Chapter 3

DESIGN OF VOLTAGE TRANSFORMER

Specification

Outdoor Type

Rated Primary Voltage	12,000	volts
Rated Secondary Voltage	120/240	volts
Rated Primary Current	0.0167	ampere
Rated Secondary Current	1.6667/0.8333	amperes
Rated Burden	200	volt - amperes
Rated Frequency	50	Hz
Accuracy Class	0.5	

The flux density in the core (B) can be chosen equal to 12 kilo - lines / sq. cm.

From core loss curve of RG - 10 (0.30 mm. thick) Fig. 4 - 2. The loss per kilogram for this density $w_c = 0.58$ watt.

Add 12% of core loss for the fundamental frequency loss.

The core loss per kilogram, $w_c = 0.58 \times 1.12 = 0.65$ watt.

For an average current density (A) = 30 amperes/sq. cm.

The copper loss per kilogram,

$$w_k = 2.37 \times A^2 \times K_5 \times 10^{-4}$$

$$= 2.37 \times (30)^2 \times 1.1 \times 10^{-4}$$

$$= 0.24 \text{ watt.}$$

The ratio of core weight to copper weight,

$$\frac{G_c}{G_k} = \frac{w_k}{w_c} \times \frac{W_c}{W_k}$$

Let $\frac{W_c}{W_k} = 7$

$$\frac{G_c}{G_k} = \frac{0.24}{0.65} \times 7 = 2.59$$

The output constant is taken equal to 0.50 and the net section area of the core,

$$A_c = c\sqrt{\frac{KVA \times \frac{G_c}{G_k} \times 10^{11}}{BAf}}$$

$$= 0.50\sqrt{\frac{0.2 \times 2.59 \times 10^{11}}{12 \times 10^3 \times 30 \times 50}} = 26.82 \text{ sq.cm.}$$

The cruciform - shaped core section will be use for this transformer. The diameter of the core,

$$D = \sqrt{\frac{A_c}{K_1 \times 0.618}}$$

where K_1 = Stacking factor = 0.96

$$D = \sqrt{\frac{26.82}{0.96 \times 0.618}} = 6.72 \text{ cm.}$$

The dimension of the core section are (See Fig. 3 - 2)

$$2a = 0.526\ D = 3.54\ ;\ \text{Use } 4.00 \text{ cm.}$$

$$2b = 0.850\ D = 5.71\ ;\ \text{Use } 5.50 \text{ cm.}$$

$$A_c = K_1 \left[2a.2b + (2b - 2a) \,.\, 2a\right] = 26.88 \text{ sq.cm.}$$

$$D = \sqrt{\frac{26.88}{0.96 \times 0.618}} = 6.75 \text{ cm.}$$

The total flux for a density of 12 kilo - lines / sq.cm.

$$\phi = B \times A_c = 322.56 \text{ kilo - lines / sq.cm.}$$

The number of turns for high - voltage winding

$$t_p = \frac{E_p \times 10^8}{4.44 \times f \times \phi}$$

$$= \frac{12,000 \times 10^8}{4.44 \times 50 \times 322.56 \times 10^3} = 16,757 \text{ turns}$$

Use $t_p = 17,000$ turns

The number of turns for low - voltage winding

$$t_s = \frac{E_s}{E_p} \times t_p$$

$$= \frac{240}{12,000} \times 17,000 = 340 \text{ turns}$$

The full - load current in the two windings

$$I_p = \frac{200}{12,000} = 0.0167 \text{ ampere}$$

$$I_s = \frac{200}{240} = 0.8333 \text{ ampere}$$

The section area of the conductor for high - voltage and low - voltage windings for the average current density = 30 amperes/sq.cm.

$$S_{cp} = \frac{I_p}{A} = \frac{0.0167}{30} = 0.00055 \text{ sq.cm.}$$

$$S_{cs} = \frac{I_s}{A} = \frac{0.8333}{30} = 0.02777 \text{ sq.cm.}$$

The area of the window opening

$$h_w w_w = \frac{2 S_{cp} t_p}{f_s}.$$

where f_s = Space factor $= \frac{10}{30 + KV}$

$$= \frac{10}{30 + 12} = 0.2380$$

Reduce 30% of f_s because of small transformer.

$$f_s = 0.2380 \times 0.70 = 0.1670$$

$$h_w w_w = \frac{2 \times 0.00055 \times 17,000}{0.1670} = 111.98 \text{ sq.cm.}$$

Let $h_w = 2.5\, w_w$

$$w_w^2 = \frac{111.98}{2.5} = 44.7920 \text{ sq.cm.}$$

$$w_w = 6.70 \text{ cm.; Use } 7.00 \text{ cm.}$$

$$h_w = 16.75 \text{ cm.; Use } 16.50 \text{ cm.}$$

The length of the yoke

$$l_y = w_w + (2 \times 2b)$$

$$= 7.00 + (2 \times 5.50) = 18.00 \text{ cm.}$$

The approximate total weight of the core

$$G_c = 2\,(l_y + h_w) \times A_c \times D_c \times 10^{-3}$$

D_c = The volume density of RG - 10 Steel

= 7.65 grams/cu.cm.

$$G_c = 2\,(18.00 + 16.50) \times 26.88 \times 7.65 \times 10^{-3}$$

$$= 14.20 \text{ kg.}$$

The length of the average mean - turn for the windings

$$L_{av} = \pi\left(D + \frac{w_w - \beta}{2}\right)$$

The clearance, β , between the two coils in the window opening should be approximately 0.50 cm.

$$L_{av} = \pi\left(6.75 + \frac{7.00 - 0.50}{2}\right)$$

$= 31.40$ cm.

The approximate total copper weight

$$G_k = 2\, t_p\, S_{cp}\, L_{av}\, D_k \times 10^{-3}$$

D_k = Copper Wire density = 8.87 grams/cu.cm.

$$G_k = 2 \times 17{,}000 \times 0.00055 \times 31.40 \times 8.87 \times 10^{-3}$$

$$= 5.21 \text{ Kg.}$$

The approximate ratio of core weight to copper weight

$$\frac{G_c}{G_k} = \frac{14.20}{5.21} = 2.73$$

Design of Windings

Low - voltage winding

A No. 15 SWG round copper wire is selected from the copper wire table. The dimensions of the conductor are :

The nominal diameter of bare conductor = 1.83 mm.

The nominal diameter of insulated conductor = 1.90 mm.

The bare conductor cross-section area (S_{cs}) = 2.63 sq.mm.

= 0.0263 sq.cm.

The secondary winding must be arranged that 120 and 240 volts can be obtain at rated capacity. To accomplish this, the low-voltage coil is divided into two equal coils, placed close to each core leg. For 120 volts the coils are connected in parallel, 240 volts the coils are connected in series.

The number of turn per coil $= \frac{340}{2}$

= 170 turns

Use 3 layers per coil consists of :

2 layers of 60 turns per layer and

1 layer of 50 turns per layer

For layer-wound coils, the space of one turn must be allowed for the start of winding. The total height of the low-voltage coils is then

$$= 0.19 \times 61 = 11.59 \text{ cm.}$$

$$\text{The volt per turn} = \frac{240}{340} = 0.7060 \text{ volt.}$$

and the maximum voltage between layers = $0.7060 \times 2 \times 60$

= 84.72 volts.

The pressphane insulation 0.13 mm. thick will be used between layers of the low-voltage coils.

The depth of each low-voltage coil is then

$$d_s = 3 \times 0.19 + 2 \times 0.013 = 0.60 \text{ cm.}$$

Use d_s = 0.63 cm.

High-voltage winding

A. No. 32 SWG round copper wire is selected from the copper wire table. The dimensions of the conductor are :

The nominal diameter of bare conductor = 0.274 mm.

The nominal diameter of insulated conductor = 0.3070 mm.

The bare conductor cross-section area (S_{cp}) = 0.0589 sq.mm.

= 589×10^{-6} sq.cm.

The number of turn per core leg = $\frac{17,000}{2}$

= 8,500 turns.

Use 27 layers per coil consists of

26 layers of 320 turns per layer and

1 layer of 180 turns per layer

The total height of the high-voltage coils is then

$$h = 321 \times 0.0307 = 9.85 \text{ cm.}$$

$$\text{The voltage per turn} = \frac{12,000}{17,000} = 0.7060 \text{ volt.}$$

and the maximum voltage between layers = $0.7060 \times 2 \times 320$

= 451.84 volts.

The pressphane insulation 0.13 mm. thick will be used between layer of the high voltage coils.

The depth of each high-voltage coil is then

$$d_p = 27 \times 0.0307 + 26 \times 0.013$$

$$= 1.1669 \text{ ; Use } 1.20 \text{ cm.}$$

The insulation between the yokes and the ends of the coils consists of press-board space block 2.45 cm. thick for the low-voltage coils, and press-board space block 3.3250 cm. thick for the high-voltage coils. The height of the coils plus insulation is then

$$\text{Low-voltage} = 11.60 + 2\,(2.45) = 16.50 \text{ cm.}$$

$$\text{High-voltage} = 9.85 + 2\,(3.3250) = 16.50 \text{ cm.}$$

The window height is not change the dimension.

The insulation between the high-voltage and low-voltage windings consists of pressphane 0.30 cm. thick and 0.50 cm. oil duct.

The total depth of the coils in the window = 2 (0.30 + 0.63 + 0.30 + 0.50 + 1.20)

= 5.86 cm.

The clearance between the outside high-voltage coil equal to 0.40 cm.

$$\text{The width of window} = (6.75 + 5.86) + 0.40 - 5.50$$

$$= 7.51 \text{ ; Use } 7.50 \text{ cm.}$$

The dimensions of the window are then

$$h_w = 16.50 \text{ cm.}, \quad w_w = 7.50 \text{ cm.}$$

Since the dimensions of the window have been changed from the value first determined, it will be necessary to recalculate the weight of the core.

The Dimension of the core yoke will be changed to $2\,a_1 =$ 4.50 cm., $2\,b_1 = 6.00$ cm.

The cross-section area of core yoke

$$A_{c1} = 0.96 \left[4.50 \times 6.00 + (6.00 - 4.50)\,4.50 \right]$$
$$= 32.40 \text{ sq.cm.}$$

The mean length of core yoke $= 7.50 + 5.50 = 13.00$ cm.

The weight of the core yokes $= 2 \times 13 \times 32.40 \times 7.65 \times 10^{-3}$

$= 6.45$ Kg.

The mean length of core leg $= 0.5 + 16.50 + 5.50 = 22.50$ cm.

The weight of core legs $= 2 \times 22.50 \times 26.88 \times 7.65 \times 10^{-3}$

$= 9.25$ Kg.

The total weight of the core $(G_c) = 6.45 + 9.25 = 15.70$ Kg.

The current density in the low-voltage winding

$$A_s = \frac{I_s}{S_{cs}} = \frac{0.8333}{0.0263}$$

$$= 31.68 \text{ amperes/sq.cm.}$$

and in the high-voltage winding

$$A_p = \frac{I_p}{S_{cp}} = \frac{0.0167}{589 \times 10^{-6}}$$

$$= 28.35 \text{ ampere/sq.cm.}$$

The length of the mean-turn for the low-voltage winding

$$L_s = 2\pi\left(\frac{D}{2} + 0.30 + \frac{d_s}{2}\right)$$

$$= 2\pi\left(\frac{6.75}{2} + 0.30 + \frac{0.63}{2}\right)$$

$$= 25.06 \quad \text{cm.}$$

and for the high-voltage winding

$$L_p = 2\pi\left(\frac{D}{2} + 0.30 + d_s + d + \frac{d_p}{2}\right)$$

$$= 2\pi\left(\frac{6.75}{2} + 0.30 + 0.63 + 0.80 + \frac{1.20}{2}\right)$$

$$= 35.83 \quad \text{cm.}$$

The low-voltage winding copper weight

$$G_s = t_s\, S_{cs}\, L_s \times 8.87 \times 10^{-3}$$

$$= 340 \times 0.0263 \times 25.06 \times 8.87 \times 10^{-3}$$

$$= 1.99 \quad \text{Kg.}$$

and the high-voltage winding copper weight

$$G_p = t_p\, S_{cp}\, L_p \times 8.87 \times 10^{-3}$$

$$= 17{,}000 \times 586 \times 10^{-6} \times 35.83 \times 8.87 \times 10^{-3}$$

$$= 3.18 \quad \text{Kg.}$$

The total copper weight

$$G_k = 1.99 + 3.18 = 5.17 \quad \text{Kg.}$$

The ratio of core weight to copper weight

$$\frac{G_c}{G_k} = \frac{15.70}{5.17} = 3.04$$

From the core loss curve for RG - 10 (0.30 mm. thick) the loss per kilo - gram for a density of 12 kilo - lines / sq.cm.

$$w_e = 1.12 \times 0.58 = 0.65 \text{ watt/kg.}$$

The total core loss

$$W_c = 0.65 \times 15.70 = 10.20 \text{ watts.}$$

The I^2R loss plus stray load loss in low - voltage winding at 75°C

$$W_s = 2.37 \times A_s^2 \times G_s \times 1.1 \times 10^{-4}$$

$$= 2.37 \times (31.68)^2 \times 1.99 \times 1.1 \times 10^{-4}$$

$$= 0.52 \text{ watt.}$$

and the I^2R loss pluss stray load loss in high - voltage winding at 75°C

$$W_p = 2.37 \times A_p^2 \times G_p \times 1.1 \times 10^{-4}$$

$$= 2.37 \times (28.35)^2 \times 3.18 \times 1.1 \times 10^{-4}$$

$$= 0.67 \text{ watt.}$$

The total copper loss,

$$W_k = 0.52 + 0.67 = 1.19 \text{ watts.}$$

The ratio of losses,

$$\frac{W_c}{W_k} = \frac{10.20}{1.19} = 8.57$$

The resistance of the low - voltage winding at 75°C

$$R_s = \frac{W_s}{I_s^2} = \frac{0.52}{(0.8333)^2}$$

$$= 0.75 \quad \text{ohm.}$$

and the resistance of the high - voltage winding at 75° C

$$R_p = \frac{W_p}{I_p^2} = \frac{0.67}{(0.0167)^2}$$

$$= 2,402 \quad \text{ohms.}$$

The total resistance in terms of the high - voltage winding

$$R_t = \frac{W_k}{I_p^2} = \frac{1.19}{(0.0167)^2}$$

$$= 4,267 \quad \text{ohms.}$$

The percent resistance drop

$$P_r = \frac{I_p R_t}{E_p} \times 100 = \frac{0.0167 \times 4,267 \times 100}{12,000}$$

$$= 0.59 \%$$

The percent reactance drop (low - voltage windings are connected in series)

$$P_x = 2 \times \frac{8.47f\ t_p^2\ I_p}{hE_p \times 10^6} \left(\frac{d_p + d_s}{3} + d\right) \frac{L_p + L_s}{2}$$

From Fig. 3 - 1

$$d_p = 1.20 \quad \text{cm.}$$

$$d_s = 0.63 \quad \text{cm.}$$

$$d = 0.80 \quad \text{cm.}$$

$$h = \frac{9.85 + 11.59}{2} = 10.72 \quad \text{cm.}$$

$$P_x = 2 \times \frac{8.47 \times 50 \times (8,500)^2 \times 0.0167}{10.72 \times 12,000 \times 10^6}$$

$$\times \left(\frac{1.20 + 0.63}{3} + 0.80\right) \times \left(\frac{35.83 + 25.06}{2}\right)$$

$$= \frac{2 \times 8.47 \times 50 \times (8,500)^2 \times 0.0167 \times 1.41 \times 30.45}{10.72 \times 12,000 \times 10^6}$$

$$= 0.34 \%$$

The percent impedance drop,

$$P_z = \sqrt{P_r^2 + P_x^2}$$

$$= \sqrt{(0.59)^2 + (0.34)^2} = 0.68 \%$$

The sustained short - circuit current for normal primary voltage

$$I' = \frac{I_p \times 100}{P_z}$$

$$= \frac{0.0167 \times 100}{0.68} = 2.46 \quad \text{amperes.}$$

The percent regulation for 100% power factor load

$$= P_r + \frac{P_x^2}{200}$$

$$= (0.59) + \frac{(0.34)^2}{200} = 0.59 \%$$

and for 80% power factor load, the percent regulation

$$= P_r \cos \theta + P_x \sin \theta + \frac{(P_x \cos \theta + P_r \sin \theta)^2}{200}$$

$$= 0.59 \times 0.80 + 0.34 \times 0.60 + \frac{(0.34 \times 0.80 + 0.59 \times 0.60)^2}{200}$$

$$= 0.68 \%$$

The mean length of the flux path (L_{av}) is shown by the dotted line in Fig. 3 - 1.

$$L_{av} = 2\left[(w_w + 2b) + (h_w + 2b_1)\right]$$

$$= 2\left[(7.50 + 5.50) + (16.50 + 6.00)\right] = 71 \quad \text{cm.}$$

From the magnetization curve of RG - 10 (0.30 mm. thick) steel (Fig. 4 - 3), the ampere - turns per centrimetre for a density of 12 kilo - lines / sq.cm. at = 0.18 ampere - turn/cm.

The total ampere - turns necessary to maintain the flux in the iron path of the magnetic circuit

$$= at \times L_{av} = 0.18 \times 71 = 12.78 \quad \text{ampere - turns}$$

The ampere - turns for 4 joints at a density of 12 kilo-lines/ sq.cm. is about 100 times the ampere - turns/cm. [1]

The ampere - turns for 4 joints $= 0.18 \times 100$

$= 18$ ampere - turns

The total ampere - turns (AT) $= 18 + 12.78$

$= 30.78$ ampere - turns

The magnetizing current,

$$I_m = \frac{AT}{\sqrt{2}\, t_p} = \frac{30.78}{\sqrt{2} \times 17{,}000} = 0.00128 \quad \text{ampere}$$

The inphase component of the no - load current,

$$I_w = \frac{W_c}{E_p} = \frac{10.20}{12{,}000} = 0.00085 \quad \text{ampere}$$

The exciting current $I_e = \sqrt{I_m^2 + I_w^2}$

$$= \sqrt{(0.00128)^2 + (0.00085)^2} = 1.537 \times 10^{-3} \quad \text{ampere}$$

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1. L.F. Blume, editor, Transformer Engineering (New York: John Wiley & Sons, 1938) P. 10.

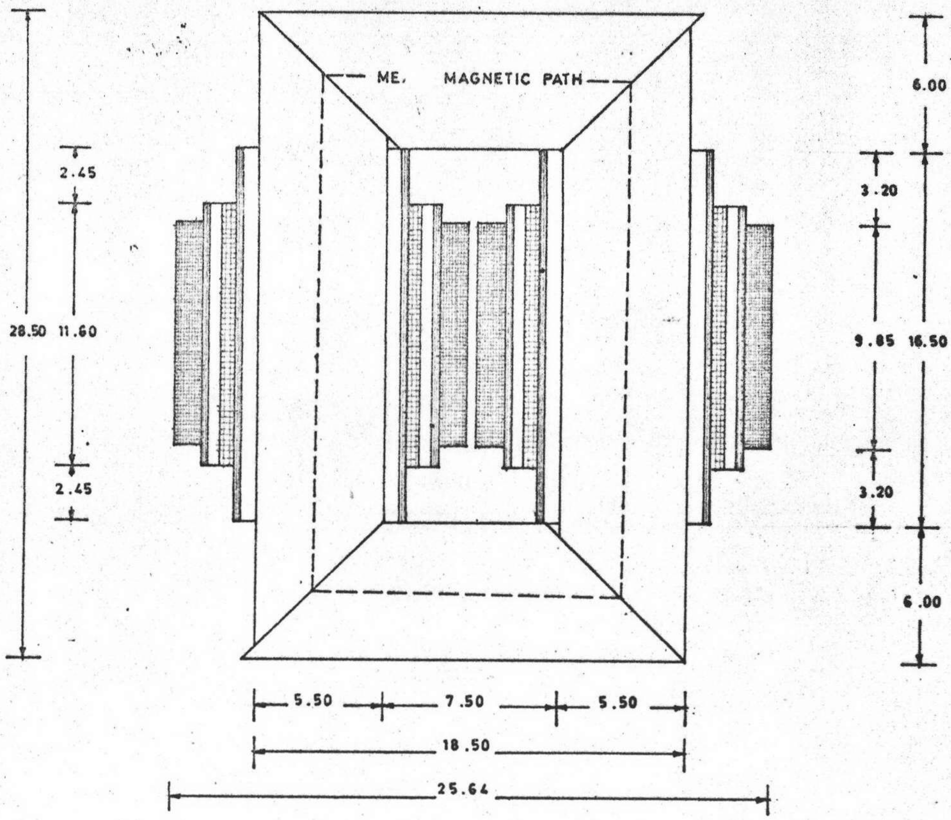

FIG.3-1 CORE DIMENSIONS, WINDOW OPENING, MEAN MAGNATIC PATH AND CROSS-SECTION OF THE WINDINGS AND INSULATIONS.

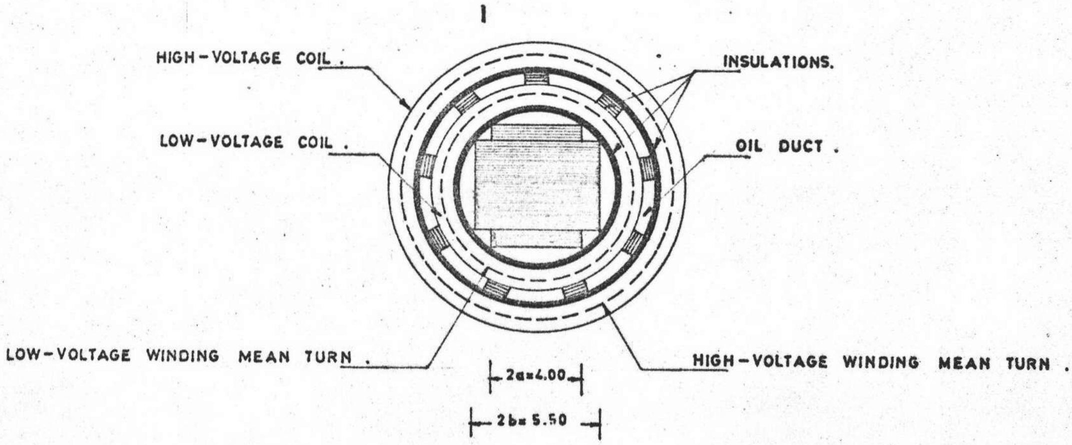

FIG.3-2 ARRANGEMENT OF HIGH-VOLTAGE AND LOW-VOLTAGE COILS AND THE MEAN LENGTH OF TURN OF THE WINDINGS.

The total radiating surface of the transformer winding and core is

$$\text{Core legs} = 2\left[2\,(5.5 \times 22.5) + (4 \times 28) + (4 \times 17)\right]$$
$$= 855 \quad \text{sq.cm.}$$

$$\text{Yokes} = 2\left[2\,(6.0 \times 13.0) + (4.5 \times 19) + (4.5 \times 7)\right]$$
$$= 546 \quad \text{sq.cm.}$$

$$\text{Low-voltage winding} = 2\,(25.06 \times 11.59 \times 2)$$
$$= 1161.78 \quad \text{sq.cm.}$$

$$\text{High-voltage winding} = 2\,(35.83 \times 9.85 \times 2)$$
$$= 1411.70 \quad \text{sq.cm.}$$

$$\text{Total radiating surface} = 3974.48 \quad \text{sq.cm.}$$

and the surface per watt loss

$$\frac{S}{W} = \frac{3974.48}{11.39}$$
$$= 348.94 \quad \text{sq.cm./watt}$$

A plain sheet-steel will be used. The surface per watt loss should then be 30. The total area of the tank wall

$$S_t = (W_c + W_k)\,\frac{S}{W}$$
$$= 11.39 \times 30$$
$$= 341.70 \quad \text{sq.cm.}$$

The plain sheet-steel with 0.24 cm. thickness are used for the tank wall. The shape of the tank section is shown in Fig. 3 - 3.

The cross-section area of the tank

$= 33 \times 5 + 2 \times 13 \times 10 + \pi (10)^2 = 739.16$ sq.cm.

The height of the tank = 35 cm.

The depth of the oil in the tank = 33 cm.

The volume of the oil in the tank = 739.16 x 33

= 24,392.28 cu.cm.

The volume of the transformer, if calculated from the active material weights with no allowance for insulation, core, clamps etc.

$$= \frac{15.70}{7.65 \times 10^{-3}} + \frac{5.17}{8.87 \times 10^{-3}}$$

= 2635.14 cu.cm.

The volume of the oil reguired = 24,392.28 - 2,635.14

= 21,757.14 cu.cm.

= 21.76 litrs.

The density of the oil is 0.9 Kg./litr.

The weight of the oil = 0.9 x 21.76

= 19.58 kg.

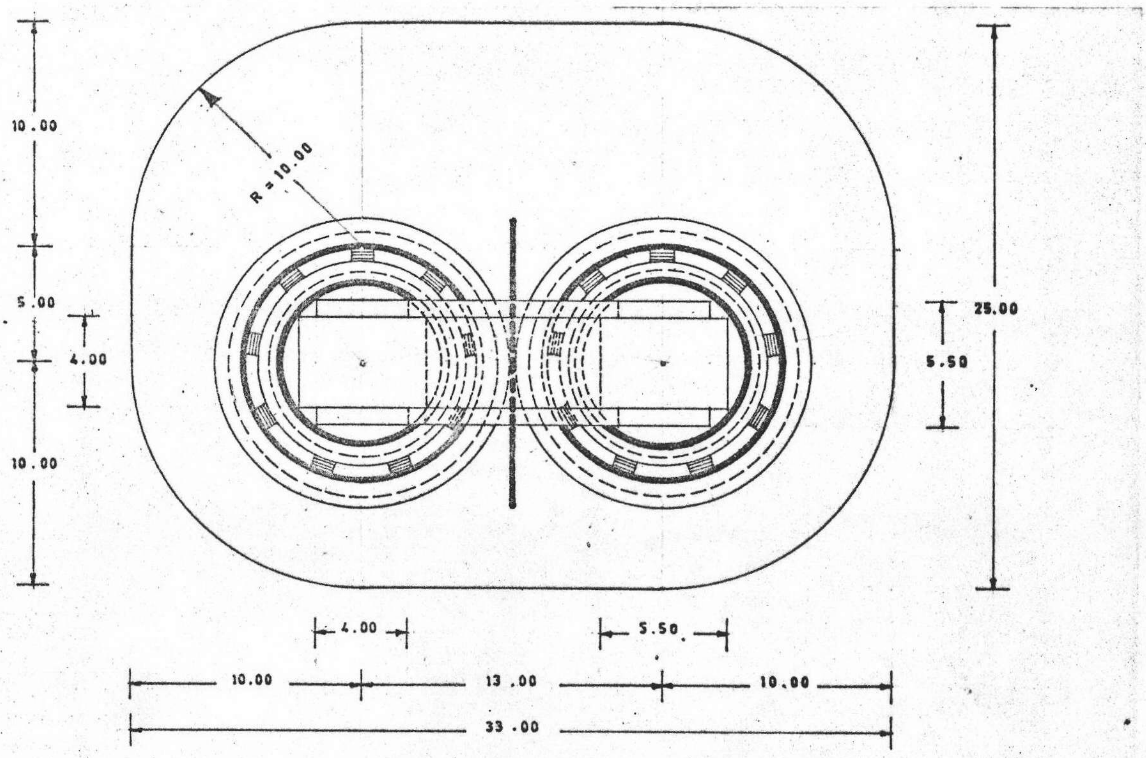

FIG 3.-3 THE SHAPE OF THE TANK SECTION AND THE POSITION OF THE TRANSFORMER IN THE TANK .

Ratio and Phase - Angle Errors

From Equation (2.1) and (2.2)

The actual voltage ratio (R) $= \frac{V_p}{V_s}$

$$= n\left[1 + \frac{I_w R_p + I_m X_p}{nV_s}\right] + \frac{nI_s(R_{ts}\cos\theta + X_{ts}\sin\theta)}{V_s} \qquad \text{..........(2.1)}$$

The ratio correction factor (RCF)

$$= \frac{\text{True Ratio (Actual Ratio)}}{\text{Marked Ratio}} = \frac{R}{m}$$

The phase angle $(\gamma) = \frac{R_p I_m - X_p I_w}{nV_s} - \frac{I_s}{V_s}(X_{ts}\cos\theta - R_{ts}\sin\theta)$

..........(2.2)

At no - load condition

$$R_o = \frac{V_p}{V_s} = n\left(1 + \frac{I_w R_p + I_m X_p}{nV_s}\right) \qquad \text{..........(2.3)}$$

and $\gamma_o = \frac{R_p I_m - X_p I_w}{nV_s}$ ....(2.4)

$$R = R_o + nI_s\frac{(R_{ts}\cos\theta + X_{ts}\sin\theta)}{V_s} \qquad \text{..........(2.5)}$$

and $\gamma = \gamma_o - \frac{I_s}{V_s}(X_{ts}\cos\theta - R_{ts}\sin\theta)$ ....(2.6)

To reduce the ratio error by adding 1.6 turns in low - voltage winding.

The number of turns in low - voltage winding

t_s = 341.6 turns

In condition of the secondary winding be connected in series the rated secondary will be 240 volts, and at the rated burden = 200 VA. I_w = 0.00085 ampere

$$I_m = 0.00128 \quad \text{ampere}$$

$$R_p = 2,402 \quad \text{ohms}$$

$$X_p = \frac{P_x}{2} \times \frac{E_p}{I_p} \times \frac{1}{100} = \frac{0.34}{2} \times \frac{12,000}{0.0167} \times \frac{1}{100}$$

$$= 1,222 \quad \text{ohms}$$

$$R_{ts} = R_s + \frac{R_p}{(n)^2}$$

$$n = \text{actual turn ratio}$$

$$= \frac{t_p}{t_s} = \frac{17,000}{341.6}$$

$$= 49.7658$$

$$m = \text{marked ratio} = \frac{12,000}{240} = 50$$

$$R_{ts} = 0.75 + \frac{2,402}{(49.7658)^2} = 1.72 \quad \text{ohms}$$

$$X_{ts} = \frac{2\,X_p}{(n)^2} = \frac{2 \times 1,222}{(49.7658)^2} = 0.99 \quad \text{ohm}$$

$$R_o = 49.7658 + \frac{0.00085 \times 2,402 + 0.00128 \times 1,222}{240}$$

$$= 49.7808$$

$$RCF_o = \frac{49.7808}{50} = 0.9956$$

$$\gamma_o = \frac{2,402 \times 0.00128 - 1,222 \times 0.00085}{49.7658 \times 240}$$

$$= 0.000171 \quad \text{radian} = 0.59 \quad \text{minute.}$$

At 100 % rated voltage and 100 % rated burden power factor 0.80 lagging

$$I_s = \frac{200}{240} = 0.8333 \quad \text{ampere}$$

$$\frac{nI_s}{V_s}(R_{ts}\cos\theta + X_{ts}\sin\theta) = \frac{49.7658 \times 0.8333}{240}(1.72 \times 0.80 + 0.99 \times 0.60)$$

$$= 0.3404$$

$$R = 49.7808 + 0.3404 = 50.1212$$

$$RCF = \frac{50.1212}{50} = 1.0024$$

$$\frac{I_s}{V_s}(X_{ts}\cos\theta - R_{ts}\sin\theta) = \frac{0.8333}{240}(0.99 \times 0.80 - 1.72 \times 0.60)$$

$$= -0.00083 \quad \text{radian}$$

$$= -2.85 \quad \text{minutes}$$

$$\gamma = 0.59 + 2.85 = 3.44 \quad \text{minutes}$$

$$TCF = \text{Transformer Correction Factor}$$

$$= RCF\left(1 + \frac{\gamma \tan\theta}{3438}\right)$$

$$= 1.0024\left(1 + \frac{3.44 \times 0.75}{3438}\right)$$

$$= 1.0032$$

At 100 % rated voltage and 25 % rated burden power factor factor 0.80 lagging, the ratio correction factor (RCF), phase angle (γ) and transformer correction factor (TCF) can be calculated the same as 100 % rated voltage and 100 % rated burden power factor 0.80 lagging, therefore

$$RCF = 0.9973$$

$$\gamma = 1.30 \quad \text{minutes}$$

$$TCF = 0.9976$$

From

$$E_p = 4.44\, ft_p\, B\, A_c \times 10^{-8} \quad \text{volts}$$

$$B = \frac{E_p}{4.44\, ft_p\, A_c \times 10^{-8}}$$

$$= \frac{E_p}{4.44 \times 50 \times 17{,}000 \times 26.88 \times 10^{-8}}$$

$$= E_p \quad \text{lines/sq.cm.}$$

Therefore

B at 80 % rated voltage = 9.6 Kilo-lines/sq.cm.

and B at 120 % rated voltage = 14.40 Kilo-line/sq.cm.

The ratio correction factor (RCF), phase angle (γ) and transformer correction factor (TCF) at 80 % and 120 % rated voltage at 25 % and 100 % rated burden power factor 0.80 lagging at rated frequency can be calculated the same as 100 % rated voltage and 100 % rated burden power factor 0.80 lagging, shown in Table 3.1.

Table 3.1 Summary of ratio correction factor (RCF), phase angle (γ) and transformer correction factor (TCF) at 80 % 100 % and 120 % rated voltage (240 volts) at 25 % and 100 % rated burden (200 VA) , power factor 0.80 lagging at rated frequency (50 Hz).

% Rated voltage (240 volts)	No load		25 % rated burden			100 % rated burden		
	RCF_o	γ_o (minute)	RCF	γ (minute)	TCF	RCF	γ (minute)	TCF
80 %	0.9956	0.61	0.9973	1.32	0.9976	1.0024	3.46	1.0032
100 %	0.9956	0.59	0.9973	1.30	0.9976	1.0024	3.44	1.0032
120 %	0.9956	0.66	0.9973	1.37	0.9976	1.0024	3.51	1.0032

In the condition of the secondary windings be connected in parallel the rated secondary voltage will be 120 volts and the rated burden 200 VA.

$$m = \frac{12,000}{120} = 100$$

$$n = 2 \times 49.7658 = 99.5316$$

$$R_p = 2,402 \text{ ohms.}$$

$$R_s = \frac{0.75}{4} = 0.1875 \text{ ohm.}$$

$$X_p = 1,222 \text{ ohms.}$$

$$R_{ts} = 0.1875 + \frac{2,402}{(99.5316)^2} = 0.43 \text{ ohm.}$$

$$X_{ts} = 2 \times \frac{1,222}{(99.5316)^2} = 0.2467 \text{ ohm.}$$

In the same as rated voltage at 240 volts, the ratio correction factor (RCF), phase angle (γ), and transformer correction factor (TCF) at 80% , 100% and 120% rated voltage at 25% and 100% rated burden power factor 0.80 lagging at rated frequency can be calculated, shown in Table 3.2 .

Table 3.2 Summary of ratio correction factor (RCF), phase angle (γ) and transformer correction factor (TCF) at 80%, 100% and 120% rated voltage (120 volts) at 25% and 100% rated burden (200 VA) power factor 0.80 lagging at rated frequency (50 Hz).

% rated voltage (120volts)	no load		25% rated burden			100% rated burden		
	RCF_o	γ_o (minute)	RCF	γ (minute)	TCF	RCF	γ (minute)	TCF
80%	0.9956	0.61	0.9973	1.34	0.9976	1.0024	3.51	1.0032
100%	0.9956	0.59	0.9973	1.32	0.9976	1.0024	3.49	1.0032
120%	0.9956	0.66	0.9973	1.39	0.9976	1.0024	3.56	1.0032

VOLTAGE TRANSFORMER DESIGN SHEET

VA., 200 PHASE, SINGLE CYCLE, 50
ACCURACY CLASS, 0.5
TYPE, CIRCULAR CORE
TYPE OF COOLING, NATURAL - OIL COOLED

VOLTS	H.V.	12,000
	L.V.	120/240
AMPERES	H.V.	0.0167
	L.V.	1.6667/0.8333

CORE

SHEET STEEL	RG-10, 0.30 mm. THICK
OUTPUT CONSTANT	0.50
CORE LEG :	
AREA, SQ.CM	26.88
DIAMETER, CM	6.75
DIMENSIONS, CM	2a = 4.00 ., 2b = 5.50
DENSITY, LINE / SQ.CM.	12,000
WEIGHT, KG	9.25
YOKE :	
AREA, SQ.CM.	32.40
DENSITY, LINES / SQ.CM.	10,000
COPPER SPACE FACTOR	0.1670
WINDOW DIMENSION, CM	h_w = 16.50
	w_w = 7.50
LAMINATION FACTOR, K_1	0.96

CORE AND WINDINGS

MEAN LENGTH OF FLUX PATH, CM	71
TOTAL AMPERE-TURN	30.78
MAGNETIZING CURRENT, AMPERE	0.00128
CORE LOSS CURRENT, AMPERE	0.00085
EXCITING CURRENT, AMPERES	1.53×10^{-3}

PERCENT :

RESISTANCE		0.59
REACTANCE		0.37
IMPEDANCE		0.70
POWER FACTOR	80	100
REGULATION	0.70	0.59

LOSSES

TOTAL CORE, WATTS	10.20
COPPER & STRAY LOAD, WATTS	1.19
SQUARE CENTRIMETRE PER WATT	348.94
RATIO OF LOSSES	8.57
RATIO OF WIGHT	3.04

TANK

TYPE OF TANK, PLAIN SHEET-STEEL 0.24 CM. THICK	
SQUARE CENTRIMETRE PER WATT	30
TOTAL WETTED SURFACE, SQ.CM	4099
DEPTH OF OIL, CM	33
LITRS OF OIL	21.76
WEIGHT OF OIL, KG.	19.58

WINDINGS	HIGH-VOLTAGE	LOW-VOLTAGE
TYPE OF WINDING	LAYER-WOUND	LAYER-WOUND
CONDUCTOR :		
NO. OF ROUND COPPER WIRE, SWG	32	15
DIA. OF INSULATED CONDUCTOR, CM.	0.0307	0.19
CROSS-SECTION AREA, SQ.CM	589×10^{-6}	0.0263
CURRENT DENSITY, AMPERES / SQ.CM	28.35	31.68
NO. OF TURNS	17,000 .	341.6
COILS :		
TOTAL NUMBER	2	2
PER. CORE LEG	1	1
TURNS :		
PER COIL	8,500	170.8
PER LAYER, NUMBER AND TURNS	26-320, 1-180	2-60, 1-50.8
COILS :		
CONNECTION	SERIES	SERIES-PERALLEL
DIMENSIONS	1.20 X 9.85	0.63 X 11.59
DUCTS, NUMBER AND SIZE	1-0.80	
INSULATION :		
LAYER, CM.	0.013	0.013
CORE AND COILS, CM.	-	0.30
H.V. AND L.V., CM.	0.30	-
VOLTAGE PER TURN	0.7060	0.7060
MAX. VOLTAGE BETWEEN LAYERS, VOLTS	451.84	84.72
LENGTH OF MEAN TURN, CM.	35.83	25.06
COPPER :		
WEIGHT, KG	3.18	1.99
LOSS, WATTS	0.67	0.52
RESISTANCE AT 75°C, OHMS	2,402	0.75

DESIGN BY : C.R.K. CHECKED BY : K.N.B. APPROVED BY : S.W.S.
DATE 20 JUNE 1975 .