DESIGN OF A 3 PHASE SPECIAL TRANSFORMER

THESIS FOR DEGREE OF B. S.

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DESIGN AND CONSTRUCTION
OF A
12 KW. SPECIAL TRANSFORMER

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to

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of

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Contents.

Introduction.

An explaination of the situation is the first step in establishing an understanding and unless one knows what is to be done there is not much use in going ahead with any kind of work. This introduction will show the situation as it was and will outline the steps taken giving the reasons for this method of attack.

The power panel board in the laboratory at Michigan State College has thereon a 220 volt D.C. circuit and it was desired that there be a source of 110 volts D.C. This would be made possible by an Edison three wire system and inasmuch as an inverted convertor was available, the most systematic way of completing this setup was to load the convertor with a star connected transformer and bring out the neutral for the third wire of the Edison system. Upon investigating the characteristics of simple star transformers for this job, there was a set in the lab, it was seen that when a heavy D.C. load to neutral was thrown on that the unbalanced D.C. flowing through the windings would saturate the transformer cores and cause a current to be drawn from the rotary which had a strong lagging component. The lagging current weakened the field of the rotary and it would tend to race . This situation was met by using interconnected star primaries on the transformers; the reason being that with this connection the unbalanced D.C. flows through the windings in such a way that their m.m.f's neutralize each other and do not affect the operation of the rotary.

It was also desirous to have 110 and 220 volts A.C. as a source of power in the laboratory to be used alone or in parallel with other machines. The solution to this part of the problem was to put a 110 and 220 volt secondary on the transformer. It was not necessary to bring this neutral out, neither was it necessary to keep it free from triple harmonic voltages so the simple star connection was used because of its requiring less wire, being cheaper, and filled the requirements as well as was necessary.

This thesis deals with the design, construction, and testing of a transformer with the following specifications; Interconnected star primary with neutral tap brought out, 110 and 220 volt secondary using the simple star connection. This transformer is to use the A.C. output of an inverted convertor as a source of power.

It is readily seen that one must be familiar with the voltage and operating characteristics of a rotary convertor in order to get the best results in this thesis so a short summary of the convertor has been included.

The author wishes to acknowledge his indebtedness to Professors Foltz and Cory for their suggestions and to Professor Naeter for his assistance throughout the work.

The Interconnected Star Connection.

In the case under consideration there is an inverted rotary convertor already installed and a three wire D.C. circuit is desirable. The three wire arraingement is obtained by connecting the neutral wire of the system to the neutral point in the primarys of the transformers. In such cases the connections should be arrainged so that the direct current in each transformer divides into two branches of equal ampere turns. This is to prevent any undirectional magnetic flux in the transformer cores which, if added to that which is already there due to the 60 cycle current, would tend to saturate the cores to a point past which it is not advisable to operate. This in turn would cause excessive heating and exciting current, except where the unbalanced current is comparitively small. The inter-connected star arraingement eliminates the flux distortion due to the unbalanced D.C. in the neutral. Two separate interconnected windings are used for each leg of the star. The unbalanced neutral current flowing in this system may be compared in its action to the affect of a magnetizing current in a transformer. The affect of the main transformer currents in the windings is balanced with regard to the flux in the circuit, and the flux in the magnetic circuit depends upon the magnetizing current. When a direct current is passed through the transformer its affect on the transformer iron varies as the magnetizing current unless the fluxes produced by it neutralize one another. If a distributed winding is used, the D.C. flows in opposite directions around the two halves of each winding and neutralizes the flux distortion.

When it comes to a decision between simple and inter-connected star transformers it is only a question of balancing the increased iron loss of the straight star against the increased copper loss, and the greater cost of the inter-connected star. E.G.Reed in his book on Transformer Practice states that the straight star is much simpler and would be permissable to use for transformers of small capacity where the direct current in the neutral is not more than 30 percent (10 percent per transformer) of the rated transformer current. The current in the neutral in this special case may run as high as 45 amperes and the average will be 30 to 35 amps while the rated current of the transformer will be in the neighborhood of 50 amps. It is readily seen that the interconnected star connection will be necessary, the average percentage being about 30 percent.

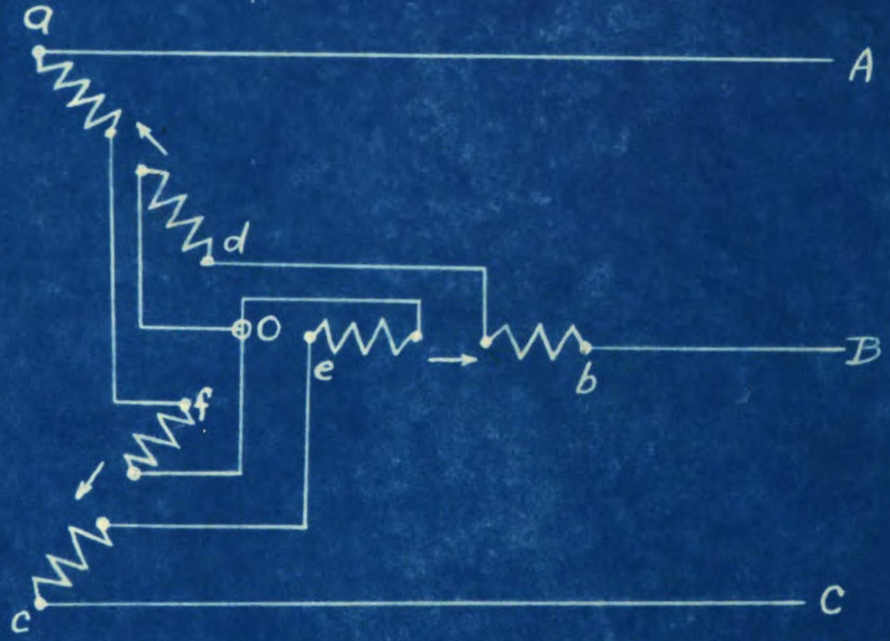
This topic is also discussed, with especial emphasis laid on the part the transformer plays in the operation of the rotary , under the next heading - Rotary Convertors.

Voltage Relations.

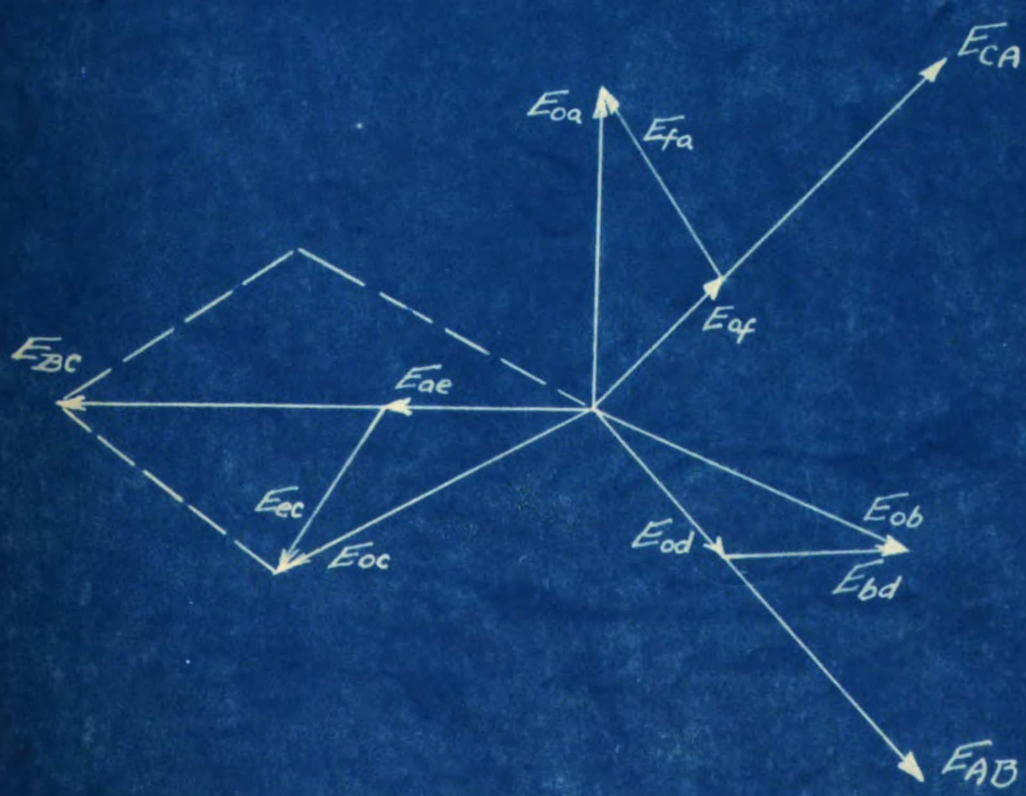
The connection diagram and vector voltage relations for the interconnected star are on the accompanying sheet. The voltage E_{OC} equals $\sqrt{3}$ E_{Oe} ,and the voltage E_{BC} equals $\sqrt{3}$ E_{OC}. Therefore E_{Oe} equals one-third E_{BC}. In other words each half of the secondary winding of each transformer has a voltage of the interconnected star voltage between the lines B and C or the voltage E_{BC} . For example,the voltage E_{OC} between the neutral point and one of the lines is 30

CONNECTION AND VECTOR DIAGRAMS.

INTERCONNECTED STAR TRANSFORMERS.



Secondary CONNECTION DIAGRAM.



VECTOR DIAGRAM.

M.G.H. '36.

The Rotary Convertor.

It is frequently necessary to obtain direct current when the available supply is alternating. Such,for instance, is the case with many electric railways,arc lighting systems etc. Changing from direct current to alternating current is also,but less frequently,required. The second is the case in the laboratory at Michigan State College where there is a D. C. supply of 220 volts and an inverted convertor available. This work of conversion from D.C. to A.C.,or vice versa, is done to great advantage by means of the rotary convertor. When used to change A.C. into D.C. it is called a direct convertor and when the reverse is true, namely a conversion from D.C. to A.C.,it is called an inverted convertor.

A rotary is a motor and generator combined into one because it receives and transmits electrical energy. If it is driven by mechanical power it may give out electrical power either in the form of direct current or alternating current or even both at the same time. It follows,then, that the convertor can work in one of four ways which are ;direct current generator, direct current motor, synchromous motor, and alternator. In any case its performance becomes that of one of these machines or a combination of them, and may be studied in that light.

There are two main objects in the construction of this thesis transformer,the first of which is to obtain a neutral for an Edison three wire system and the second is to get suitable output voltages so that this convertor may be used as a source of power in parallel wihh other machines in the laboratory,with the power house supply, or alone.

When an inverted convertor is operated in parallel with another source of A.C. its speed will be fixed by the alternator because they must operate in synchronism. If, however, the convertor is the only source of A.C., the speed will be affected by a change in field strength in the convertor and the machine will act as a shunt wound motor. It follows that an inductive load on the A.C. side of an inverted convertor, when operated alone, would tend to weaken the field and cause the machine to speed up. For this reason an inverted convertor should have overspeed protective devices.

The design in this thesis has a direct bearing on what has been stated in the previous paragraph. If a simple star transformer is connected on the A.C. output of the rotary to derive the neutral for an Edison three wire system and a heavy D.C. load to neutral is applied, it will cause considerable unbalanced D.C. to flow through the transformers. This unbalanced D.C. will saturate the core of the transformer to such an extent that the magnetizing A.C. will increase very materially and reduce the power factor on the A.C. side. The lagging current component decreases the field flux and the convertor speed increases. It follows that if the D.C. load were thrown on to neutral suddenly the convertor would tend to race to such an extent that the overspeed devices would operate and take the machine off the line.

The use of interconnected star transformers eliminates this by dividing the primary into two parts and putting half of the primary on the next core and connecting those on the same core in such a manner that they are "bucking" each other as far as the D.C. is concerned.Then the mmf's set up by the D.C. are neutralized,thus keeping the flux density in the transformer cores the same and this in turn does not give the rotary any chance to race because of its field becoming weakened.

It is evident that the voltage and current ratios of the unit taken as a whole are important . These are explained to some detail in the succeeding paragraphs.

Voltage Ratios.

Symbols used; f = frequency.

b = flux per pole cutting the conductors.

t = total number of turns between brushes.

The fundimental equation of a D.C. generator has been found to be -

$$E = \frac{4\ f\ b\ t}{10^8} \quad \text{volts.}$$

If the armature is tapped at two symmetrical points,for each pair of poles,and the taps brought out to slip rings, then the voltage across the slip rings according to the fundimental equation for A.C. generators is;

$$E = \frac{4.44\ f\ b\ t}{10^8} \quad \text{effective volts}$$

The previous equation holds only for concentrated windings. For distributed windings it is ;

$$E = \frac{2}{\pi} \times \frac{4.44\ f\ b\ t}{10^8} \quad \text{effective volts.}$$

and by substituting for 4.44 its equal 2 the maximum voltage is

$$E = \sqrt{2} \times \frac{2}{\pi} \times \frac{2\ f\ b\ t}{10^8} = \frac{4\ f\ b\ t}{10^8} \quad \text{volts}$$

which is the same as for direct current.

In polyphase machines it is more convenient to use one-half the D.C. voltage and then use phase voltage,or voltage to neutral for the A.C.

The D.C. voltage to neutral then is;

$$E_n = \frac{E}{2} = \frac{2\ f\ b\ t}{10^8} \quad \text{volts.}$$

Single phase voltage to neutral then is;

$$\frac{E_n}{2} = \frac{E}{2\sqrt{2}}$$

and in a three phase machine te slip ring voltage is;

$$\sqrt{3}\ E_n = \sqrt{3} \times \frac{2\ f\ b\ t}{10^8} \quad \text{volts.}$$

In an N phase machine; the maximum voltage between rings,

$$E_m = 2\ E_n \times \sin\frac{\pi}{N} = E \times \sin\frac{\pi}{N} \quad \text{volts.}$$

The effective ring voltage is;

$$E_{eff} = 2\ E_n \times \sin\frac{\pi}{N} = \frac{E}{2}\ \sin\frac{\pi}{N} \quad \text{volts.}$$

A three phase convertor is the one dealt with in this thesis ,therefore the following will be true;

$$E_n = \frac{E}{2} = \frac{220}{2} = 110 \text{ volts.}$$

and $\quad E_m = 220\ \sin\frac{\pi}{3} = 191$ volts. (phase)

and $\quad E_{eff} = \frac{220}{2}\ \sin\frac{\pi}{3} = 135$ volts. (phase)

The preceeding discussion only applies to a condition under which the A.C. voltage follows the sine law. Steinmetz shows mathematically that if the A.C. voltage wave is flat the D.C. voltage will be lower,and conversely if the A.C. voltage wave is peaked the D.C. will be higher. This is found to be the case in tests on convertors.

Design of the Transformers.

GIVEN: Core stampings for the transformers, with dimensions as shown on the accompanying drawing. The loss due to hysteresis and eddy currents in this iron is approximately 1.36 watts per pound as determined by tests on similiar iron in the department, This figure is apt to vary but will be sufficiently accurate for the computations.

REQUIRED: Complete design of a three phase, interconnected star transformer with rating as 4 KVA per phase.

Note; All computations are for one phase.

** ** **

Volume of Iron;

(The core stampings are <u>6</u>" deep per phase)

Volume = (Exterior volume) - (Window volume) also
- volume cut off the corners.

$= (9.25 \times 6.75 \times 6) - (5.75 \times 3.25 \times 6) - 6.$

= 256.5 cubic inches.

Weight of iron;

Weight = (Weight per cu.in.) x (Volume)

$= .26 \times 256.5$

= 66.75 lbs per phase.

Iron Loss (per Phase)

Given ; loss is 1.36 watts per pound.

Loss = Loss per lb. x Weight.

$= 1.36 \times 66.75$

= 91.3 watts loss per phase.

Preliminary Design.

Terms Used; E_p = Primary Voltage.

f = frequency.

N = Number of turns.

A = Area of core.

B = Flux density. = (60,000 lines)

** **

Number of primary turns; (.85 is lamination factor)

$$N_p = \frac{E_p \times 10^8}{f\ A\ B\ 4.44}$$

$$= \frac{135/\sqrt{3} \times 10^8}{60\ (6 \times 1.75 \times .85) \times 4.44 \times 60{,}000}$$

$$= 54.8$$

Actual Number of primary turns;

(Due to phase relationship of half the coil)

$$N_p = 2 \times 54.8/\sqrt{3} \quad 63.4$$

N_p = use 64.

Effective Primary Turns.

It is the effective turns that produce the flux, and all relations must take this into account.

$$\text{Effective turns} = \sqrt{3} \times 64/2 \quad 55.4$$

Number of secondary Turns;

$$N_s = N_p \times E_s/E_p$$

$$= 55.4 \times 110/135$$

N_s = 45 for 110 volts.

N_s = 90 for 220 volts.

Current Densities.

Use current density of 1500 amperes per square inch for first approximation and assume the full-load copper loss equal to the iron loss which will give highest efficiency at full load.

Primary Current;

$$I_p = \frac{\text{(Watts rating plus Losses)}}{\sqrt{3} \times \text{Voltage}}$$

$$= 3(4000 + 182) / \sqrt{3} \times 135$$

$$= 53.8 \text{ amps.}$$

Wire size;

Area of wire = amperes/ amperes per sq. in.

= 53.8 /1500

= .0359 sq. in.

From wire tables use 2 # 6's in parallel which will give the necessary area and be easy to handle.

Area of 2 #6's in parallel = .0412 sq. in.

Current density then is ;

53,8/.0412 = 1305 amps per sq. in.

Resistance of 2 #6's in parallel ;

$$R = (.3951)^2/2(.3951)$$

$$= .1975 \text{ ohms per 1000 feet.}$$

** ** **

Preliminary Design.

Losses.

Resistances.

Resistance of a coil = (Number of turns)x(Mean length of turn in feet)x(Resis.per ft)

By inspecting the assembly drawing it can be seen that the mean lengths per turn are as follows;

Primary = 1.5 feet.

Secondary = 1.8 " (110 volt sec.)

" = 2.0 " (220 part of sec.)

R_p = 64 x 1.5 x .1975/1000

= .01952 ohms.

R_s = 45 x 1.8 x .1975/1000

= .01628 ohms for the 110 volt secondary.

The 220 volt part of the secondary is made of single wire while the 110 part is double. It follows that the resistance of the 220 volt circuit is 1.5 times that of the partial 220 volt coil, there being the same number of turns in each.

R_s = 220 volt total

= 1.5 x 45 x 2 x .3951/1000

= .0534 ohms.

Currents.

I_p = 53.8 from previous work.

I_s = 3(4000)/110 x$\sqrt{3}$ 63 amps (110 volts)

Is 3(4000)/220 x$\sqrt{3}$ 31.5 amps (220 volts).

Preliminary Design.

I^2R Losses.

$$I^2R_p = (53.8)^2 x (.01953)$$
$$= 56.5 \text{ watts.}$$

$$I^2R_s = (63.0)^2 x (.01628) \qquad (110 \text{ volts})$$
$$= 64.6 \text{ watts.}$$

$$I^2R_s = (31.5)^2 x (.0534) \qquad (220 \text{ volts})$$
$$= 53.0 \text{ watts.}$$

It is seen that the largest possible computed losses are when the output is at 110 volts. By figuring through for the worst case the limits will be found.

Total I^2R losses per phase ; (using worst case)

$$\text{Loss} = 56.5 + 64.6$$
$$= 121.1 \text{ watts per phase.}$$

Grand total losses per phase;

$$\text{Total loss} = I^2R + \text{Iron loss.}$$
$$= 121.1 + 91.3$$
$$= 212.4 \text{ watts.}$$

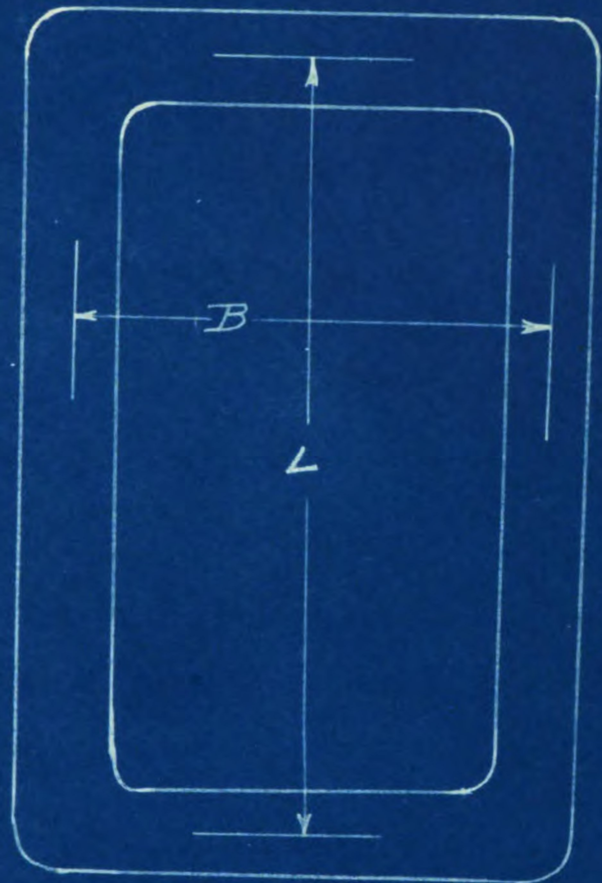
There are approximately 250 square inches of radiating surface per phase on the finished transformer.

Watts radiated per square inch;

$$= 212.4/250$$
$$= .848 \text{ watts}$$

.85 watts per square inch is very high and can not be tolerated for an air cooled transformer. Design data shows it is not advisable to go above .5 watts per sq. in.

COIL DATA.



All coils are $2\frac{1}{2}$" wide at the face.

Dimensions of the average turn.

Primary Coils.

B is $2\frac{1}{2}$". L is $6\frac{3}{4}$".

110 Secondary Coils.

B is 4 and1/16" L is 9 and 5/16".

220 Secondary Coils.

B is 3 and 5/16". L is 8 and 7/8".

M.G.H.'28.

Preliminary Design.

It is also seen that the copper loss is 30 % higher than the iron loss; i.e. 121.1 watts copper loss to 91.3 watts iron loss. For highest efficiency at full load the copper loss should equal the iron loss at that point.

RESULTS of the preliminary design.

1. Losses are too high making radiation per sq.in. too high.
2. Copper losses are out of proportion to iron losses.

REMEDY.

Increase the size of copper and cut down the copper losses to a value near that of the Iron loss(at full load operating point.)

FINAL DESIGN.

WIRE SIZE.

Approximate check on size of wire needed;

Watts radiated per sq.in. = $(I^2R + \text{Iron loss}) / \text{Area}$.

$$.5 = (53.8^2 \times R + 91.3) / 250$$

$$R = .18 \text{ ohms per 1000 feet.}$$

By using the wire tables it is seen that 2 #4's in parallel will apply all the correction needed.

NEW current density;

$$= 53.8 / .0657$$

$$= 820 \text{ amps per sq.in.}$$

Resistance of 2 #4's in parallel;

$R = (.2485)^2/2(.2485) = .1245$ oh[illegible] 1000 f[illegible]

Final Design.

Coil Data.

One-sixteenth of an inch will be allowed for clearence on all dimensions where clearence is necessary.

Sizes of coils are shown on the drawings included and in this thesis and will illustrate questions which may come up in the computations. Knowing the size wire and the turns per coil there is no difficulty in getting the sizes of the coils.

Primary Coils.

64 turns per phase, double #4.

Use 4 coils of 16 turns each(for convenience)

Average Length per coil; Of one turn - the average one.

L = (2 x 2.5 + 2 x 6.75) / 12

= 1.51 ft.

Resistance per coil.

R=(Length in feet)x(resistance per foot)

=(16 x 1.51) x (.1245/1000)

= .00301 ohms.

110 Volt Secondary coil.

46 turns per phase, double #4.

Use 2 coils , 23 turns each.

Length of average turn;

L = (2 x 4.06 2 x 9.313) / 12

= 2.23 ft.

Resistance per coil;

R = (23 x 2.23) x (.1245/1000)

= .00638 ohms

FINAL DESIGN.

220 volt secondary.

44 turns per phase, single #4.

Use 2 coils with 22 turns per coil.

Length of average turn;

$L = (2 \times 3.313 + 2 \times 8.875) / 12$

$= 2.09$ ft.

Resistance per coil;

$R = (22 \times 2.09) \times (.2485/1000)$

$= .0114$ ohms.

** ** **

New Losses .

Total Resistances. (Per phase)

4 Primary Coils -

Total Resistance $= 4 \times .00301$

$= .01204$ ohms

2 - 110 volt secondary coils;

Total Resistance $= 2 \times .00638$

$= .01276$ ohms.

2 - 220 volt secondary coils;

Total Resistance $= 2 \times .0114$

$= .0228$ ohms.

Then include the 110 volt secondary with which this coil is in series;

$R_t = 1.5 \times .0228$

$= .0342$ ohms for total 220 volt circuit.

FINAL DESIGN.

I^2R losses.

$I^2R_p = (53.8)^2 x (.01204) = 34.85$ watts.

$I^2R_s = (63.0)^2 x (.01276) = 50.6$ " (110 volts)

$I^2R_s = (31.5)^2 x (.03420) = 33.95$ " (220 volts)

Now using the case which will give the highest losses so as to be on the safe side ,it is evident that the 110 volt output is the one, the total losses are computed.

Total I^2R loss per phase.

Loss = 34.85 + 50.6

= 85.45 watts.

Grand total loss .(Taking iron loss into account)

LOSS = 85.45 + 91.3

= 176.75 watts.

Watts radiated per square inch of surface;

= 176.75 / 250

= .706 watts.

The loss of .706 watts per square inch is still large but inasmuch as this transformer is not for continual use, being used only part of each day in the lab, it was not thought to be necessary or economical to use more copper in order to bring the losses below .5 watts per square inch.

The transformer will then be constructed .

Wire Necessary to Build the Transformer.

Primary - 4 coils per phase of double #4.

Average length per turn = 1.51 ft.

Number of turns = 16

Length per coil = 16 x 1.51 = 24.2 ft.

4 coils per phase gives = 4 x 24.2 = 96.8 ft.

Double wire gives = 2 x 96.8 = 193.6 ft.

Total Primary, 3 phases = 3 x 193.6 = 580.8 ft.

110 Volt Secondary. 2 coils per phase, double #4.

From similiar computations;

L = 23 x 2.23 x 2 x 2 x 3

Total Length = 615.6 ft.

220 Volt Secondary. 2 coils per phase, single #4.

L = 22 x 2.09 x 2 x 3

Total Length = 274.8 ft.

GRAND TOTAL LENGTH. (Allowing 30 feet for connections)

Length = 580.8 + 615.6 + 274.8 + 30

= 1501.2 ft.

Weight of wire.

#4 weight per 1000 feet 126.4 lbs.

Total weight;

= (1,501.2 x 126.4)/1000

= 189.6 lbs.

ORDER 190 lbs of #4 wire. Double cotton covered.

** ** **

RESULTS.

The first trouble experienced was in winding the coils. A form was made to wind them on but due to the extreme stiffness of the wire and the fact that no machines were available to shape the coils it was not possible to get them quite down to the dimensions and form as shown on the sketch. This would be possible if a winding and shaping machine were available and the transformer coils ,as designed,would be all right. The handwound coils were thicker than was expected and if they were made according to the previous rating, 12 KW for both 110 and 220 volts output, they would be too thick for the window of the transformer iron. This difficulty was overcome by winding the 110 volt secondary with single instead of double wire. It is evident that this reduced the area of copper by one-half so that the same conditions will hold if the 110 volt rating is reduced to 6KW. The author was fairly liberal in his values of current density and watts radiation per square inch of surface and is of the opinion that 9 KW could be drawn from the 110 volt secondary without over-heating or otherwise injuring the transformer providing the primary D C neutral and 220 volt secondary were not called upon to serve at the same time.

The transformers were constructed as described in the final design except for the change previously described.

The transformers were tested by what might be called the shop method. The first half of the test consisted in reading the watts input to the transformer with no load on the secondary and rated voltage applied to the primary. The current in each lead was also read and recorded, this being the exciting current of the transformer. The input in this case, no load being on the secondary, may be taken to be entirely hysteresis and eddy current losses and are present in the same amount as long as the transformer has rated voltage applied to it.

The values obtained in this first half are as follows:

Iron Loss and Exciting Current.

	E	I_1	I_2	I_3	W_1	W_2	f
Meter#21573		6183	8392	22010	1314	410	
Constant 1.		1.	1.	1.	1.	1.	
	135	2.3	2.25	2.6	282	30	60 cycles.

** **

To get the total iron loss add the two wattmeter readings which gives 312 watts for this value. It must be remembered that the iron is over ten years old and is of the soft steel variety which was used at that time in transformers.

Bearing the previous point in mind the 312 watts iron losses for a 12,000 watt transformer is not at all out of proportion, it being 2.6% of the total output.

The exciting current is found by taking the average value of current which flows in the three leads. This is 2.37 amperes. The full-load primary current being 53.8 amperes it follows that the exciting current is 4.4% of the full-load current. This value is a very reasonable one and is to be expected in a transformer of this capacity.

The current in the three leads of the transformer do not balance but this can be expected. Even a new induction motor upon test in the factory will very seldom have current balance.

The second part of the test is the determination of the copper losses at full load.

This is done by short-circuiting the secondary with ammeters in the leads and impressing a low voltage at rated frequency on the primary and raising this value until rated current flows in the secondary. The watts input are sensibly all copper loss because the voltage is so low that the iron losses will be negligable. It does not make any difference which side is the input side on this test but it was easier to use the 220 volt terminals as the input side and short-circuit the 135 volt leads through the ammeters. This was done with the following results:

Copper Losses.

	I_1	I_2	I_3	W_1	W_2
Meter #	13946	21518	1158	1614	410
Constant	10	1	10	10	10
	2.7	30	2.9	40	0

** **

In order to find the full-load copper losses add the wattmeter readings and multiply by the constant 10 which came in because of using 50 - 5 current transformers on the input side in order to reduce the current to a value which could be used in the wattmeters available.

This gives the full-load copper loss as 400 watts or 3.33% of the full-load output ,which value is very reasonable and to be expected on a small transformer such as this one is.

It is well to remember that this transformer was designed primarily to get results with a safe radiation per square inch and not for the highestoperating efficiency. The efficiency obtained is comparable to that of other small transformers of its size found on the market.

EFFICIENCY.

The efficiency of the unit can be calculated from the data already taken by using standard shop methods as follows:

The 312 watts iron loss are present in the same quantity as long as the transformer is supplied at rated voltage and frequency and do not change appreciably with the load applied. This ds one element of the total loss and the other is the copper losses.

It is evident that the copper losses change with the load it readily follows that the change is proportional to the load change;i.e. with full-load copper losses equal 400 watts, $\frac{3}{4}$ load copper loases will be 300 watts,etc.

Manifestly the total losses at any point will be the sum of the 312 watts iron loss and the copper loss for that point. Full-load losses are 312 plus 400 or 712 watts. The efficiency can then be calculated from the formula, %Eff is 100(Watts load)/(Watts load)plus(Losses at that point). Calculation be this method shows:

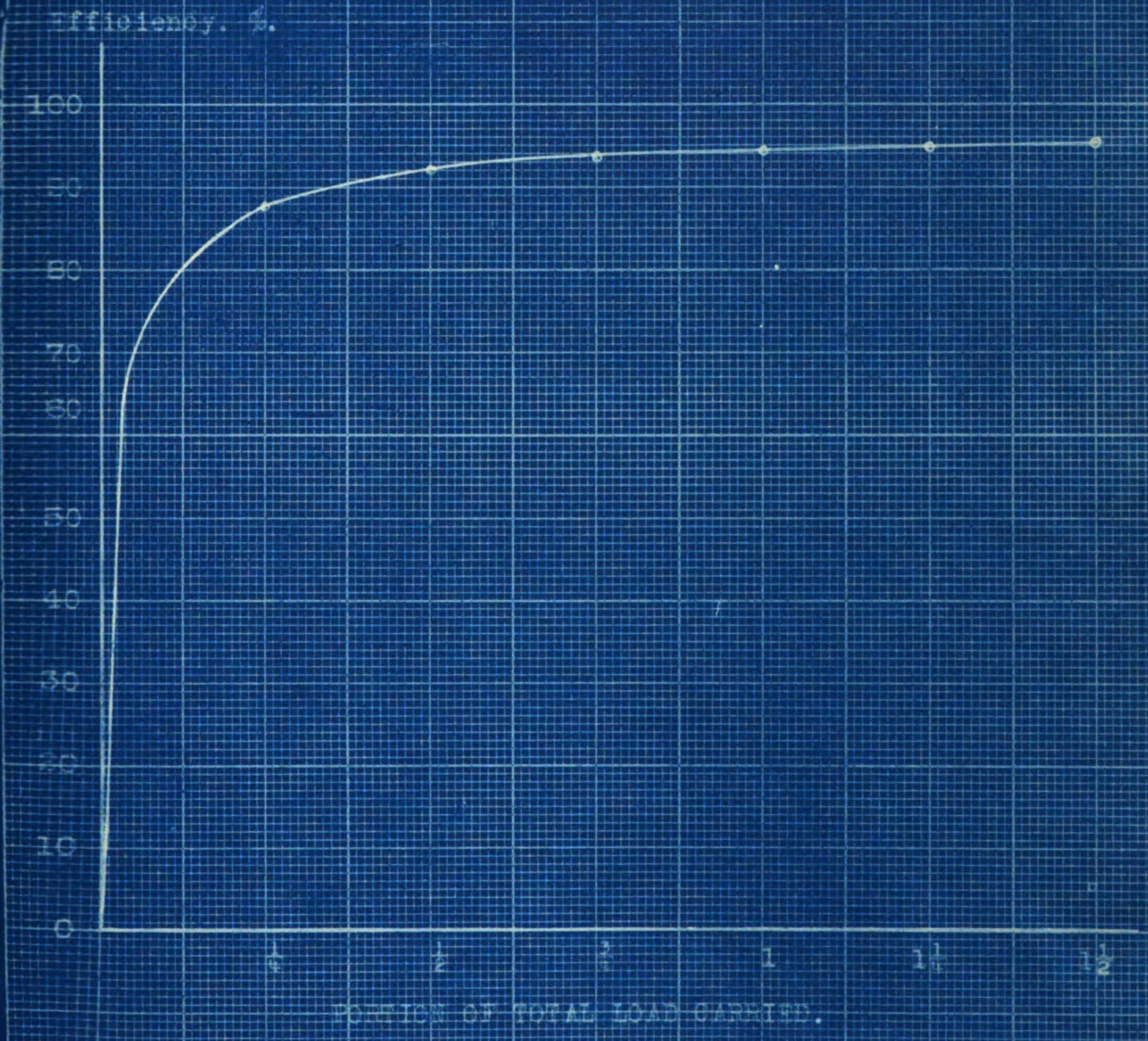
EFFICIENCY.

Load	I^2R Loss.	Total Loss.	Efficiency.
$\frac{1}{4}$	100 watts	412 watts	88.0
$\frac{1}{2}$	200 "	512 "	92.1
$\frac{3}{4}$	300 "	612 "	93.8
1	400 "	712 "	94.5
$1\frac{1}{4}$	500 "	812 "	94.9
$1\frac{1}{2}$	600 "	912 "	95.2

** **

EFFICIENCY CURVE OF COMPLETE TRANSFORMER.

(Computed from test data)



Test run with pure sine wave from special generator manufactured by G.E. for such tests. #G3 at M.S.C.Lab.

Note:

Efficiency over 95% from ¾ load and up.

Efficiency over 90% from $\frac{3}{8}$ load and up.

M.T.H. '26

SPEED REGULATION OF THE CONVERTOR.

One of the reasons for choosing the interconnected star connection for the transformer was because it gave so much better speed regulation on the rotary convertor. This was explained in detail in the general discussion.

A.P.Bock in his thesis on A D.C.Neutral for a Three Phase Convertor ,gives the following comparitive data on this point. The graphical results are also included.

Convertor R_1 with Interconnected Star Transformers.

D.C.Amperes to Neutral.	R.P.M.
0	1600
10	1600
15	1605
21	1610

** **

Convertor R_1 without I.S.T. Using Simple Star Connection.

D.C.Amperes. to neutral.	R.P.M.
0	1600
10	1620
15	1650
20	1670

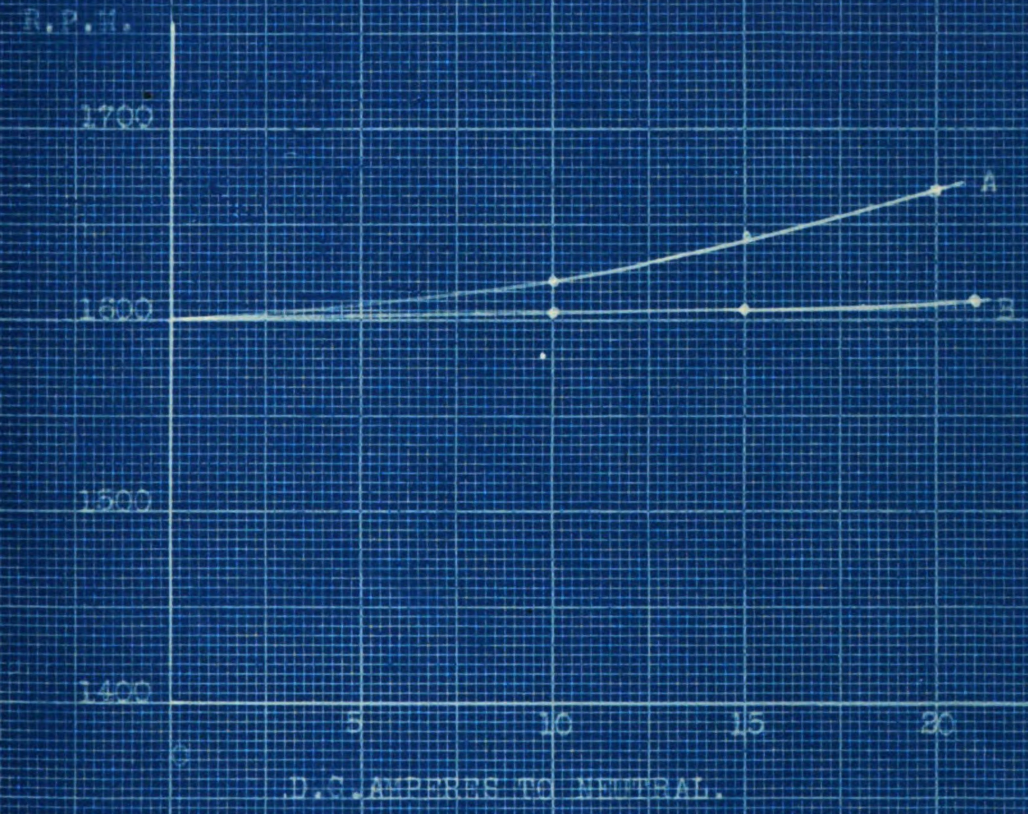
** **

CURVES SHOWING SPEED REGULATION

OF ROTARY WITH HEAVY D.C.LOAD TO NEUTRAL.

"A" WITH SIMPLE STAR TRANSFORMERS.

"B" INTERCONNECTED STAR TRANSFORMERS.



This shows that the converter has much better speed regulation with the interconnected star transformers than with the simple star. This situation is desirable. See explaination enclosed.

M.C.M. '20.

Bibliography.

"Electrical Engineering" Berg & Upson.

"Elements of Electrical Engineering" Cook.

"Transformer Practice" Reed.

"Alternating Currents" Magnusson.

"Experimental Electrical Engineering" Karapetoff.

"Transformer Design" Still.