THESIS

on

DESIGN OF A STANDARD SPEED, REVOLVING FIELD TYPE, THREE-PHASE ALTERNATOR.

Submitted to the Faculty of the

OREGON AGRICULTURAL COLLEGE for the degree of Bachelor of Science in Electrical Engineering by

Redacted for privacy

and

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Department of Electrical Engineering

Approved: Redacted for privacy
Dean School Engineering.
INTRODUCTION.

The designing of electrical machinery is fully as essential to the thorough understanding of power equipment and apparatus, as is the taking of a laboratory testing course. One learns the relationship of the different parts, the methods of computing their dimensions, and the predetermination of outputs, efficiencies etc. and thus is enabled to better judge the favorable and unfavorable qualities—the good and bad points of generators, motors and other appliances used in the great field of electrical engineering. The realization of the training value of such work especially in alternating current design led the writers of this thesis to select the subject chosen.

F. J. W.
R. E. R.

June 2, 1910.
Design of a standard Speed, Revolving Field Type, Three-Phase Alternator.

General Specifications

Revolving field—three phase—60 cycles—514 R.P.M.—400 K.W. output—no load voltage 2200, full load voltage 2300—power factor 85%. Net head 47 feet. Driven by 2—22" turbines mounted on a horizontal shaft.

Number of Poles.

\[
\text{R.P.S.} = \frac{2 \times \text{cycles}}{\text{Np}} \quad \text{equals} \quad \frac{514}{60} \\
514 = \frac{2 \times 60}{60} = \frac{2}{Np} \Rightarrow Np = \frac{2 \times 60 \times 60}{514} \quad \text{equals} \quad 14 \, \text{poles} \quad \text{where} \quad 2 \, \text{equals constant,} \quad 60 \, \text{equals number of seconds in a minute,} \quad 60 \, \text{equals number of cycles, and} \quad 514 \, \text{equals revolutions per minute.}
\]

Current.

Current per winding \( I \) equals \[ \frac{W}{E \times 3 \times \text{P.F.}} \times \frac{3}{3} \]
equals \[ \frac{400000 \times 1.73}{2300 	imes 3 \times 85} \] Where 400,000 equals watts output, 1.73 equals \( \sqrt{3} \), 2300 equals terminal voltage, and 85% equals power factor.

FLUX.

\[
\text{K.V.A.} = \frac{471}{514} \quad \text{equals} \quad 0.91 \, \text{K.V.A. per} \quad \text{R.P.M.}
\]
R.P.M., where 471 equals kilovolt amperes, and 514 equals revolutions per minute. From a curve taken from a design book it is found that the flux equals
Conductors per Phase.

\[
\text{K.V.A.} = \frac{M \times Z \times C \times \phi \times \text{form factor}}{N} \times \frac{120 \times 10^6}{2.26}
\]

\[.91 = \left( 32 \times 118 \right) \times 57 \times 10^6 \times \frac{2.26}{120 \times 10^6}
\]

\[Z = 240 \text{ conductors.}
\]

\[.91 = \text{Kilovolt amperes per revolution per minute, } M = 3 = \text{number of phases, } Z = \text{conductors per phase, } C = \text{current per phase, } \phi = 57 \times 10^6 = \text{flux, } 2.26 = \text{form factor, and } 120 \times 10^6 = \text{constant.}
\]

\[3 \times 3 \times 14 = 126 \text{ slots, where } 3 \text{ slots are used per phase per pole and } 14 \text{ equals poles; } 126 = \text{total number of slots.}
\]

\[126 \div 3 = 42 \text{ slots per phase, where } 126 = \text{total number of slots and } 3 = \text{number of phases.}
\]

Since the number of conductors must be divisible by 42, 210 were used.

Total number of conductors for the three phases equals 210 \times 3 = 630.

**DIAMETER OF REVOLVING FIELD.**

\[(zc) = \frac{M \times Z \times C}{D \times 3.14}
\]

ampere conductors. 480 equals \[\begin{align*}
\frac{3 \times 210 \times 118}{D \times 3.14}
\end{align*}\]

\[D = 49.9 \text{ use } 50'' \text{ as the diameter of the revolving field. In this case } XC = \text{ampere conductors, } M
\]
equals number of phases, \( Z \) equals conductors per phase and 3.14 equals \( \pi \).

**PERIPHERAL VELOCITY.**

\[
V = D \times 3.14 \times \frac{N}{12}, \quad \text{where } V \text{ equals peripheral velocity.}
\]

D equals diameter of revolving field, 3.14 equals \( \pi \), \( N \) equals revolutions per minute, and 12 equals conversion factor.

\[
V = 50 \times 3.14 \times \frac{514}{12} \quad \text{equals 6725 peripheral velocity.}
\]

**SIZE OF CONDUCTORS.**

\[
\begin{align*}
\text{Current per phase} & = 118 \\
\text{Current density per sq. in.} & = \frac{1800}{18} \quad \text{equals .0605 sq. in.}
\end{align*}
\]

Circular mils equals \( .0656 \times 10^6 \) equals 83500, where \(.7854 \) equals \( \frac{1}{4} \) of \( \pi \).

83500 corresponds to 2 No. 4 B & S wires.

2 No. 4 B & S wires were used in parallel per conductor. Total diameter of No. 4 wire equals 2.16".

**SLOT AND TOOTH DIMENSIONS.**

Thickness of insulator equals .05". Thickness of wooden wedge equals .2". Distance of wedge from end of tooth equals .04". Since there are five conductors per slot (2 wires equals 1 conductor), the slot must be two wires wide and five deep.

\[
(2 \times .05) + (2 \times .216) \quad \text{equals .532" width of slot.}
\]

\[
(2 \times .05) + (5 \times .216) \quad .04 \quad .3 \quad \text{equals 1.42" depth of slot.}
\]
Tooth pitch equals internal bore \( \times \pi \) \( \frac{\text{equal} \text{number of teeth}}{136} \) equals 1.26".

Tooth pitch—slot width equals 1.26 \( \frac{-.532}{.728} \) width of top of tooth.

\[
\text{(Root pitch—slot width)} \times \pi \frac{\text{equal} \text{width of}}{\text{number of teeth}} \frac{(50.6 + 2.82)}{136} \frac{- .532}{.798} \text{width of root of tooth.}
\]

Mean thickness of tooth equals \( \frac{.728}{.798} = .763 = R \) where \( .728 \) = width of top of tooth, and \( .798 \) = width of root of tooth.

**LENGTH OF POLE ARC.**

Ratio of pole arc to pole pitch was taken as \( .65 \) from a table. \( .65 = \frac{L}{\text{pole pitch}} \) equals \( \frac{L}{11.25} \).

Then \( L \) equals 7.3" equals length of pole arc.

**POLE PITCH.**

Pole pitch equals \( \frac{\text{diameter of revolving field} \times \pi}{\text{number of poles}} \) equals \( \frac{50 \times 3.14}{14} \) equals 11.25".

**AIR GAP CALCULATIONS.**

Calculation of Armature Ampere Turns.

\( T \) equals \( 210 \frac{105}{210} \) turns per phase, where 210 equals conductors per phase. \( \text{AT}_{\text{b}} \) equals \( 212 \times c \times T \) equals \( 2.12 \times 118 \times 105 \) equals 26260 armature back ampere turns, where 212 equals constant, 118 equals amperes per phase, and 105 equals turns of wire per phase. \( 26260 \times 2.75 \) equals 72300 total number of ampere turns in the field, where 275 represents the times that the field ampere turns are
larger than the armature ampere turns.

Total number of ampere turns in field equals 5150
number of poles

Ampere turns per pole.

5150 x 70% equals 3610 Ampere turns lost in air
gap where 5150 equals ampere turns per pole, and 70%
are lost in air gap.

Ampere turns lost equals \( \mathcal{A} \times \) constant
pole pitch \times \text{length of pole} \times \text{flux}.

\[
3610 = \frac{2 \times \mathcal{A} \times 0.313 \times 4.07 \times 10^6}{7.3 \times 15.2}
\]

\[ \mathcal{A} = \frac{3610 \times 7.3 \times 15.2}{4.07 \times 10^6 \times 0.313} \]

Length of air gap was taken as .3

**LENGTH OF ARMATURE.**

Flux per pole equals area of teeth
under pole.

\[
\frac{4.07 \times 10^6}{70000} \quad \text{equals area of teeth under a pole}
\]

\[
a \times r \times l = \text{area of teeth under a pole}
\]

\[ a = 7.3" \text{ pole arc.} \]

\[ o = \text{Tooth pitch equals } 1.26"
\]

\[ r = 0.763" \text{ mean thickness of tooth.}
\]

\[
1 = \frac{58 \times 1.26}{7.3 \times 0.763} \quad \text{equals } 15.5 \text{ Approximate length of armature. use } 2 - \frac{1}{2}" \text{ ventilating ducts.}
\]

\[
13.1 + l = \text{165}" \text{ Length of armature, where .85}
\]
equals factor used to correct for laminations.

**ARMATURE CORE.**

Crosssection = \( \frac{\text{pole flux}}{2} \) core density.

\[
\frac{4.07 \times 10^6}{2 \times 35000 \times 0.85} \quad \text{equals 68.2 sq. in. in cross}
\]
35000 lines were taken as the density of the armature.

Depth of core equals \( \frac{\text{core cross section}}{\text{core length}} \)

\[ \frac{68.2}{15.5} = 4.4" \text{ depth of arc.} \]

\[ 4.4 + 50.6 + (1.42 \times 2) = 62.24" \text{ outside diameter of armature where 50.6 equals inside diameter of armature, and 142 equals depth of slot.} \]

**POLE CALCULATIONS.**

\( \text{Leakage factor} \times \text{flux per pole} \) equals sq. in.

Density per sq. in.\( \times \) crossection of pole.

\[ \frac{1.3 \times 4.07 \times 10^6}{102000} \] equals 50.4 sq. in. cross section of pole.

15.2 was taken as the length of a pole.

\[ \frac{50.4}{15.2 \times .95} \] equals 3.5" width of pole, where 50.4 equals cross section of pole, 15.2 equals length of pole, and .95 equals factor to correct for laminations.

\[ \frac{5160}{1300 \times .4} \] equals 9.9 sq. in. cross section of winding.

5160 equals ampere turns per pole, 1300 current density in amperes per sq. in., .4 space factor.

Limit of winding depth was taken as 1.8"

\[ \frac{9.9}{1.8} \] equals 5.5 Height of coil, where 9.9 equals cross section of winding, 1.8" and 1.8" equals winding depth.

Allow 1" for depth of pole shoe.
5.5 + 1 equals 6.5"  Total depth of pole.

50 - (6.5 x 2) equals 37"  Diameter of revolving field at base of poles where 50 = outside diameter of revolving field, and 6.5 x 2 equals total depth of two poles.

**CALCULATIONS OF LEAKAGE FACTOR.**

0 equals \( \frac{1}{r_0} + \frac{r_1}{r_1 + r_2} + \frac{r_2}{r_2} \)

\( r_0 \) equals \( \frac{0.313}{\frac{a \times r \times k + a \times l \times (u + s)}{0 \times o}} \)

Reluctance of air gap system.

\( r_1 \) equals \( \frac{0.313}{\frac{4c \times f + 4d \times f + 4b \times d}{N + m + b}} \)

Reluctance of field path.

\( r_2 \) equals \( \frac{0.313}{\frac{(a \times r \times k + a \times l \times (u + s))}{x} + \frac{v}{2k \times l \times u \times a \times j}} \)

Reflux of armature system.

\( f \) equals Length of air gap equals .3"

\( f \) of pole " 15.2"

\( c \) Thickness of pole shoes equals 1".

\( d \) Distance between pole shoe and wheel rim equals 5.5".

\( v \) equals flux path in armature equals 6.86"

\( i \) Depth of slot equals 1.42"

\( o \) Slot pitch " 1.26"
a equals Pole pitch equals 7.3"

r " Mean thickness of tooth equals .763"
l " Length of armature equals 15.5
u, " Permeability of armature equals 1950
j " Constant for lamination equals .85
s " Width of slot equals .532"
N " Mean distance between pole shoes equals 3.91"
M " " " " poles equals 6.05"
K " Depth of armature core equals 4.4"
b " Width of pole equals 3.5
u " Height of tooth above wires equals .24"

Substituting in the formulas we get:

\[ r_0 \text{ equals } .00102 \]
\[ r_1 \text{ equals } .004 \]
\[ r_2 \text{ equals } .000018 \]
\[ r_2' \text{ equals } .00745 \]

\[ \mathcal{d} \text{ equals } 1 + \frac{.00102}{.004} + \frac{.000018}{.004} + \frac{.000018}{.00745} \]

\[ \mathcal{d} \text{ equals } 1 + .256 + .0045 + .00242 \text{ equals } 1.263 \]

Actual leakage factor.

CALCULATION OF ARMATURE RESISTANCE.

A chain winding was used. The lengths of the flat coils are 79.2", 72.6" and 67.2". The lengths of the bent coils are 83.14", 75.16", and 67.5". Mean length of a coil equals \( \frac{79.2 + 72.6 + 67.2 + 83.14 + 75.16 + 67.5}{6} \)

\[ \text{equals } 74". \]

Since 210 conductors per phase there are 105
turns per phase.

Then the length of winding per phase equals $105 \times 74$ equals 7770" where 105 equals turns per phase, and 74 equals mean length of a turn.

Resistance equals $\frac{\text{length in inches} \times 0.8}{\text{cross section of con.}} \times 10^6$ equals .095 ohms per phase.

**WHEEL RIM.**

Assuming that the rim projects 1.9" on either side of the poles then 19" equals width of rim.

Thickness equals $\frac{\text{pole flux}}{2 \times 19 \times \text{rim density}}$.

$$\frac{4.07 \times 10^6}{2 \times 19 \times 45000}$$ equals 3" depth of wheel rim.

**CALCULATION OF SHORT CIRCUIT CHARACTERISTIC.**

$K_s$ equals $1 + \frac{r_0}{r_1} + \frac{r_2}{r_3} + \frac{r_4}{r_5}$.

All of these reluctances were found except $r_6$.

$r_6$ equals $0.313 \times \left( \frac{d}{b \times f \times x \times up} + \frac{e}{3g \times h \times x \times ut} \right)$

equal magnetic reluctance of the field system.

To find the length of the path $c$:

50" - 2(1+5.5) - 3 equals 34" mean diameter of wheel rim, where 50 equals diameter of revolving field and 5.5 equals height of coil.

$\frac{1}{28}$ of pole arc at this diameter equals $\frac{7 \times 34}{28}$

equals 3.82". Length of path on diameter equals $\frac{2}{4}$

$3.82 - 3.5 - 1.5$ equals 1.44. Length of path $= e$
e equals $1.44 + \frac{3 + \pi}{4} \quad$ equals 3.81" length of path through the wheel rim.

$u_r$ equals Permeability of wheel rim equals 350
$u_p$ " " " pole " 1600
$d$ " distance from wheel rim to pole shoe.
$b$ " thickness of pole equals 3.5"
$g$ " width of wheel rim " 19"
$h$ " thickness of wheel rim equals 3"
$f$ " length of pole " 15.2"
$r$ " 0.313\left(\frac{5.5}{3.5 \times 15.2 \times 350} + \frac{3.8}{38 \times 3 \times 1600}\right)$

equals .0000992

$K_s$ equals $1 + \frac{.00102}{.00745} + \frac{.000992}{.00745} + \frac{.000992}{.004}$

$K_s = 1 + .137 + .0133 + .0248$ equals 1.175 Effect of leakage on short circuit current.

$2 P x A,\text{equals } K_s x 2.12 x z x c.$

$2 P$ equals 14 poles, $K_s$ equals effect of leakage on short circuit current, $A,\text{equals } 5000$ ampere turns necessary for shunt field to supply; this was taken from curve, one of the curves drawn.

$Z$ equals 210 Conductors per phase, 212 equals constant.

$14 \times 5000 \text{ equals } 1.175 \times 2.12 \times 105 C$

$C$ equals 268 Short circuit current.

CALCULATION OF SHUNT FIELD.

100 volts used in D.C. exciter for shunt field.
Table of Flux and Cross sectional areas of different parts for different loads. Ampere turns per paths. etc.

<table>
<thead>
<tr>
<th>E. M. F.</th>
<th>3000</th>
<th>2300</th>
<th>1600</th>
<th>1000</th>
</tr>
</thead>
<tbody>
<tr>
<td>ARMATURE FLUX</td>
<td>$5.3 \times 10^6$</td>
<td>$4.07 \times 10^6$</td>
<td>$2.83 \times 10^6$</td>
<td>$1.77 \times 10^6$</td>
</tr>
<tr>
<td>FIELD FLUX</td>
<td>$6.7 \times 10^6$</td>
<td>$5.14 \times 10^6$</td>
<td>$3.58 \times 10^6$</td>
<td>$2.24 \times 10^6$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Material and sectional area in sq. in. of:</th>
<th>Magnetic densities and corresponding amp. turns per in. of length.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cast iron</td>
<td>57</td>
</tr>
<tr>
<td>.04&quot; Pole Rim</td>
<td>58</td>
</tr>
<tr>
<td>Sheet 50.4 .02&quot; Pole Core</td>
<td>58</td>
</tr>
<tr>
<td>Sheet .02&quot;</td>
<td>45600 12 35000 9 24300 73 15200 6</td>
</tr>
<tr>
<td>.02&quot; Sheet</td>
<td>45600 12 35000 9 24300 73 15200 6</td>
</tr>
<tr>
<td>3.8&quot;</td>
<td>30</td>
</tr>
<tr>
<td>6.5&quot; Arm. Pole Core</td>
<td>45</td>
</tr>
<tr>
<td>1.42&quot; Arm. Pole Core</td>
<td>45</td>
</tr>
<tr>
<td>6.86&quot; Arm. Pole Core</td>
<td>82</td>
</tr>
<tr>
<td>$\rho$ .00102</td>
<td>5410 4150 2890 1805</td>
</tr>
</tbody>
</table>

| Total ampere turns per pole | 11063 5372 9 3341.1 2024.1 |
Allowing 22% drop in the rheostat we have 78 volts delivered to the shunt winding. It takes 70000 ampere turns to excite the shunt field at no load and 2200 volts. Sectional area of conductor equals \( \text{Ampere turns} \times \text{length of a turn} \times \frac{8}{10^7} \).

Length of one turn of the field winding:

Mean diameter equals \( 3.5 + 1.75 = 5.35" \) where

\( 3.5 \) equals width of pole and \( 1.75 \) equals depth of winding.

Length equals \( 14.45 \times 2 + 5.25 \times \pi \) equals 45.4" Mean length of turn, where \( 14.45 \) equals straight part of pole and \( 5.25 \) equals mean diameter.

\( q \) equals \( \frac{70000 \times 45.4 \times 8}{78} \) equals 0.0325 Sectional area of conductor, where 70000 equals shunt ampere turns 45.4 equals mean length of turn \( \frac{0.0325 \times 10^6}{7354} \) equals \( 1 / 1615 \) circular mils.

Sq. in. equals 0.0326.

This corresponds to a No. 4 B & S wire.

Using a current density of 1300 amps. per sq. in. 1300 x 0.0326 equals 42.4 amperes that must be delivered to the shunt field.

\( \frac{\text{Ampere turns}}{\text{ampere used in shunt field}} = \frac{70000}{42.4} \) equal 1650 turns in shunt field.

\( R = \frac{\text{Turns} \times \text{length in inches} \times 8}{\text{Sectional area of conductor} \times 10^6} \)

\( 1650 \times 45.4 \times \frac{0.0326}{0.8} \times \frac{8}{10^6} \) equals 1.83 Ohms resistance.
of shunt winding.

CALCULATION OF SERIES WINDING.

Ampere turns necessary to excite field to 2300 volts at no load equals 70000. Ampere turns necessary to excite the field at 2300 volts or at full load equals 102000. Then the compensating winding should supply 22200 ampere turns at full load.

Use 1500 amperes per sq. in. in series winding.
A-3 to 1 transformer gives 39.4 amperes.

\[
\frac{39.4}{1500 \times 0.7854} = 33124 \text{ Circular Mils.}
\]

This corresponds to a No. 5 B & S wire.

\[
\frac{32200}{39.4} = 58.4 \text{ use 59 turns per pole.}
\]

\[
\frac{R}{\text{Length of a turn x turns x Area of conductor}} = \frac{8}{10^7}
\]

\[
R = \frac{45.4 \times 59 \times 8}{0.026 \times 10^7} \text{ equals 1.15 Ohms resistance of series field.}
\]

CALCULATION OF WIDTH AND DEPTH OF SHUNT & SERIES WINDINGS.

\[
1650 \div 14 = 118 \text{ Shunt turns per pole}
\]

where 1650-series turns per pole. Allow 55" on each end of coils for iron plates.

Diameter of No. 4 wire equals .216"

\[8 \times .216 = 1.73" \text{ depth of shunt winding.}\]

Since the winding is 15 turns wide and 8 deep:
\[15 \times .216 = 3.24" \text{ width of shunt winding.}\]

The series winding is 6 turns wide and 9 deep.
\[6 \times .194 = 1.16" \text{ width of winding.}\]
9 x .194 equals 1.74" depth of winding.
Total width of windings equal 3.24+1.16 equal 4.4".

**CALCULATION OF LOSSES.**

Hysteresis loss equals \( W_h \) equals \( AxVxf \)

Mean diameter of the armature core equals 50.6+2.32+4.4 equals 57.82. Width equals 15.5" and depth equals 4.4".

\[ V = 57.82 \times 11 \times 15.5 \times .85 \] equals 10500 cu. in. in armature, where .85 is a factor to correct for laminations.

Mean thickness of a tooth equals .763. Length equals 15.5".
Depth equals 1.42" and number equals 126.

\[ V = .763 \times 15.5 \times 1.42 \times .85 \times 126 \] equals 1800 cu. in. in teeth.

a equals Hysteresis factor corresponding to 35000 lines equals .0054.

f equals 60 cycles.

\[ W_h = .0054 \times 10500 \times 60 \] equals 3400 watts lost in armature due to hysteresis.

Hysteresis factor for 70000 lines equals .00164

\[ W_h = .00164 \times 1800 \times 60 \] equals 1770 watts lost in teeth due to hysteresis.

**CALCULATION OF EDDY CURRENT LOSS.**

\[ W_e = EVf^2 \]

E equals Eddy current factor for 3500 lines equals .000021.
\[ W_e = 0.000021 \times 10500 \times 3600 \text{ equals } 794 \text{ watts lost in armature due to eddy currents, where } 10500 \text{ equals } \text{cu. in. in armature and } 3600 \text{ equals cycles squared.} \]

Eddy current factor for 70000 lines equal \(0.000082\).

\[ W_e = 0.000082 \times 1800 \times 3600 \text{ equals } 531.5 \text{ watts lost in teeth due to eddy currents where } 1800 \text{ equals } \text{cu. in. in teeth and } 3600 \text{ equals cycles squared.} \]

Total iron loss equals \(3400 + 1770 + 794 + 531 \text{ equals } 6496 \text{ watts where } 3400 \text{ equals hysteresis loss in armature, } 1770 \text{ equals hysteresis loss in teeth, } 790 \text{ equals eddy current loss in armature, and } 531 \text{ equals eddy current loss in teeth.} \)

### DATA FOR CALCULATING EFFICIENCY

<table>
<thead>
<tr>
<th>Load Watts</th>
<th>Iron Loss</th>
<th>Friction loss</th>
<th>(I^2) Loss shunt</th>
<th>(I^2)R loss shunt</th>
<th>Windage loss</th>
<th>Armature loss</th>
<th>Total Eff. in %</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>6496</td>
<td>6300</td>
<td>29.5</td>
<td>247.5</td>
<td>4240</td>
<td>6496</td>
<td>6300</td>
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<tr>
<td>200</td>
<td>6496</td>
<td>6300</td>
<td>59</td>
<td>290</td>
<td>4240</td>
<td>6496</td>
<td>6300</td>
</tr>
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<td>300</td>
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<td>6300</td>
<td>88.5</td>
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<td>4240</td>
<td>6496</td>
<td>6300</td>
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<td>400</td>
<td>6496</td>
<td>6300</td>
<td>118</td>
<td>3966</td>
<td>4240</td>
<td>6496</td>
<td>6300</td>
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<tr>
<td>500</td>
<td>6496</td>
<td>6300</td>
<td>147.5</td>
<td>6204</td>
<td>4240</td>
<td>6496</td>
<td>6300</td>
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<tr>
<td>600</td>
<td>6496</td>
<td>6300</td>
<td>177</td>
<td>8925</td>
<td>4240</td>
<td>6496</td>
<td>6300</td>
</tr>
</tbody>
</table>

\(I^2\) R loss continued.

\(I^2\) R loss total loss in shunt loss in %

<table>
<thead>
<tr>
<th>Series field</th>
<th>447.25</th>
<th>17731</th>
<th>82.26</th>
</tr>
</thead>
<tbody>
<tr>
<td>894.5</td>
<td>18320</td>
<td>90.5</td>
<td></td>
</tr>
<tr>
<td>1340</td>
<td>20608</td>
<td>93</td>
<td></td>
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<td>1789</td>
<td>23791</td>
<td>94.3</td>
<td></td>
</tr>
<tr>
<td>2236.25</td>
<td>25416</td>
<td>94.9</td>
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<tr>
<td>2683.5</td>
<td>28644</td>
<td>95.2</td>
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### TABLE OF WEIGHTS.

<table>
<thead>
<tr>
<th>Parts</th>
<th>Cubic inches</th>
<th>Weight in Lb.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Teeth</td>
<td>1800</td>
<td>500</td>
</tr>
<tr>
<td>Body of armature</td>
<td>10500</td>
<td>2910</td>
</tr>
<tr>
<td>Poles</td>
<td>3880.8</td>
<td>1080</td>
</tr>
<tr>
<td>Pole shoes</td>
<td>1551</td>
<td>432</td>
</tr>
<tr>
<td>Wheel rim</td>
<td>8070</td>
<td>2105</td>
</tr>
<tr>
<td>Hub</td>
<td>3720</td>
<td>968</td>
</tr>
<tr>
<td>Frame</td>
<td>11900</td>
<td>3100</td>
</tr>
<tr>
<td>Ribs</td>
<td>2000</td>
<td>520</td>
</tr>
<tr>
<td>Bearing</td>
<td>3064</td>
<td>800</td>
</tr>
<tr>
<td>Armature key stays</td>
<td>1200</td>
<td>313</td>
</tr>
<tr>
<td>Supports</td>
<td>872</td>
<td>227</td>
</tr>
<tr>
<td>Winding guard</td>
<td>780</td>
<td>203</td>
</tr>
<tr>
<td>Base of machine</td>
<td>12620</td>
<td>3290</td>
</tr>
<tr>
<td>Shaft</td>
<td>5890</td>
<td>1670</td>
</tr>
<tr>
<td>Coupling</td>
<td>530</td>
<td>150</td>
</tr>
<tr>
<td>Spokes</td>
<td>4017.34</td>
<td>1044</td>
</tr>
<tr>
<td>Armature wire (length in ft)</td>
<td>3880</td>
<td>525</td>
</tr>
<tr>
<td></td>
<td>(width per ft) .126</td>
<td></td>
</tr>
<tr>
<td>Wire on shunt field</td>
<td>6270 (ft. long)</td>
<td>788</td>
</tr>
<tr>
<td>&quot; series &quot;</td>
<td>3130</td>
<td>313</td>
</tr>
<tr>
<td>Postes for holding brushes</td>
<td>456</td>
<td>118</td>
</tr>
<tr>
<td>Pole rings</td>
<td>206.4</td>
<td>57</td>
</tr>
<tr>
<td>Copper in commutator</td>
<td>340</td>
<td>108</td>
</tr>
<tr>
<td>&quot; slip rings</td>
<td>170</td>
<td>54</td>
</tr>
<tr>
<td>Iron in commutator</td>
<td>250</td>
<td>71</td>
</tr>
<tr>
<td>&quot; slip rings</td>
<td>160</td>
<td>45</td>
</tr>
</tbody>
</table>

**Total**                                    **21391**
Diagram of rectifier for series field.

Armature windings.

Current transformer.

Series field.
Plate 1 gives end and side elevation of the field.
Plate 2 gives elevations of wheel rim and spider, and end and side elevations of field poles.
Plate 3 gives shaft, commutator, slip rings, and coupling.
Plate 4 gives side and end elevations of armature.
Plate 5 gives section of armature, armature ring and bearings.
Plate 6 gives plan of the alternator.
Plate 7 gives excitation, load and compounding curves.
Plate 8 gives loss and efficiency curves.
End elevation of wheelrim and spider. Scale 1:5
Side elevation of wheelrim and spider.

End and side elevations of field pole. Scale 1:2.

THREE PHASE ALTERNATOR
REVOLVING FIELD TYPE
421 KVA—60 Cycles—No load 2200 Volts—
Full load 2300 Volts—14 Poles—Speed 317 R.P.M.
Designed by F.J. Williams & E. Rawson
Drawn by F.J. Williams
Plate No. 2.
THREE PHASE ALTERNATOR

REVOLVING FIELD TYPE

421 KVA ~ 60 Cycles ~ No load 2200 Volts ~
Full load 2300 Volts ~ 18 Poles ~ Speed 1740 RPM

Designed by F.J. Williams
Drawn by F.J. Williams
Date: Jul 26, 1910

Plate No. 3
THREE PHASE ALTERNATOR REVOLVING FIELD TYPE

721 KVA 60 Cycles 2200 Volts loaded 2300 Volts full load 19 Poles Speed 514 RPM

Designed by
F. L Williams & H. E. Rowton

Date May 1, 1911

Drawn by Roy C. Hauser

Plate No. 9
THREE PHASE ALTERNATOR REVOLVING FIELD TYPE
121 KVA 60 Cycles 2200 volts no load 2300 volts full load 19 Poles Speed 514 RPM
Designed by T.L. Williams & P.E. Hansen
Date May 12, 1910
Drawn by Ray C. Ryan
Plate No. 5
TEREE PHASE ALTERNATOR
REVOLVING FIELD TYPE
421 KVA 60 Cycles 2200 Volts, no load
2100 kilowatt 10 K.P.S. Speed 574 RPM
Designed by F.W. Williams
A.E. Prewett
Drawn by Roy C. Bower
Plate No.

Plan View of Alternator.