Sessions Engineering Company
Consulting Engineers
Chicago

22 West Monroe Street
Phone Randolph 3223

September twenty-sixth,
Nineteen-nineteen.

Prof. A. R. Sawyer,
Michigan Agricultural College,
East Lansing, Michigan.

Dear Sir:

In accordance with your request I am sending you my copy of the thesis Mr. Holley and I worked out, and which is represented in a physical way by the wreck you showed me.

I was sorry not to be able to see you again before I left, but will arrange things differently next time.

Very truly yours,

R. B. Dennis

RBD:O.

THESIS

ALTERNATING CURRENT
LABORATORY EQUIPMENT

FOR

MICHIGAN STATE COLLEGE

BY

O. B. HOLLEY

R. B. DELVIN

1912.

THESIS

PREFACE.

In this THESIS the authors have endeavored to compile from various sources a set of experiments for our Alternating Current Laboratory and to design, construct, and test as far as possible such apparatus as is most needed.

In preparing the following set of experiments, we have endeavored to be as concise and to the point as possible, and to select such experiments as would best illustrate the fundamental principles of alternating currents, machines and apparatus. The last experiments consist of such commercial tests as come within the scope of the present (or probable) equipment of this laboratory.

Free use has been made of laboratory text books, hand books, and such trade publications as were accessible. Several of the experiments are used as presented this year by our instructor, Mr. G. A. Kelsall, being merely rearranged to conform to the general outline.

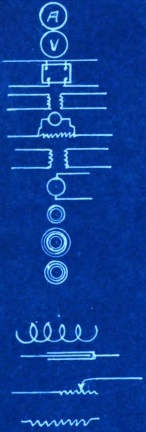
In order that the student may proceed more directly with the experiment, all explanatory matter formulae etc. has been put under the heading "Report".

CONTENTS.

PART 1.

PART 2.

1. Design of Voltage Regulator.
2. Design of Wave Form Apparatus.



Ammeter	A
Voltmeter	V
Wattmeter	W
Potential Transformer	P.Tr.
Current "	C.Tr.
Transformer	Tr
Generator D.C.	D.C. Gen.
" A.C. 1 phase	A.C. Gen.
" " 2 "	"
" " 3 "	"
Potential Regulator	P. Reg.
Inductive Coil	L
Condenser	C
Rheostat	Rh
Resistance	R
Impedance	Z
Reactance	X

Swenson & Frankenfield	F.
Karapetoff Exp. Eng. Vol. 2.	Kar. II
Sheldon & Mason (A.C.)	S. & M.
Gen'l Elect. Inst. Book	G.E. Inst Bk.
Gen'l Letters - E.E. by C.P. Steinmitz.	C.P.S.

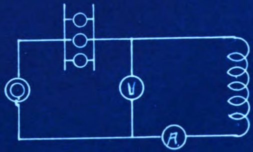


Fig 1.

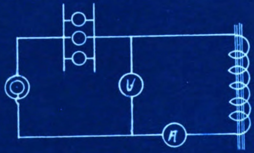


Fig 2.

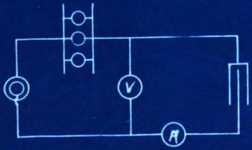


Fig 3.

Diagram of Connections

Experiment No 1.

Experiment No. 1.

A Study of Reactance and Impedance.

References;- Kar.I Art. 99, 100, II p 1.

Object;- To determine the reactance and impedance of a simple series circuit containing inductance or capacity, to study the effect of iron core on inductance and to determine the power factor.

Apparatus;- 1-Voltmeter
1- Ammeter
1- Bank of Lamps

Method;- (1) Use an inductance without an iron core. Connect as in Fig. 1 with some resistance in series to prevent current from becoming too great for the ammeter. Take readings of ammeter, voltmeter, and frequency at about six different frequencies within the range of the machine supplying the current. As the inductance in this coil with out an iron core is independent of current and voltage values, they need not be kept constant. Measure the resistance of the inductive part of the circuit.

(2) Place an iron core thru this coil and take similar readings, referring to Fig. 2. Try also keeping the current constant on account of permeability of iron.

(3) In a similar manner connect up a condenser as per Fig. 3, and take set of readings as in (1).

Report;- (1) Compute the reactance according to Kar. Fig. 108 & 109 and draw impedance triangle. Plot a curve between reactance and frequency using latter as abscissae. Compute coefficient of self induction and power factor.

(2) Plot a curve of frequency and reactance. Comput power factor.

(3) Plot a curve of frequency and reactance. Compute power factor.

Question;- State effect of frequency on a coil with and without iron core.

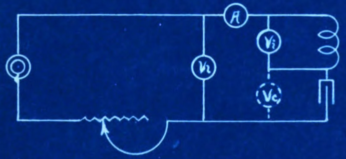


Diagram of Connections

Experiment No. 2.

Experiment No. 2.

A Study of Inductance and Capacity in Series and Voltage Resonance.

References;- K 2 p. 24

Object;- To measure the reactance and impedance of a series circuit containing capacity and inductance and get a resonance effect.

Method;- Connect as shown in diagram, putting in a resistance to prevent too high a current from flowing and vary the capacity and inductance until a condition of resonance occurs within the range of the frequency of the machine furnishing the current. When such a condition is obtained, take readings of voltage across the inductance, the capacity and across both.

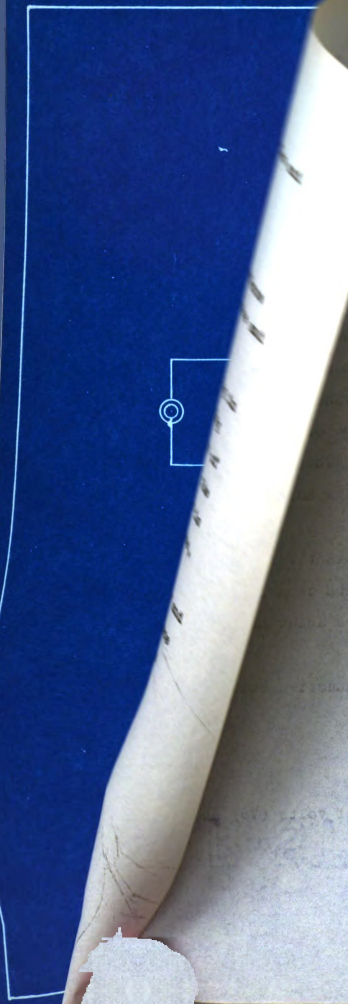
Keeping the current constant vary the frequency and read volts (Ve) and frequency with capacity and inductance the same, with point of resonance about half way between the two external values of Ve.

Measure resistance of inductive coil.

Apparatus;- 1- Voltmeter.

1- Ammeter.

Report;- Plot a curve of volts (Ve) and frequency as per reference.



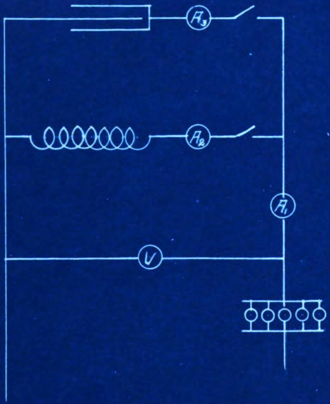


Diagram of Connections for
Experiment No. 3.

Experiment No. 3.

A Study of Inductance and Capacity in Parallel and of Current Resonance.

References;- Sheldon and Mason p 81.
Karapeloff 2 p.20.

Object;- To determine the combined impedance (Z) and reactance (X) and to measure the current in the line and in each branch of the divided circuit. Also to study current resonance.

Apparatus 1 low reading ammeter
2 high " "
1 voltmeter

Method. (a) Measure the resistance of the inductance. Keeping the frequency constant, vary the capacity so that it is equal to, less than and greater than the inductance respectively and read all the instruments. See diagram.

(b) With the machine running at about the middle of its speed range, adjust the capacity and inductance so that the max current occurs at or near the max reading of the ammeter in the line. Then beginning with a low frequency vary the frequency from minimum to maximum and read simultaneously line amperes and frequency.

Caution: Be sure to have enough resistance in the line because near the peak of the curve (i.e.resonance) the current rises very fast.

Report:

(a) Calculate X and Z and draw the admittance triangles in each case.

(b) Plot a curve with amperes as ordinates and frequency as abscissa.

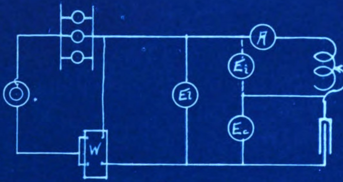


Fig 1.

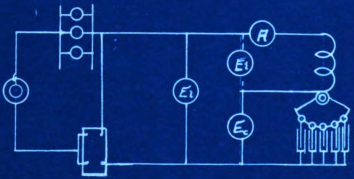


Fig 2.

Diagram of Connections.

Experiment No. 4.

Experiment No. 4.

Variations of I and Ø with varying Inductance and Capacity.

References ;- F. Exp. 5, 6.

Object;- to note the changes in current and phase angle on varying (1) inductance and (2) capacity, letting other conditions remain constant, also to compare power factor results obtained by theory and from experimental data.

Apparatus;- 1- Ammeter.
1- Voltmeter.
1- Wattmeter.

Method;- (1) To vary the inductance. Measure resistance of inductive coil. Connect apparatus as shown by diagram. Maintain constant frequency, voltage, resistance and capacity. The inductance may be varied by using an adjustable coil or by putting iron in the circuit. Take readings of amperes in line, line voltage (El), voltage across condenser (Ec), voltage across inductance (Ei) and wattmeter.

(2) To vary the capacity. Connect as shown by Fig. 2 and vary the capacity by means of a dial arranged to give parallel connection of the condensers. Take readings as in (1).

Caution;- Care must be taken to discharge the condenser before a change of connections is made, as dangerous voltages may exist at a near resonance.

Report;- Notation:

r equals resistance of inductive part of circuit

L " coefficient of self inductance.

Z " impedance.

ϕ " $\tan^{-1} \frac{2\pi fL - \frac{1}{2\pi fC}}{r}$

(1) Plot curves showing variation phase angle and current with each change in inductance using latter vaules as abscissae. Also curves showing variation of pressures across the inductance. Compute power factor (cos ϕ) and compare with same of watt meter. The capacity should be varied thru as wide a range as possible. Readings of current should be taken for each value of capacity, the pressure, frequency, resistance and induction being constant.

(2) Plot curves between current and phase angle with values of capacity as abscissae, also curve showing variations of pressure across capacity with variations in capacity.

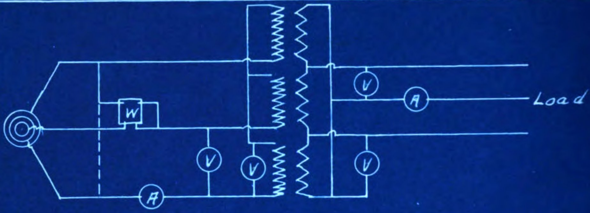


Fig. 1.

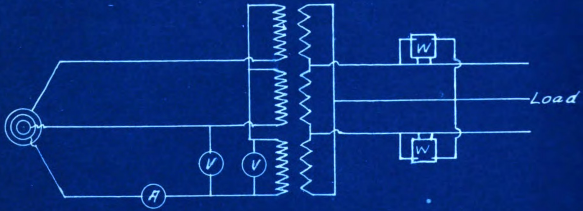


Fig 2.

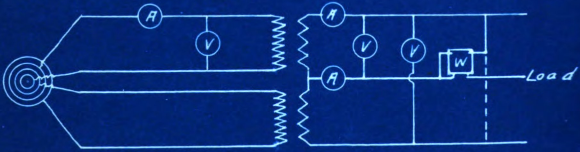


Fig 3.

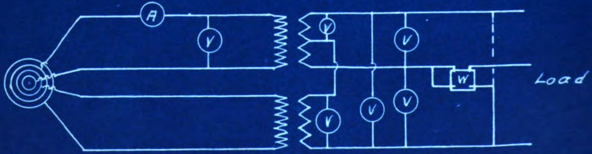


Fig 4.

Diagram of Connections
Experiment No. 5.

Experiment No. 5.

Measurement of Power, Varying the Number of Phases and Type of Connections.

References;- Sheldon and Mason p 47 and 69

Scott or T connection, S & M Fig. 130 and 131.

Object;- To study the different methods of connecting transformers, and what values of voltage and current to measure in order to calculate the power.

Apparatus;- 1 Wattmeter.
2 Ammeters.
2 Voltmeters.

Method;- Connect as per diagram in each case. Take all readings for three loads for each connection, (One load being inductive)

Caution;- If the secondary potentiol is high current and potential transformers will be necessary for the instruments, and the load must be suitable for that voltage. It is better to use low ratio transformers or use the high voltage side for the primary.

Report;- Calculate the power input and output in each case and compare with that of the wattmeter.

Calculate the power from both the line voltage and the coil voltage.

Questions;- What are the advantages of using $\triangle$ connections? Y connections?

For what measurements does $P = 3EI \cos \phi$, $2EI \cos \phi$, $\sqrt{3}\, EI \cos \phi$, $\sqrt{2}\, EI \cos \phi$?

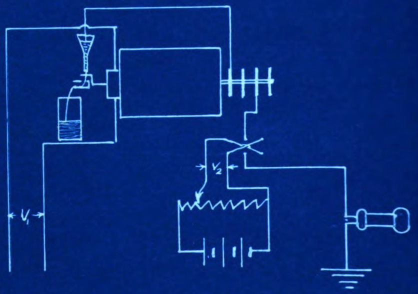


Diagram of Connections

Experiment No. 6.

Experiment No. 6.

A Study of Wave Form

References S and F p 204

Object;- To determine the wave form of an A.C. generator by determining the instantaneous E.M.Fs. at intervals of 10 electrical degrees.

Apparatus;- 1 D.C. Voltmeter
1 A.C. "
1 Contact maker
1 Telephone receiver or galvanometer
1 Resistance coil
1 Double throw switch.
98 Ft. #30 Advance R. wire.

Method;- Mershon Connect according to diagram. Keep V_1 constant absolutely. Beginning with the sliding contact of the resistance near point A determine which position of the Double Throw switch puts the E M F of the battery in opposition to that of the machine. Adjust the resistance until a balance is obtained i.e. until the T.R. is silent. Read the voltage V_2 for positions of the contact 10 electrical degrees apart. The double throw switch must be reversed when the voltage passes through zero.

Report;- Draw a diagram of the connections used. Describe the expt. Plot a curve with volts as ordinates and degrees as abscissa and draw the curve thru all the points.

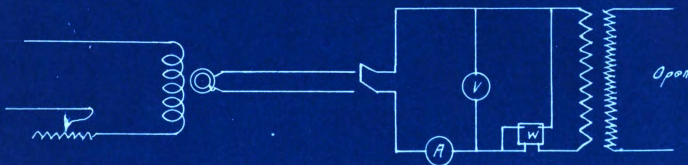


Diagram of Connections for
Experiment No 7.

Experiment No. 7.

Efficiency Test of a Transformer.

References;- Swenson and Frankenfield, p79.

Object;- To determine the efficiency of a transformer under various loads and to study its losses.

Apparatus;- 1 Ammeter.
1 Voltmeter.
1 Wattmeter.

Method of losses;- Determine the ratio of transformation. Measure the resistance of both coils; that of the primary by the drop in potential method, and that of the secondary by an acme testing set.

Connect as shown in the diagram. Keep the frequency constant by means of a tachtometer on the generator and vary the voltage by means of a rheostat in the generator field.

For each voltage take simultaneous readings of wattmeter, ammeter and voltmeter and also of the tachtometer (or frequency).

Caution; Insulate, or beware of the secondary leads as they are of high potential.

Report;- The wattmeter reading is the core loss of the transformer and the ammeter reading is the exciting current. The I^2R loss is very small when the secondary is open circuited and may be neglected. Hence the wattmeter reading at normal voltage is very nearly the core loss for all loads at normal voltage.

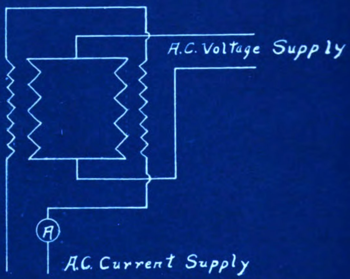
Use this core loss in the following formula and calculate the efficiency at 1/4, 1/2, 3/4, 1, 1¼ and 1½ times rated load.

Plot curves for core loss and exciting current with A.C. volts as abscissa.

Plot a curve of efficiency with load as abscissa.

$$\text{Efficiency} = \frac{W_o}{W_o + \left(\frac{W_o}{E_p}\right)^2 R_p + \left(\frac{W_o}{E_s}\right)^2 R_s + \text{Core loss}}$$

Wo = output at various fractions of rated load.



Opposition Transformer Test

Diagram of Connections

Experiment No. 8.

Experiment No. 8.

Heat Test of Transformers.

References;- K. Vol. 2 par 492. G. E. Inst. Bk. #8317 p. 30.

Object;- To determine the temperature rise in a transformer under continuous full rated load conditions.

Apparatus;- 1 A.C. Ammeter.
1 D.C. Voltmeter.

Method;- "Opposition" or "Motor Generator" method. Measure the resistance of the high tension windings before and after the test, i.e. cold and hot. Test each transformer for polarity in this manner. Put a D.C. voltmeter across the low tension side and observe the direction of the kick of the voltmeter needle. If the transformers have the same polarity connect them as shown in the diagram.

Apply an A.C. voltage to the low tension windings approximately equal to normal low tension voltage. By this method the voltage supplies all the iron and other losses, and as the two high tension coils are connected in opposition, no current will flow.

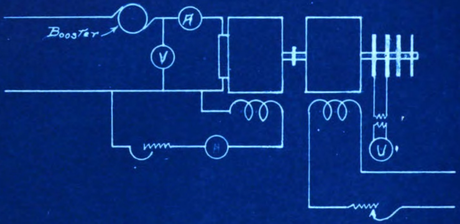
Send full rated load A. C. current through the high tension windings. This will supply the full load current and copper losses.

The low tension coils receive just a little magnetizing current. Take temperature of room.

Report;- Calculate rise in temperature by equation; $(238 + t)\left(\frac{Q}{R} - 1\right) =$ degrees C where R. is initial resistance at room temperature, t degrees C, and Q is final resistance.

Plot curve of heat test, using degrees C as ordinates and hours as abscissae.

Note: By this method a full load test mey be run on large transformers with no loss of energy except that due to inefficiency of the set.



M.G. Set to Determine Core Loss of Generator

Diagram of Connections

Experiment No. 9.

Experiment No. 9.

Determination of Core Loss of an A. C. Generator.

References;- K 2 p 129.

Object;- To determine the core loss of an A.C. generator with different voltages.

Apparatus;- 1- Voltmeter.
2- Ammeters.
1- Potential Transformer.

Method;- Connect apparatus as per diagram.

(1). To measure core loss of motor plus friction loss of set, run the motor-generator set at normal speed without field of alternator excited. Read watts input to ammature of D.C. motor.

Note;- To obtain accurate results, the capacity of the motor should nearly equal core loss of motor plus friction loss of set.

(2). To measure core loss of set plus friction loss of set. Run set at normal speed. Keep speed constant by varying voltage on ammature of motor by means of a booster set connected in series with the D.C. supply. Keep excitation of motor constant to maintain its core loss constant.

Excite field of alternator and vary voltage from 25% below to 25% above normal. Take simultaneous readings of input to motor and E.M.F. of alternator. This gives total core and friction loss for each voltage.

(3). Measure resistance of motor armature to get its I^2R loss.

Report;- Compute the constant losses (Wc) of the motor generator set consisting of friction losses plus core loss of motor by the formula:

$$Wc = I_a E_a - I_a^2 Ra.$$

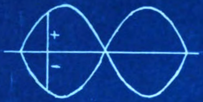
I_a and E_a are readings from (1) and (3).

The core loss for each voltage of alternator is obtained by formula.

$$\text{Watts core loss} = I_a E_a - We - I_a^2 Ra$$

I_a and E_a are readings from (2) and (3)

Plot a curve of voltage and core loss using voltage as abscissae.



Curves of E.M.F.

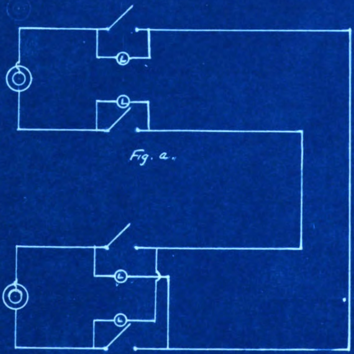


Fig b

Diagram of Connections

Experiment No. 10.

Experiment No. 10.

Synchronization and Parallel Operation of A.C. Machines.

References;- To synchronize two alternators and study their behaviour when operated in parallel.

Apparatus ;- None.

Method;- Alternators to run in parallel must be similar in wave form, voltage, frequency and phase relation.

(1). There are two methods of synchronizing A.C. generators:by using lamps , as shown by diagram (a) which indicates the time to connect the two machines together by their brightness and (b) by their darkness. This exact time is when the algebraic sum of the voltages of the two machines is zero, or when they are bucking each other as shown by their curves of E.M.F.

Bring one machine up to normal speed and voltage and adjust speed of second till lamps go out and brighten slowly. Test voltage of each machine to see that they are similar within a few volts. With synchronizing switches in position close them at the centre of a long dark period (a) or a long light period (b).

(2). A synchronous motor may be started by first running it up to speed (a) as an induction motor and then closing the field switch or (b) by some prime mover and then synchronizing.

(3). Rotary convertersare similarly started and operated, and in addition may be started from the D.C. end.

Experiment No. 11.

Efficiency Test of and A.C. Generator.

References;- K 2 p 129.

Object;- To determine the losses of an A.C. generator under all conditions of loading, and to use these losses in calculating the efficiency of the machine.

Method;- To determine the losses. The machine is to be driven by a small motor to determine its friction, windage and iron losses. Friction and iron losses should be measured by driving the alternator at rated speed with field excited, by a motor of which the efficiency is known for all values of input. The motor should be direct coupled if possible so that no allowance need be made for belt friction. The capacity of the motor should be not greater than that sufficient to run the alternator on open circuit with field fully excited, for the motor on full to overload its efficiency is more nearly constant. Input to motor times its efficiency equals watts lost in friction, windage and irons.

The I^2R losses require a measurement of resistance of windings. The armature resistance loss = $nI_a^2 R_a$ where n = no. of phases. The field resistance loss = $E_f I_f$ where E is voltage of exciting current.

Report;- Plot efficiency curves from half to one, and to one and one half full load.

Having determined the losses, the efficiency may be found from the following formula.

$$E = \frac{Wo \text{ (output)}}{Wo + nI_a^2 Ra + E_f If + \text{Stray power losses.}}$$

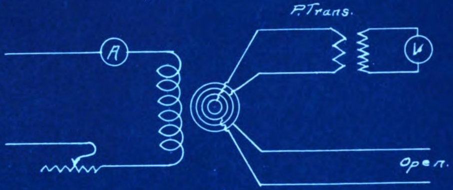


Fig 1.

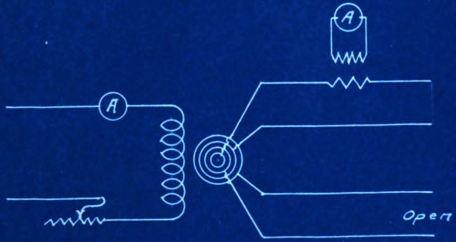


Fig 2.

Diagram of Connections for
Experiment No. 12.

Experiment No. 12.

No Load Characteristics of an A.C. Generator.

References: Karapetoff 1- p 348.

Object;- To determine the voltage drop and the synchronous impedance with full load current.

Apparatus;- 1 Voltmeter.
1 Ammeter.
1 Potential transformer.
1 Current "

Method (a) First connect as in Fig. 1 and read voltage across one phase and amperes field current, varying the field current.

(b) Connect as in Fig. 2, i.e. short circuiting one phase through a current transformer with an ammeter. Read armature amperes and field amperes up to 1¼ times full load.

(c) Do the same as in (b) but short circuit both phases.

(d) Leave the field circuit closed(being separately excited) and stop the machine. Observe the action of the armature current.

Note; It is well to take readings increasing the field current and also decreasing it. The average will eliminate the effect of residual magnetism.

Report;- Plot results of (a) (b) and (c) with field amperes as abscissa. From curves (b) and (c) find the field current necessary when full load current flows thru the armature.

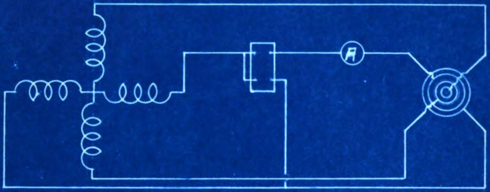


Fig 1.

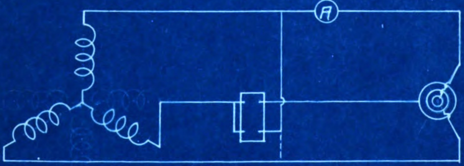


Fig 2.

Measurement of Power

Diagram of Connections

for Experiment No. 13.

Experiment No. 13.

Test of an Induction Motor..

The Circle Diagram.

References;- K 2 p 167-172. S S M Art. 84-5

Object;- To determine the preformance of an induction motor.

Apparatus;- 1- Ammeter.

1- Voltmeter.

1- Wattmeter.

Method;- (1). Applying to a two phase motor. Measure resistance of stator windings per phase. Connect to a two phase circuit as in Fig. 1. Run motor idle and measure current (exciter current per phase), voltage, and watts input per phase. I_s is found by lockingthe rotor and putting full load current into motor at reduced voltage, afterwards correcting to current at normal voltage. Having determined I_0 and I_s the point K may be found.

(2). Applying to three phase. Connect as in Fig. 2 and proceed as above.

Report;- Plot curves shown on p 238 S S M.

Question;- Explain why the point I_s does not coincide with K.

Experiment No. 14.

Hunting of Synchronous Converters.

References;- C.P.S. Lectures p 120.

Object;- (a) To locate the machine at fault and determine the cause.

(b) To remedy the defect.

Note;- Since the 125 V rotary hunts but may be cured by putting inductance in series with one phase adjust this inductance in series with one phase adjust this inductance so that machine will still hunt but not enough to throw it out of step.

Method;- With the two rotaries running from alt. Count the beats (including intermissions) and the intermissions per min and get the two frequencies ($= \frac{\text{beats} \pm \text{intermissions}}{2}$) Do they correspond with any known speed in the system?

Compare ammeters with Station ammeter. i.e. do rotaries hunt with each other, or with the generator?

Vary the field excitation and note effect.

Either connect D.C. sides in parallel or separate them and note effect.

Run either one alone and see if it hunts.

If the hunting is magnetic varying field may stop it, or putting on a flywheel or belt.

If they hunt against each other connect coll rings together and watch brushes for sparking.

Try pole pieces or short circuiting rings.

Report;- Write a discussion of the events which occured.

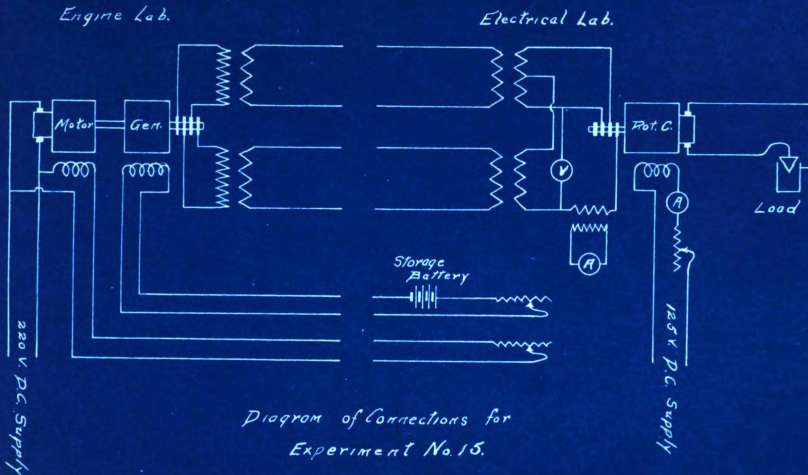


Diagram of Connections for
Experiment No. 15.

Experiment No. 15.

The Influence of Excitation of a Synchronous Motor on the Power Factor.

References Sheldon and Mason Art. 95.

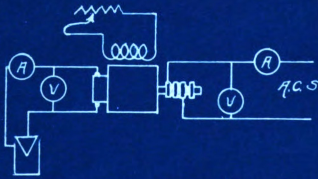
Object;- To study the effect of varying the excitation of a synchronous motor.

Apparatus;- 1 A.C. Ammeter.
1 D.C. "
1 A.C. Voltmeter.
1 Current Transformer.

Method;- Connect as per diagram and read the amperes per phase for different values of exciting current for 0, ½ and full rated load. Keep the frequency and A.C. voltage constant and have all control in the Electrical Laboratory.

Report;- Plot a curve for each load, plotting amperes, armature current as ordinates and amperes field current as abscissa.

Discuss the significance of the curves.



Efficiency Test of Rotary Converter

Diagram of Connections for

Experiment No. 16.

Experiment No. 16.

Efficiency Test of a Rotary Converter.

References;- F 2 p 268.

Object;- To determine the efficiency of a rotary converter under various loads, and power factors but with the same frequency and A.C. voltage.

Apparatus;- 1 A.C. Ammeter.
1 A.C. Voltmeter.
1 D.C. Ammeter.
1 D.C. Voltmeter.

Method;- (a) Connect as per diagram and read imput and output at from ½ to 1½ times the full rated load, with field rheostat adjusted for unity power factor.

(b) Same at .80 power factor (lagging) .

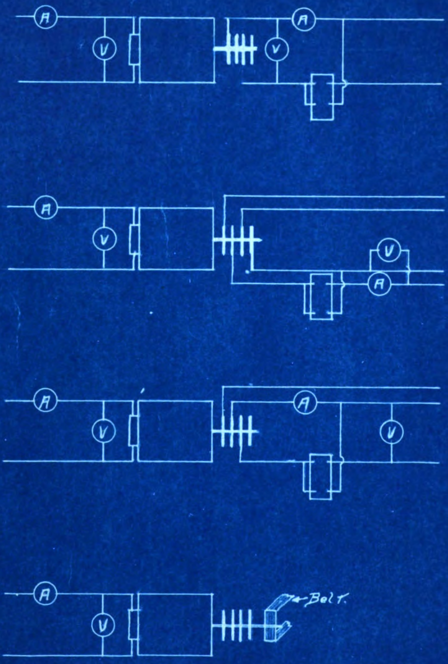
(c) Same at .80 " " (leading).

Keep a constant A.C. Voltage and frequency throughout.

Report;- Plot curves of efficiency with load as abscissa.

What effect does power factor have on efficiency?

Discuss the difference between corresponding A.C. and D.C. voltages.



Methods of Running Rotary Converter
to Determine its Capacity

Diagram of Connections.

Experiment No. 17.

Experiment No. 17.

Capacity Test of a Rotary Converter.

References;- S. and M. p 291.

Object;- To study the action of a given rotary converter when run as a single phase, two phase and three phase converter and D.C. generator respectively, as regards the maximum output obtainable and the limiting condition (sparking or heating) in each case.

Note;- A two phase converter may easily be run as a single phaser or D.C. generator, but for a three phase test special taps must be made to the armature winding. This can only be done with the 220V Rotary in this laboratory.

Apparatus;- D. C. Ammeter and Voltmeter.
A. C. " " and Wattmeter.

Method;- Connect the machine first to a non inductive load and then to an inductive load and load it until excessive sparking (or heating) makes further loading impracticable and until the adjustment of the brushes will no longer correct it. Measure the input and output in K.V.A. and K.W. Do the same for each test.

In testing as a D.C. generator drive the rotary by means of a belt.

Run all tests under normal speed and voltage.

Report;- Determine the ratios of maximum single phase, two phase and three phase load to Maximum D.C. load.

Were you obliged to shift the brushes for the different tests.

Did it make any difference whether the load was inductive or not?

Compare results with those of S. and M. p 191.

Experiment No. 18.

A Test of Mercury Arc Rectifier.

References;- S.H. 6-280. F - - 296.

Object;- To study the preformance of a mercury arc rectifier or converter.

Apparatus;- 1- A.C. Ammeter
1- A.C. Voltmeter
1- D.C. Ammeter
1- D.C. Voltmeter

Method;- Applying to Fig. 1 for single phase and Fig. 2 for three phase, connect as shown by diagram. (a) Start and operate at rated frequency and vary A.C. voltage over a safe range. Measure the output and input at terminals.

(b) With constant frequency and voltage determine output and input for different values of current.

Report;- (a) Plot curves of efficiency and D.C. voltage, using A.C. voltage as abscissae.

(b) Plot curves of efficiency and D.C. current using A.C. current as abscissae.

Question;- Sketch current wave before and after it passes thru the rectifier as you think it would look.

PART 2.

DESIGN OF VOLTAGE REGULATOR.

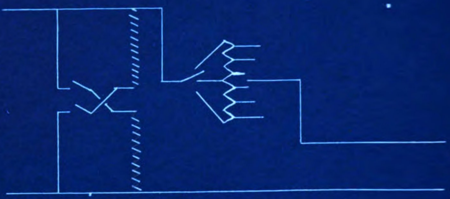


Fig 1.

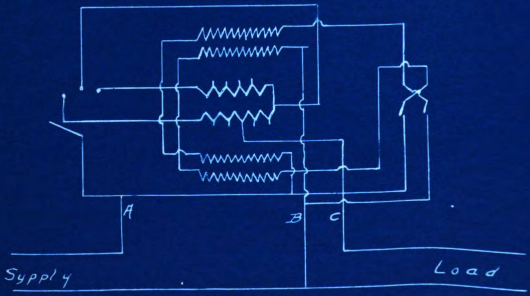


Fig 2.

Note – Letters correspond to letters on terminals.

Object of Design.

Following the suggestion of the instructor we decided to build a single phase voltage regulator capable of connection to either 110 or 220 volt supply mains and having a capacity equal to 1 phase of either the 10 or 8 KW rotary in the laboratory. The regulator was to be capable of raising or lowering the 110 primary voltage 50% and the 220 voltage 25% , in either case a buck or boost of 55 volts.

Old Material Available.

There was available for our purpose a 5 KW $\frac{100-200}{2000 \text{ Vol}}$ 60 cycle single phase Westinghouse transformer. This we proposed to reconstruct into an auto transformer with enough taps in the secondary to give the desired voltage steps. There were also some old transformer coils with heavy rectangular wire available for rewinding for the secondary.

Fundamental Design.

Fig. 1. shows diagramatically the design adopted. By means of the double throw double pole switch the secondaries may be put in series or parallel for 220 or 110 volt connection respectively. The 3 point switch makes possible a reversal of the secondary coil to secure either a buck or boost in voltage. The variable voltage taps are connected to a dial and thence through the arm to the load circuit. The letters A.B. and C. on the diagram refer to terminals similarly labled on the regulator.

Calculations.

Pressure across 1 primary coil = 110 volts

Full load current in line @ 95% efficiency through switchboard and transformers

$$I_1 = \frac{5000 \times .95}{2 \times 110} = 21.6 \text{ amps.}$$

Full load current in secondary @ 55 volts secondary pressure and 90% efficiency

$$I_s = \frac{5000 \times .90}{55} = 81.8 \text{ Amps.}$$

As the regulator will probably seldom or never be required to handle the full 5 K.W. at 55 volts secondary pressure we have designed the secondary apparatus for 50 amperes throughout and depend on overload capacity for more than that amount.

With 50 amperes in the secondary there would be approximately $\frac{50-25}{2} = 12.5$ amps. per primary coil.

$$\text{No turns in Sec} = \frac{\text{No turns in each per coil}}{2} = 24$$

$$\text{Voltage per turn} = \frac{220}{96} \text{ or } \frac{110}{48} = 2.29 \text{ volts}$$

The size of wore required in the secondary at 55 volts pressure would be approximately twice that in the 100 volt original coils.

Contact area of brushes on dial as follows:

$1\frac{1}{4} \times 9/16 = .71$

$\frac{50 \text{ amps}}{.70}$ 71 amps per sq. in.

Construction.

We first dissembled the transformer and removed the high voltage coils leaving the low voltage coils connected

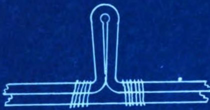


Fig. 3.

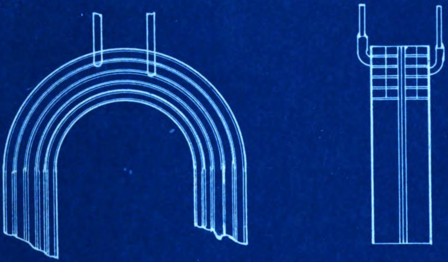


Fig. 4.

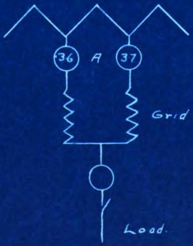


Fig. 5.

as before. The secondary was wound in two coils with 1 tap per turn and the two coils placed back to back and bound together as shown in Figs. 2 and 4. The conductor used consisted of two rectangular wires wound side by side. Fig. 3 shows the method of making the taps. The terminal leads consisted of seven strands of # 14 wire. The dial contacts were sawed from a rolled brass bar having the section shown in the drawing. The movable contact was made in two brushes with a preventative resistance between them to avoid arcing or short circuiting one turn of the secondary in passing from one contact to another.

Following is some interesting data from attempt to use a cast iron grid for preventative resistance in such a way that intermediate voltages could be obtained by leaving the brushes on two adjacent contacts at the same time. See Fig. 5 The attempt was abandoned because the distribution of the current in the grid and also the intermediate voltages varied with the load.

Resistance of grid. 14 ohms.

Primary voltage 120

Secondary " 90

Table 1.

Ammeter #	Ammeter #	Ammeter #
29	36	37
0	12.8	12.4
10.5	17.4	6
20	21.5	2
22	21	1
25	23.5	2
67	43	23.5

Table 2.

Load-Voltage Test.

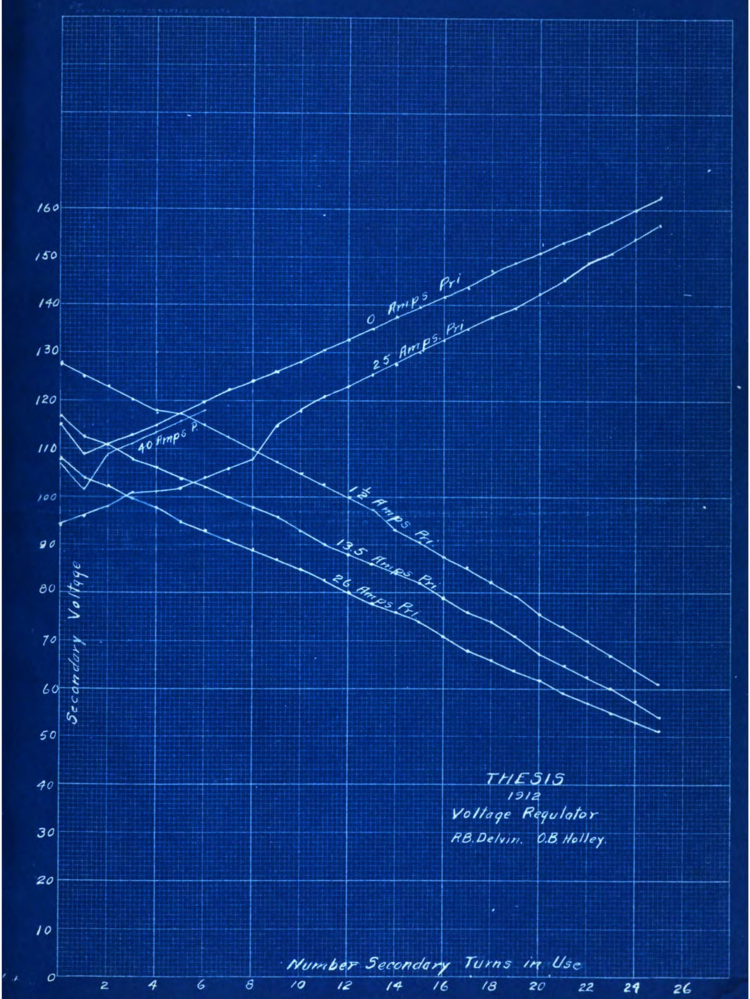
	BUCK			BOOST		
Amps. Pri.	1½	13.5	2.6	0	25	40
Amps. Sec.	0	35	50	--	--	--
Points						
0	127.5	115	107	114	94	107
1	125	112.5	104	109	96	102.5
2	123	110	102.5	111	98	109
3	120	108	101	113	100	111
4	118	106	98	115	101	113.5
5	111.5	104	95	117.5	102	116
6	115	102	93.5	120	104	118
7	112.5	100	91	122	106	119
8	110	98	89	124	108	
9	107.5	96	87	126	115	
10	105	93	85	128	118	
11	102.5	90	82.5	130.5	121	
12	100	88	80	132.5	123	
13	97.5	86	78	135	125.5	
14	93	84	76	137.5	127.5	
15	90.5	82	74	139.5	130	
16	87.5	79	71	141.5	132.5	
17	85	76	68	143.5	135	
18	82.5	74	66	147.5	137.5	
19	79.5	71	64	149	139.5	
20	75.5	67.5	62	151	142.5	
21	73	65	59	153	145	
22	70	62.5	57	155.5	149	
23	67	60	55	157.5	151	
24	64	57.5	53	160	154	
24	61	55	51	162.5	157	

Table 2 shows the effect of load on the secondary voltage. When the secondary is bucking, the more turns in use the lower the secondary voltage, and visa versa. The load in each case included the entire secondary.

Table 3.

Primary			Secondary			Eff.
Volts	Amps.	KVA_p	Volts	Amps.	KVA_s	$\frac{KVA_s}{KVA_p}$
111	17.75	1.97	55	32.5	1.79	.91
109	121	2.29	53	41	2.17	.95
116	25	2.9	141.5	19	2.71	.935

Table 3 shows the efficiency of the regulator under various loads and voltages. There is probably some loss due to magnetic leakage between the coils, as they were necessarily spaced some distance apart.



0 Amps Pri
25 Amps. Pri
40 Amps P.
1½ Amps Pri
13.5 Amps Pri
26 Amps Pri
Secondary Voltage
Number Secondary Turns in Use
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
2
4
6
8
10
12
14
16
18
20
22
24
26
THESIS
1912
Voltage Regulator
R.B. Delvin. O.B. Holley.