the secondary. The primary leakage flux opposes the flow of current into the transformer. Hence part of the applied voltage is used in overcoming this obstacle. Likewise part of the voltage induced in the secondary is used in forcing current out of the transformer. This is true as long as the power factor is not leading. Then the applied voltage may be raised by the leakage reactance as shown by the following vector diagrams:



Leakage flux exists in all transformers. With the primary wound all together on one leg of the transformer and the secondary on the other, obviously the leakage flux and hence the leakage reactance would be a maximum. Hence transformers are never built in this manner. In this study, two common coil arrangements are observed and facts concerning the leakage reactance in each arrangement determined.

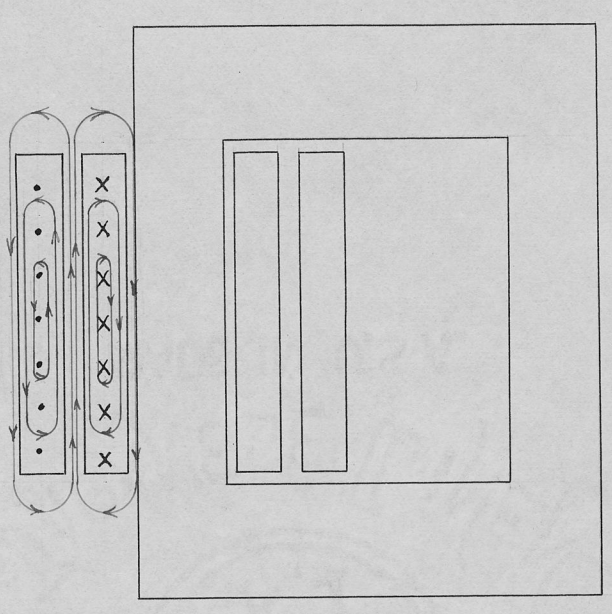


FIGURE 1
COIL ARRANGEMENT A

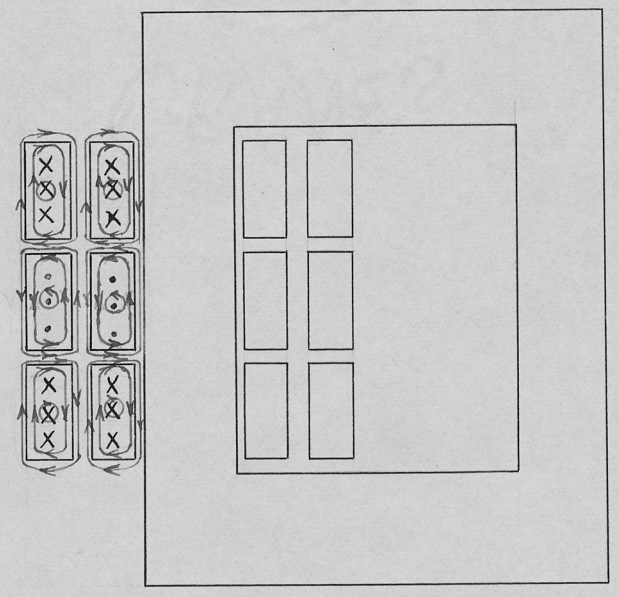


FIGURE 2
COIL ARRANGEMENT B

Chapter 4

CONSTRUCTION

Having designed the transformer core and coils, the problem was then that of determining the best method of varying the leakage flux. This obviously was to be accomplished by using different arrangements of the primary and secondary coils with respect to each other. At first, it was decided to make two separate sets of coils--one set consisting of a primary and secondary winding on each leg of the core, and one having three sets of windings on each leg. The top of the core was to have been easily removed so that either set of coils could be quickly assembled. Apparently this was a very good method, but it was discovered that there would exist between the movable and stationary parts of the core an air gap, irrespective of how the movable part was clamped. This air gap would have offered a higher reluctance to the flow of the flux around the core than if there were no air gap. This would be a very undesirable condition.

It was then decided to make six coils for each leg, three outer coils and three inner coils, and to bring each terminal of the coils out to the terminal board. This meant that there would be twelve separate windings, and twenty-four terminals on the board. In this manner the windings could be connected in any desirable arrangement without having to remove the top of the core each time.

Chapter 5

PROCEDURE FOR TEST

Sources of Error.--There were only two important sources of error in this test. The most important was in maintaining constant voltage on the primary of the transformer. The regulation test for a transformer must be carried out with a constant voltage on the transformer. Another source of error was in the voltage, current, and power measurements.

Precautions Taken To Avoid Errors.--The best method to maintain constant primary voltage was obviously to have used an induction voltage regulator in the primary circuit, but it was found that the rated current of the regulator was much lower than the rated current for the transformer, and thus could not be used.

The main power supply could not have been used, for as the secondary of the transformer was loaded, the primary voltage would have decreased.

It was then decided to obtain the power supply from one of the synchronous Motor-Generator sets, varying the field excitation of the generator to obtain the constant voltage necessary.

The errors involved in making the measurements varied directly as the constants for the meters. Thus to make the errors as small as possible, the constants for the meters were made as small as possible in each case.

Measurements Made.--1. A resistive load was connected in the secondary with meters for measuring the primary and secondary voltage, current, and power, and the load was varied from no-load to 1 1/2 times the rated load for the transformer. The meters were read and the readings tabulated for each variation of the load. This procedure was carried out for both coil arrangements, A and B.

2. The above procedure was repeated with a low power factor load in the secondary.

RESISTIVE LOAD COIL ARRANGEMENT A

E Volts	I Amps.	W Watts	E Volts	I Amps.	W Watts	Eff. %
110	9.65	1047	107	8.9	960	91.7
"	13.7	1520	106.6	13.2	1420	93.4
"	18.05	1990	105.7	17.45	1860	93.5
"	22.0	2415	104.3	21.5	2290	94.8
"	29.0	3220	104	28.6	2980	92.6
"	30.3	3320	103	29.75	3080	92.8
"	34.3	3800	103	34.0	3520	92.7
"	38.6	4280	102	37.85	3840	90
"	42.2	4660	101.2	41.7	4240	91.1
"	49.5	5480	100	49.3	4944	90.3
"	62.1	6848	97.3	60.8	5888	86

INDUCTIVE LOAD COIL ARRANGEMENT A

E Volts	I Amps.	W Watts	E Volts	I Amps.	W Watts	Eff. %
110	3.83	84.0	108.2	2.05	12	14.3
"	9.08	131.2	108.5	7.4	52	39.6
"	11.28	156.8	108.0	9.6	68	43.4
"	15.52	234.8	108.0	13.88	112	47.8
"	23.4	321	107.8	21.9	150	46.7
"	28.1	408	107.0	26.8	190	46.5
"	34.3	523	106.5	33.0	230	44.0
"	44.8	750	105.7	44.0	304	40.5
"	54.4	1008	104.8	53.6	384	38.1
"	64	1245	103.8	62.7	464	37.3

RESISTIVE LOAD COIL ARRANGEMENT B

E Volts	I Amps.	W Watts	E Volts	I Amps.	W Watts	Eff. %
110	2.71	205	108.2	1.44	156	76.1
"	4.8	490	108.0	3.85	420.8	86.0
"	6.5	691.5	107.5	5.75	618	89.5
"	10.8	1155	106.5	10.0	1060	91.8
"	14.8	1598	105.5	14.0	1483	92.9
"	20.8	2270	104.6	20.0	2110	93.1
"	23.8	2578	103.0	23.0	2400	93.2
"	30.1	3280	101.9	29.5	3040	92.7
"	33.7	3645	100.6	33.0	3346	91.7
"	37.2	4025	99.5	36.4	3666	91.0
"	43.0	4620	98.7	42.5	4180	90.0
"	48.8	5340	98.0	47.9	4815	90.0
"	56.0	6120	96.0	54.7	5400	88.1
"	63.5	6800	94.0	61.9	5880	86.5

INDUCTIVE LOAD COIL ARRANGEMENT B

E Volts	I Amps.	W Watts	E Volts	I Amps.	W Watts	Eff. %
110	3.05	78.8	108.5	1.2	6.5	8.25
"	8.3	120.0	107.0	6.6	37.5	31.3
"	11.0	151.0	106.0	9.45	57.5	38.0
"	15.85	234.0	103.3	14.3	110.0	47.0
"	20.6	305.0	102.2	19.05	140.0	46.0
"	25.5	392.5	100.0	24.1	177.5	45.2
"	31.3	463.0	97.8	30.3	200.0	43.2
"	36.0	555.0	96.0	35.0	220.0	39.7
"	42.0	691.0	94.0	41.1	260.0	37.5
"	47.2	830.0	91.5	46.7	305.0	36.7
"	58.4	1120	88.2	57.1	368.0	32.9
"	65.1	1358	85.2	63.6	432	31.9

Chapter 6

CALCULATIONS

Voltage Regulation at Rated Current.

I. Low Power Factor Load

a. Coil Arrangement A

$$V.R.= \frac{110-105.5}{110} \times 100 = 4.1\%$$

b. Coil Arrangement B

$$V.R.= \frac{110-92.5}{110} \times 100 = 16\%$$

II. Resistive Load

a. Coil Arrangement A

$$V.R.= \frac{110-101}{110} \times 100 = 8.2\%$$

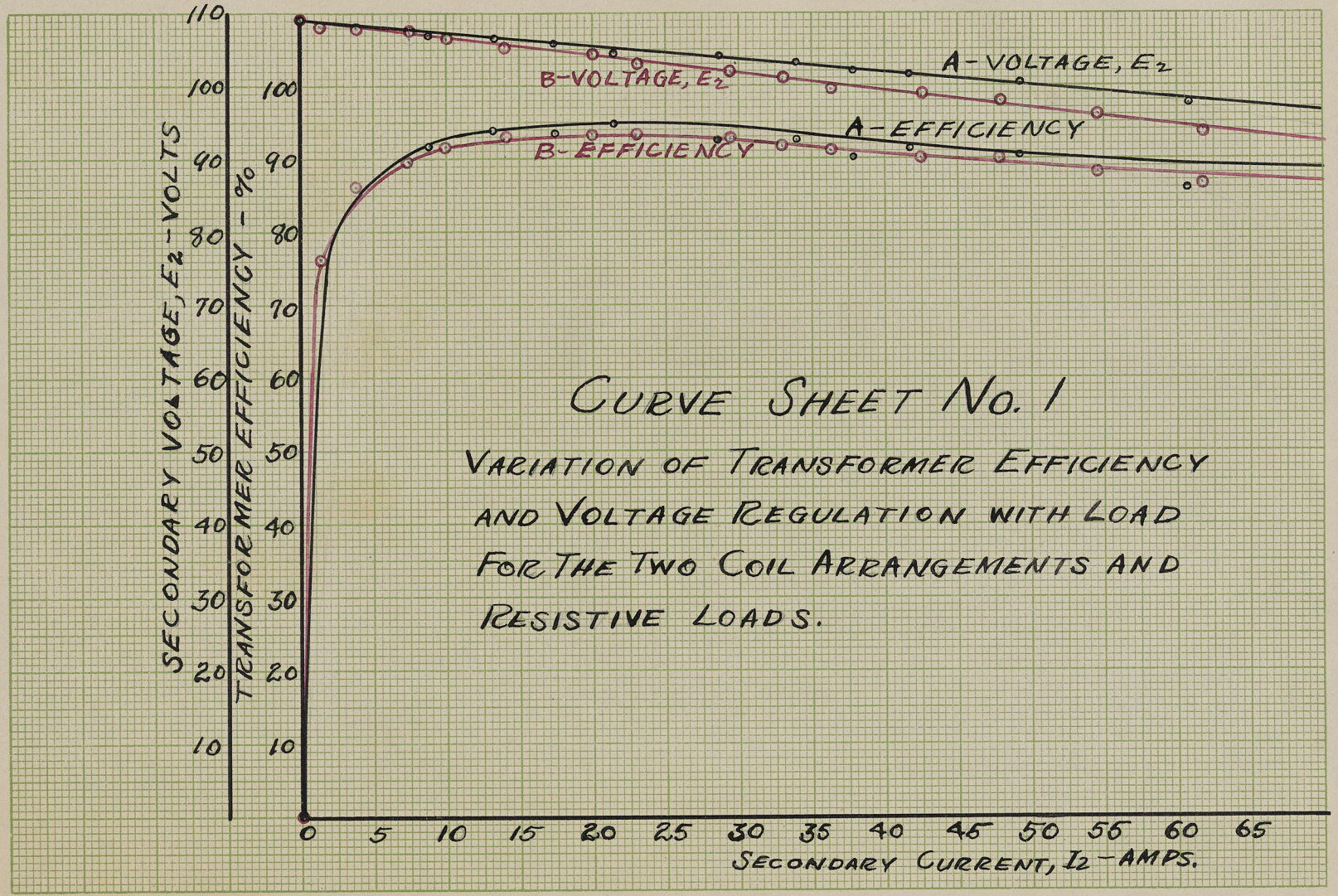
b. Coil Arrangement B

$$V.R.= \frac{110-98}{110} \times 100 = 11\%$$

III. Efficiency

$$Eff.= \frac{Output}{Input} \times 100$$

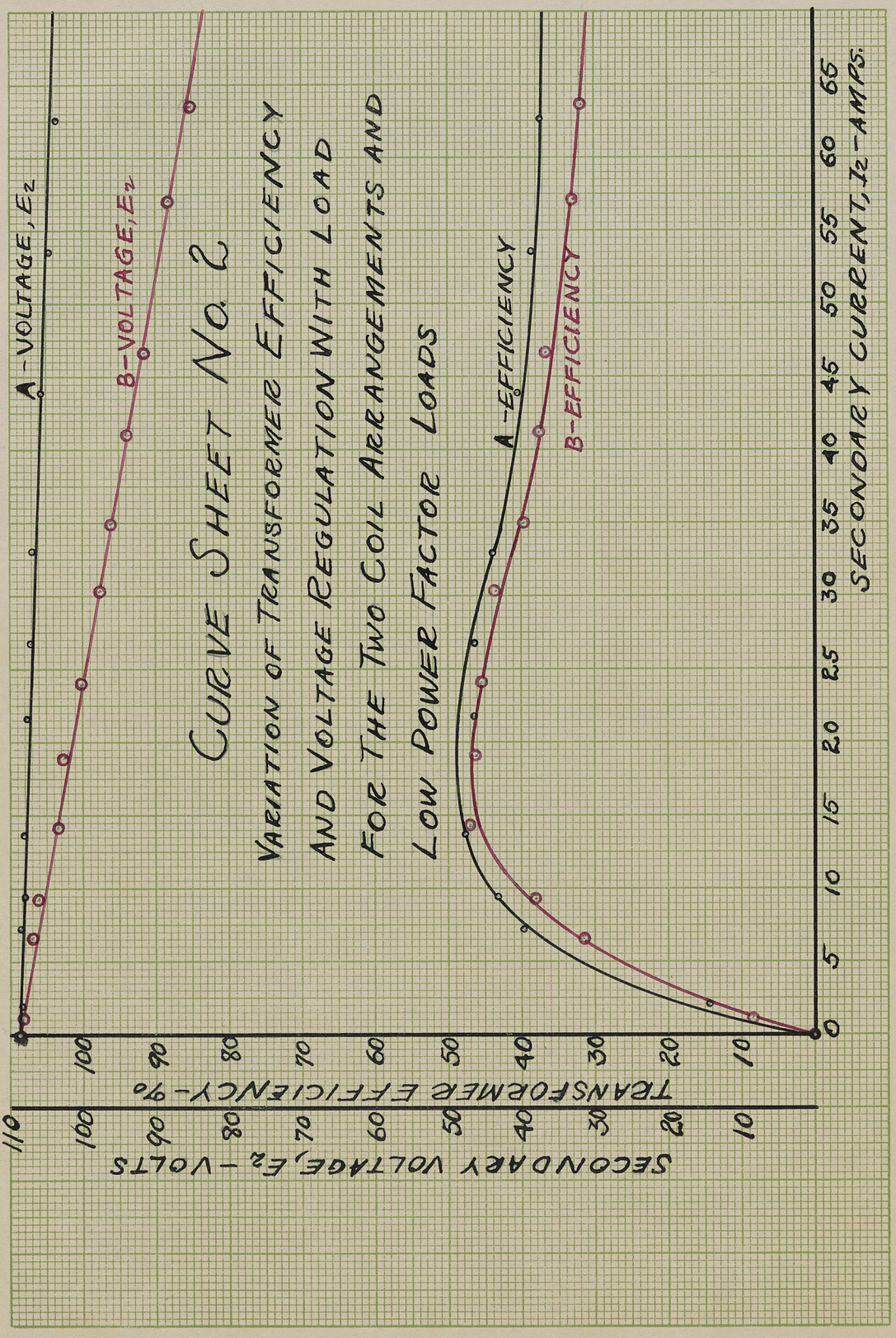
Eff. = 90.5% for both coil arrangements at rated current, resistive load.



CURVE SHEET NO. 1

VARIATION OF TRANSFORMER EFFICIENCY AND VOLTAGE REGULATION WITH LOAD FOR THE TWO COIL ARRANGEMENTS AND RESISTIVE LOADS.

Published by The H. Cole Co., Columbus, Ohio. No. 290 G.



Published by The H. Cole Co., Columbus, Ohio. No. 290 G.

Chapter 7

RESULTS AND CONCLUSIONS

The curve sheets show very nicely the different leakage reactances of the two coil arrangements. In both the resistive load and the low power factor load, coil arrangement B showed a greater leakage reactance than arrangement A.

The voltage regulation curve for arrangement B dropped considerably more in the low power factor load than in the resistive load. This is due to the phase position of the IX_L drop as has been shown by a previous vector diagram.

The efficiency curves practically coincide. They would be expected to be about the same since the leakage reactance does not consume power, but acts as a pure inductance in series with the transformer.

It is obvious therefore, that in order to obtain a low leakage reactance a design similar to the coil arrangement A would be followed, rather than that of B.

BIBLIOGRAPHY

1. Still's ELEMENTS OF ELECTRICAL DESIGN

2. Karapetoff's EXPERIMENTAL ELECTRICAL ENGINEERING*VOL.I

3. Dawes' ELECTRICAL ENGINEERING

4. Tarboux's ALTERNATING CURRENT THEORY * VOL.II

APPROVAL

The foregoing thesis is hereby approved as a creditable study of an engineering subject, carried out and presented in a manner sufficiently satisfactory to warrant its acceptance as a prerequisite to the degree for which it has been submitted. It is to be understood that by this approval the undersigned does not necessarily endorse or approve any statement made, opinions expressed, or conclusions drawn therein, but approves the thesis only for the purpose for which it is submitted.

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