Design of a 45 K.W. Generator.

May 8, 1909.

W.K.C. 6-26-'35

Approved

Design for General Electric Company's Generator.

Ring Armature. High Speed.

Output = 45 K.W.

R.P.M. = 975 = n_1

E.M.F. = 125 VOLTS.

I = 360 AMPERES.

Peripheral Speed of Armature.

$$v = \frac{D_a \pi}{12} \times n_1 = \frac{17.5\pi}{12} \times 975 = 4485 \text{ ft per min.}$$

Diameter of Armature.

$$D_a = 3.8 \frac{v}{n_1} = 3.8 \frac{4500}{975} = 17.5''$$

Approximate Cooling Surface of Armature.

$$S_a = 2\pi \times D_a^2 (1-m_1) \times (m+m_1)$$

$$= 2\pi \times (17.5)^2 \times (1-.3) \times (1+.3) = 1736 \text{ sq. in.}$$

Determination of Armature Diameter by S_a.

$$D_a = \sqrt{\frac{S \times k \times W}{2\pi(1-m')(m+m')}} = \sqrt{\frac{.85 \times 45 \times 45000}{6.2832(1-.3)(1+.3)}} = 17.5''$$

Specific Cross Section of Armature Conductors.

$\frac{360}{2} = 180$ amperes per circuit.

$600 \times 180 = 108000$ circular mills

∴ Size of wire = 2 #3 wire in parallel.

Approximate Number of Inductors.

83 slots × 2 wires in parallel in each slot.

$N = 166$ inductors.

Length of Armature Conductor.

$$\frac{NL_a}{12} = \frac{166 \times 9.25}{12} = 128 \text{ ft.}$$

Length of Armature Core.

$$L_a = \frac{12 l_a}{N} = \frac{12 \times 128}{166} = 9.25''$$

$$\phi = \frac{6 \times 10^9 \times n_p \times E}{N \times m_1} = \frac{6 \times 10^9 \times 1 \times 125}{166 \times 975} = 4,630,213 \text{ lines.}$$

Radial depth of Armature Core.

$$B_a = \frac{\phi}{2 n_p \times L_a \times B_g} = \frac{4630213}{4 \times 9.25 \times 60000} = 2.1$$

Total Length of Armature Conductor.

$$l_A = N \times \frac{2L_a + 2B_a + h_a\pi}{12} = 166 \times \frac{2 \times 9.25 \times 2 \times 2.1 + .5\pi}{12}$$

$$= 388.7 \text{ feet.}$$

Armature Resistance.

$$r_a = \frac{C_A \times l_f}{4 n_p^2} = \frac{388.7 \times .000099}{4} = .0096 \text{ ohms}$$

To find warm resistance multiply $r_a = .0096$ by 1.16; $r_a' = .0096 \times 1.16 = .0111$

Power Consumed in Armature Winding.

$$w_a = C^2 \times r_a'$$

$$= (360)^2 \times .0111 = 129600 \times .0111$$

$$= 1438.56 \text{ watts.}$$

Power Loss by Hysteresis.

$w_h = \eta \times f \times M$ $\qquad f = \frac{n_1}{60} \times \omega p$

$= .0095 \times 32.5 \times 1642$ $\qquad = \frac{975}{60} \times 4$

$= 506.96$ watts. $\qquad = 32.5$

$M = 1642$

Power Loss by Eddy Current.

$w_e = \varepsilon \times f^2 \times M$

$= .000044 \times 956 \times 1642$

$= 69$ watts.

Specific Power Loss in Armature.

$S = \frac{S_a}{w_a + w_h + w_e} = \frac{1736}{2014.52} = .862$

About 34.5°C.

Circumfrential Current Density in Arm.

$c = \frac{N \times C}{6.283 \times D_a \times n_p} = \frac{166 \times 360}{6.283 \times 17.5 \times 2}$

$= \frac{59760}{220} = 271.6$

About 44°C rise.

$$f = \frac{n_1 \times n_p}{60}; \; n_1 = \frac{60 \times f}{n_p} = \frac{60 \times 32.5}{2} = 975.$$

$$S_m = \frac{\lambda \Phi}{B_m} = \frac{6 \times 10^9 \times n_p \times E \times \lambda}{N \times n_1 \times B_m} = \frac{125 \times 6 \times 1000000000 \times 2 \times 1.14}{166 \times 975 \times 90000}$$

$= 117.5$ sq. in. in both north poles

$\frac{117.5}{2} = 58.7 =$ sq. in. per pole.

$$D_m = \sqrt{S_m \times \frac{4}{\pi}} = \sqrt{58.7 \times 1.273} = 8.6''$$

Length of Magnet.

The length of the magnet in case of a smooth-armature machine, is approximately:

$L_m = D_m \times .85 = 8.6 \times .85 = 7.3''$,

and in case of a toothed armature machine:

$L_m = 7.3 \times .7 = 5''$

The Yoke.

Cross section of yoke $= \frac{S_m}{2 n_p} = 29.4$ sq. in. making the frame 10" wide, which gives a flang, or, over lap of .7" on either side of the core in the direction of the shaft.

The radial thickness will then be: $29.4 \div 10 = 2.94''$, which we will rais to 3.3" to allow for rounding the corners of the Yoke-Section.

Air Gap.

From tables of standard practice we find the air gap for a machine of this size to be $\frac{3}{16}''$.

Calculation of Magnetizing Force.

$$AT = at_g + at_a + at_m + at_r.$$

$$at_g = .313 \times B_g'' \times l_g'' = .313 \times 38000 \times \tfrac{3}{8} = 4460$$

$$\left.\begin{array}{l} at_a' = 700 \times 1.4 = 980 \\ at_a'' = 31 \times 9.6 = 297 \end{array}\right\} \text{total } at_a = 980 + 297 = 1277$$

From table and calculating we find $at_m = 1958$

$$at_r = K \frac{N' \times C}{2np} \times \frac{\alpha}{180} = 1.75 \times \frac{166 \times 360}{4} \times \frac{5.4}{180} = 781$$

$$\therefore AT = 4460 + 1277 + 1958 + 781 = 8476.$$

$$\begin{array}{r} 1277 \\ 1958 \\ 781 \\ \hline 8476 \end{array}$$

Calculation of Magnet Winding.

Shunt Winding.

$$AT = \frac{E \times d_m^2}{l_t''}$$

$$8476 = \frac{125 \times d_m^2}{27}$$

$$d_m^2 = \frac{8476 \times 27}{125} = \frac{228852}{125} = 1831 \text{ circ. mils}$$

For a four pole machine, we have;

1831 × 2 = 3662, and allowing 15% for resistance of rheostat resistance we have,

3662 + 600 = 4200 circ. mils.

This will be #14 B&S wire (S.C.C.)

which weighs .0128 lbs per ft.

Ohms per ft. at 20°C = .00253.

Diameter of wire in inches = .071 (S.C.C.)

Number of turns per inch = 14.1 (S.C.C.)

Winding depth = 2.5 inches.

$C = \frac{w_m}{E'}$; $w_m = CE' = 360 \times 55 = 1980$ watts.

Available length of winding space = 4.25"

Cooling Surface of Magnet Winding.

$S_m = (8.6 + 2 \times 2.5) \times \pi \times 4.25 \times 2 + 35.4 \times 2.5 \times 2.$

= 430 sq. inches.

Shunt Current.

$$C_{sh.} = \frac{30° \times 430}{75 \times 50} = 3.44 \text{ amperes.}$$

A Cooling Surface of 430 Sq. inches, gives $\frac{430}{50 \times 3.44} = 2.5$ Sq. inches per watt.

Number of Turns per Core.

$$T = \frac{AT}{C_{sh}} = \frac{8476}{3.44} = 2446$$

$$\frac{2446}{2} = 1223 \text{ turns per Core.}$$

Number of Turns per Layer.

$$\frac{\text{available length of winding space}}{\text{Diameter of \# 14 (S.C.C. wire)}}$$

$$= \frac{4.25}{.071} = 60,$$

and there must be 32 layers. making a winding depth = $32 \times .071 = 2.3''$ not including the core insulation.

Resistance of Shunt Winding.

$$r_{sh} = 4 \times 45 \times 32 \times \left(\frac{8.6 \times 2.5 \times \pi}{12}\right) \times .00252 = 33 \text{ ohms}$$

at 20°C

$33 \times 1.14 = 35$ ohms at 55°C, and the actual Shunt current necessary is:

$C_{sh} = \frac{8476}{2 \times 45 \times 32} = 2.94$ amperes, and total resistance of Shunt Circuit $\frac{125}{2.94} = 43$ ohms, making resistance of rheostat: $43 - 35 = 8$ ohms.

Electrical Efficiency.

$$\text{El. Eff.} = \frac{EC}{EC + C_a^2 r_a + C_{sh}^2 r''_{sh}}$$

$$= \frac{125 \times 360}{125 \times 360 + (360)^2 .0096 + (2.94)^2 \times 33}$$

$$= \frac{45000}{46635} = 96.5\%$$

Commercial Efficiency.

$$\text{Com. Eff.} = \frac{EC}{EC + C_a^2 r_a + C_{sh}^2 r''_{sh} + wh + we + wf.}$$

$$= \frac{45000}{46635 + 2300 + 69 + 507}$$

$$= \frac{45000}{49511} = 90.8\%$$
