CHAPTER II

LAY-OUT AND CONSTRUCTION

2-1 Introduction

After studying the general theories and facts relating to the Tesla Transformer, this chapter presents the design, lay-out, and construction of the Tesla Transformer. It shows step by step of laying-out and construction. Some parts of them give details and illustration by pictures. The step of design and construction starts first from the High Voltage or Secondary coil and then works back to the Low Voltage or Primary coil, the base for supporting the coils and others concerning to the Tesla Transformer.

2-2 Lay-out and Construction of High Voltage coil

2-2a Selection of wire size and total length required. With the porcelain former provided by the High Voltage Laboratory, Department of Electrical Engineering, the dimensions of the porcelain former are shown in Fig.2-1.

There are spaces available for wire of High Voltage coil around and through the whole length of the porcelain former in a helical form and counter-clockwise direction.

By measuring and numbering, the numbers of spaces,

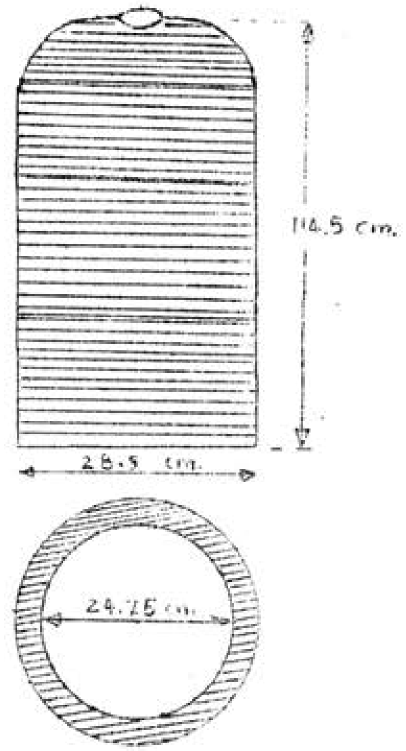


Fig.2-1 Dimensions of porcelain former for High Voltage coil.

N_2 available are 670 turns and each space is 0.075 cm. width.

Therefore, the total length of wire for High Voltage coil is $\pi D \times N_2$

$$= \pi \times 28.5 \times 670$$

$$= 600 \text{ metres}$$

Under operating condition, the temperature of the coil is increased. Therefore, in selection the size of copper wire the margin of the spaces should be left to include this effect and also the spacing for casting the copper wire with insulating material. Then the size of round copper wire for High Voltage coil is No.24 Standard Wire Gauge (S.W.G) with a diameter of 0.0559 cm. and purity 99.8 percent.

2-2b Properties of copper wire No.24 S.W.G., 0.0559 cm. diameter and purity 99.8% available in the market. From Appendix C, the round copper wire No.24 S.W.G has a diameter of 0.0559 cm. and resistance 6.316 ohms/100 m.

Round copper wire No.24 S.W.G available in the market has the following properties:-

From section 1-4, $R_{20^oC} = \rho \frac{l}{A}$

where $\rho = 1.724 \times 10^{-6}$ ohm - cm.

$l =$ 10,000 cm.

$A = \frac{3.141}{4} (0.0559)^2 cm^2$.

$$\therefore R_{20^oC} = \frac{1.724 \times 10^{-6} \times 10,000}{\frac{3.141}{4} \times (0.0559)^2}$$

$$= 7.026 \text{ ohms/100 m.}$$

The room temperature during the measurement is 30.8^oC. Then, from section 1-4b,

$$R_{30.8^oC} = R_{20^oC} \left[1 + \alpha_{20}(T - 20^o) \right]$$

$$= 7.026 \left[1 + 0.00393 \times 10.8 \right]$$

$$= 7.302 \text{ ohms/100 m.}$$

By measuring the resistance of copper wire No.24 S.W.G. at room temperature, 30.8^oC by Ohm-meter is

$$R_{30.8^oC} = 7.2 \text{ ohms/100 m.}$$

Comparing these results of resistance between the standard resistance of wire and resistance measured at the same temperature, their resistances are not much difference; so it is choosen as a wire for High Voltage coil. For further properties of the wire, the skin depth is to be checked.

From section 1-4d, the skin depth at the operating frequency, 100 Kcs. is

$$S = \frac{6.62}{\sqrt{f}} \text{ cm.}$$

$$= \frac{6.62}{\sqrt{100 \times 10^3}} \text{ cm.}$$

$$= \frac{6.62\sqrt{10}}{10^3} = 0.021 \text{ cm.}$$

The skin depth (0.021 cm.) is not more than the radius of the wire size (0.0279 cm.), then the wire No. 24 S.W.G. is used for High Voltage coil.

2-2c Construction of High Voltage coil. The High Voltage coil is constructed by winding the copper wire No.24 S.W.G., purity 99.8 percent around the porcelain former starting from the top in clock-wise direction. The High Voltage coil will consist of 670 turns. The process of winding is shown in Fig. 2-2.

When the winding of High Voltage coil is finished, the problem of insulation between turns is considered. The insulating materials used in this case is Araldite epoxy resin provided by the High Voltage Laboratory, Department of Electrical Engineering, Chulalongkorn University. Its properties is good having high dielectric strength (about 420 volts per mil). The recommended hardener for mixing with Araldite D is HY 956. The amount of Araldite epoxy resin needed for casting is calculated.

With 1 mm. thickness of epoxy resin to be casted the epoxy resin required = $\pi D \times \ell \times t$

$$= \pi \times 28.5 \times 114.5 \times 0.1 \text{ cm}^3$$

Fig.2-2 Winding of the High Voltage coil.

$$= 1028.29 \quad cm^3$$

For including the epoxy resin required in the space available for wire, assume to be 10 percent of the total required and the effect of its shrinkage, then the total epoxy resins required

$$= 1028.29 + \frac{1028.2 \times 10}{100} \quad cm^3$$

$$= 1131.2 \quad cm^3$$

$= 1300\ cm^3$ (including shrinkage effect)

Since, the specific gravity[4] of the Araldite D is 1.2 gm/cm^3. Then, the epoxy resin required by weight = 1300 x 1.2 = 1560 gm.

The mixing and casting process of the resin is made following the instruction in section 1-8c with the weight required is 1560 gm. The flash-**lamps** are used to heat the casting process and accelerate the curing time. The process shown on Fig.2-3.

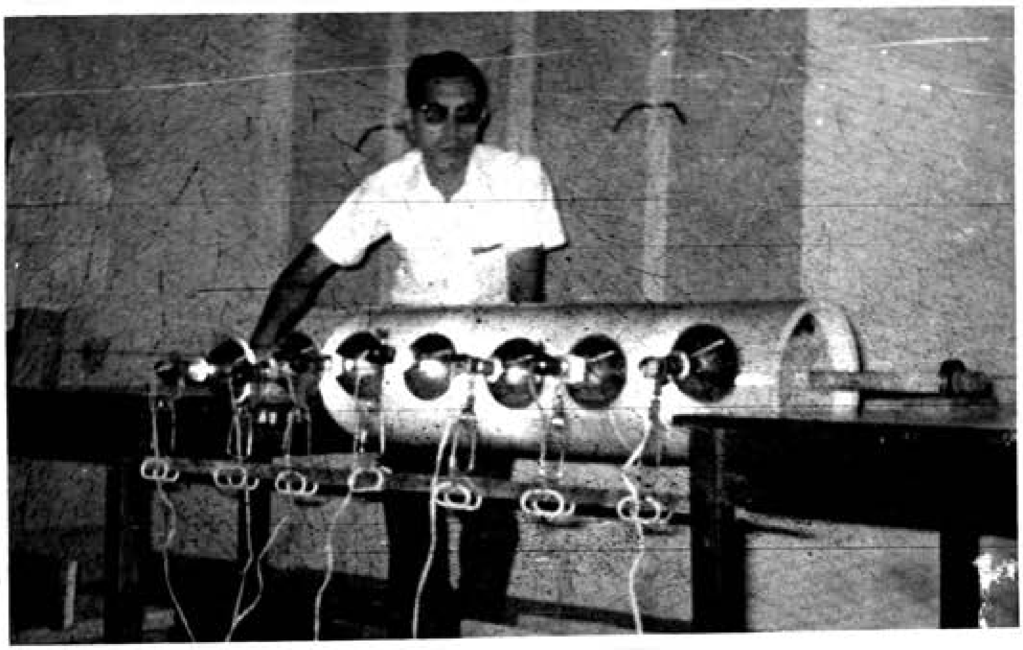


Fig.2-3 Casting and Curing process of Epoxy resin for High Voltage coil.

2-2d <u>Measurement of Inductance and Oscillating frequency</u>.

From Appendix C(1), the inductance of High Voltage coil are approximately calculated by $L = \frac{r^2N^2}{9r+10\ell} \times 10^{-6}$ henry

where $r = 14.25 - \frac{0.0559}{2} = 14.222$ cm.(5.59 inches)

$\ell = 114.5$ cm. (45.12 inches)

$N = 670$ turns

$$\therefore L_2 = \frac{(5.59)^2\ (670)^2}{9 \times 5.59 + 10 \times 45.12} \times 10^{-6} = 0.0272 \text{ henry}$$

$$= 27.2 \text{ milli-henry (mh.)}$$

By measurement, $L_2 = 30$ mh.

Then, the average inductance, $L_2 = \frac{30+27.2}{2} = \underline{28.6 \text{ mh.}}$

The Oscillating frequency on High Voltage coil is measured by Double-beam Oscilloscope and arranged the circuit as shown in Fig. 2-4.

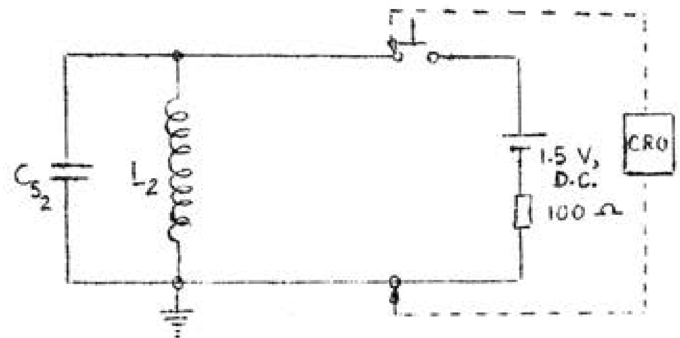


Fig.2-4 Equivalent circuit for measuring the Oscillating frequency on H.V. coil with 1.5 V.D.C. source.

In Fig.2-4, the High Voltage coil is connected through the push-button switch, 1.5 V,D.C. flash-light battery and 100 ohms resistance. The Double Beam Oscilloscope is connected across the switch and the ground. The switch is switched on to charge the coil, then switched off. The Oscillating frequency is observed on the CRO after switching off. The switching off characteristic is recorded as shown in Fig.2-5.

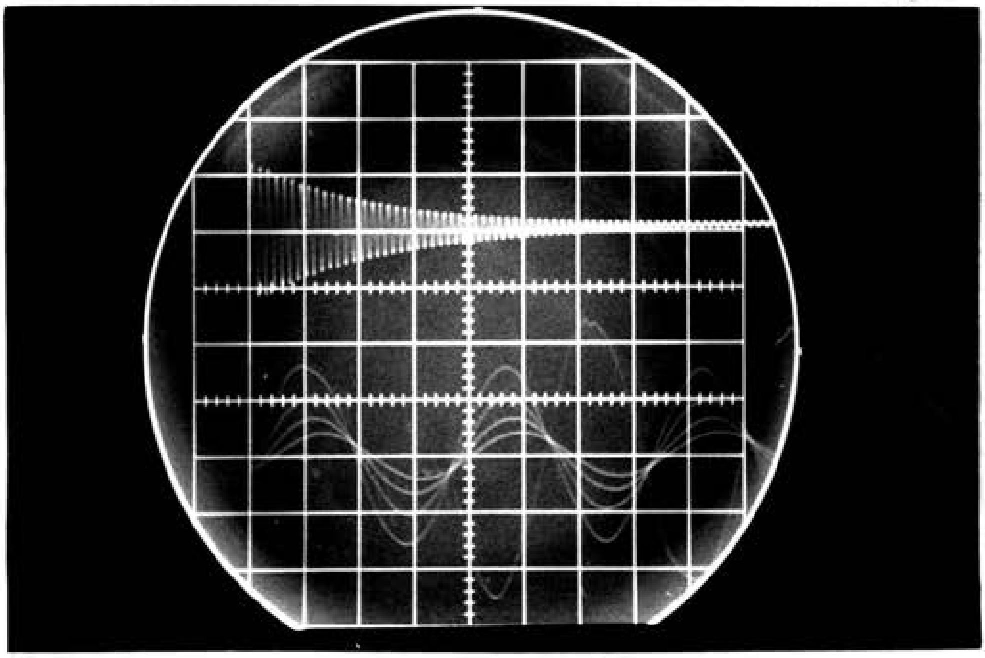


Fig.2-5 Oscillating frequency on H.V. coil at 1.5 V. DC.

The upper beam comes from Channel 1 with A-time base of the CRO setting at 50 μsec per division; the lower beam from Channel 1 with B-time base and setting at 2 μsec per division. There are 3.9 divisions in one cycle for the lower beam, the period, T is 3.9 x 2 = 7.8 μsec

$$\therefore \text{ oscillating frequency,} \quad f = \frac{1}{T} = \frac{1}{7.8\times10^{-6}}$$

$$= 128 \times 10^{3} \text{ cps}$$

$$= \underline{128 \text{ Kcs}}.$$

From section 1-3b, the stray-capacitance, Cs_2 of the High Voltage coil is $Cs_2 = \dfrac{1}{4\pi^2 f^2 L_2}$

$$C_{S_2} = \frac{1}{4\pi^2(128\times10^3)^2\times28.6\times10^{-3}} \quad F$$

$$= \underline{58.1 \quad pF}$$

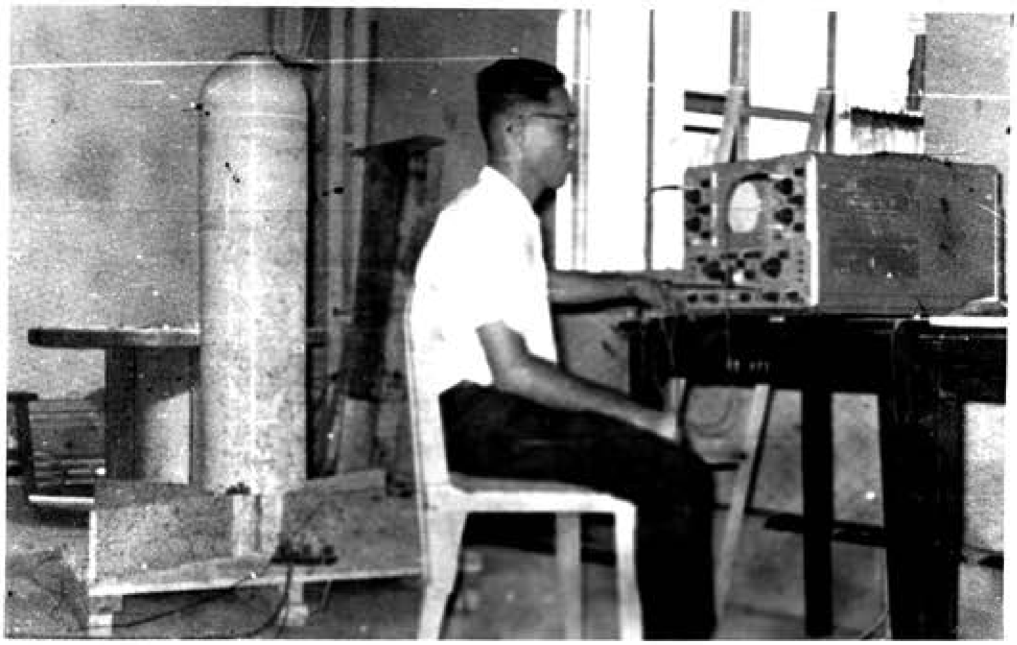


Fig.2-6 Measurement of Oscillating frequency on H.V. coil at 1.5 V. DC.

2-3 Lay-out and Construction of Low Voltage coil.

In design the Low Voltage coil, there are several problems which have to be considered i.e. electric field strength, varying capacitance, radius and positions of coil, number of turns, and voltage build up in the High Voltage coil.

2-3a Radius of the Low Voltage coil. The cylindrical coil shape is to be constructed, then the two coils (High and Low Voltage) are considered to be concentric cylinder condensor with the positions of the Low Voltage coil to be varied for changing the mutual inductance.

For concentric cylinder coil, the maximum electric field strength occurs at the outer surface of the inner (or High Voltage) coil. Then, from section 1-5 the radius of the Low Voltage coil with the maximum voltage difference between two coils is R = 2.718 r

When the radius of High Voltage coil, r is 14.5 cm. (including the thickness of wire and epoxy resin)

Therefore, R = 2.718 x 14.5 = 39.44 cm.

<u>40 cm</u>.

2-3b <u>Number of turns and Capacitance used</u>. The Oscillating frequency in Low Voltage coil will be the same as that obtained from the High Voltage coil and lower when it is actually operated. So, the frequency considered in the design of the Low Voltage coil is 120, 110 and 100 Kcs. respectively.

In actual operation, the capacitance on the Low Voltage side should be varied. The capacitances available by the High Voltage Laboratory, Department of Electrical Engineering,Chulalongkorn University are :

a) 8 oil condensers of 0.125 μF, 175 Kv. and

b) 2 oil condensers of 4000 pF., 350 Kv.

The equivalent circuit for the High Voltage and the Low Voltage coil is arranged as shown in Fig.2-7 with Q is the quenched air gap and R is the current limit-ing resistance.

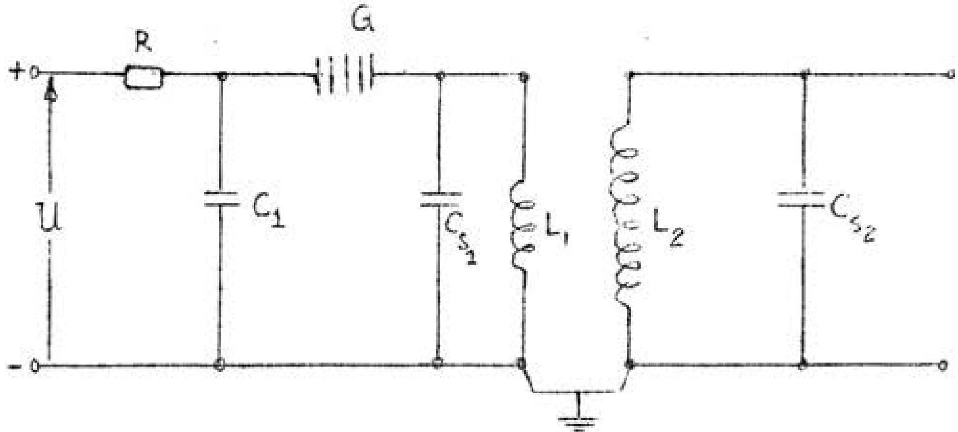


Fig.2-7 Equivalent circuit for H.V. and L.V. coils.

From section 1-3b, the Oscillating frequency is

$$f = \frac{1}{2\pi\sqrt{LC}}$$

or $$L = \frac{1}{4\pi^2 f^2 C}$$

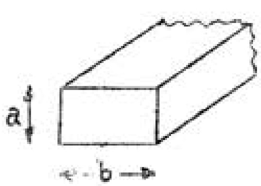
$$\therefore \quad L_1 = \frac{25,330 \times 10^3}{f^2 C_1} \quad \ldots\ldots\ldots\ldots(a)$$

where L in mh.

f in Kcs.

C in pF.

The copper wire used for Low Voltage coil is a rectangular cross-section provided by the High Voltage Laboratory, Department of Electrical Engineering. Its dimensions are as follow:



a = 0.5 cm.

b = 1.0 cm.

From Appendix B (2), the inductance of the Low Voltage coil is

$$L_1 = 4\pi \times 40 \times N_1^2 \left[\log_e \frac{8 \times 40}{0.224(1.5)} - 2\right] \times 10^{-9} \text{ henry}$$

Where $R = 40$ cm.

$$= 502.40\, N_1^2 \left[6.89 - 2\right]$$

$$\therefore N_1 = \sqrt{\frac{L_1 \times 10^6}{2460}} \ldots\ldots\ldots\ldots\ldots\ldots (b)$$

Where L_1 in mh.

<u>Design Data</u>

C_1 (pF)	f (Kcs)	$L_1 = [\text{equ.}(a)]$ (mh)	$N_1 = [\text{equ.}(b)]$ (turns)	Power consumed by C_1, P_c (Kw)
8,000	100	31.5×10^{-2}	≈ 10	6.29 at 50 kv
(2 of 4000pF	110	26.4×10^{-2}	≈ 9	3.06 at 35 kv
in parallel)	120	21.9×10^{-2}	≈ 9	0.25 at 10 kv
				0.0625 at 5 kv
15,600	100	16.2×10^{-2}	≈ 8	12.15 at 50 kv
(8 of 0.125 μF	110	13.4×10^{-2}	≈ 7	5.72 at 35 kv
in Series)	120	11.3×10^{-2}	≈ 6	0.49 at 10 kv
				0.122 at 5 kv
62,500	100	4.05×10^{-2}	≈ 4	49.1 at 50 kv
(2of 0.125 μF	110	3.34×10^{-2}	≈ 4	24.6 at 35 kv
in Series)	120	2.81×10^{-2}	≈ 4	1.94 at 10 kv
				0.49 at 5 kv

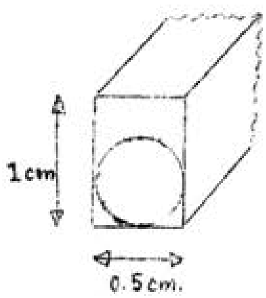
Design Data (cont.)

C_1 (pF)	f (Kcs)	L_1= [equ.(a)] (mh)	N_1=[equ.(b)] (turns)	Power consumed by C_1, P_c (Kw)
125,000	100	20.3×10^{-3}	4	98.1 at 50 kv
(=0.125 μF)	110	16.65×10^{-3}	3	48.3 at 35 kv
	120	13.91×10^{-3}	3	3.93 at 10 kv
				0.981 at 5 kv

Suppose the capacitances, C_1 on Low Voltage side is arranged to fix at different values shown in the data and the Oscillating frequency is at distinct values of 100, 110 and 120 Kcs. respectively. The inductance and the number of turns of the Low Voltage coil L_1 and N_1 can be calculated from equations (a) and (b) respectively. Power consumed by the capacitors on the Low Voltage side at the indicated values of the applied voltage is calculated from $P_c = \frac{U^2}{X_c} = wC_1U^2 \times 10^{-3}$ Kw.

For the purpose of varying number of turns when needed, the number of turns on Low Voltage coil is 10 turns.

2-3c Spacing distance between turns of L.V. coil. The spacing distance between turns of Low Voltage will be arranged so that the maximum electric field strength is less than or equal to 21 Kv/cm. For a rough idea and basis for the design, the formula of maximum electric field strength of round copper wire in section 1-5 is used. Assumed the rectangular wire for Low Voltage is round wire with the radius of about 0.25 cm. If the voltage difference between two wires is 5 Kv and the distance apart is 1 cm., then



$$E_{max.} = \frac{U}{r \log_e \frac{d}{r}}$$

$$= \frac{5}{0.25 \log_e \frac{1}{0.25}} = \frac{1}{0.05 \log_e 4}$$

$$= \frac{1}{0.05 \times 1.38}$$

$$= 14.5 \quad Kv/cm.$$

Therefore, the maximum electric field strength is less than 21 Kv/cm the assumed conditions above is all right. Then the spacing distance between turns of Low Voltage coil is 1 cm. apart.

2-3d Construction of L.V. coil. The Low Voltage coil is designed to be wound on the wooden-frame. By the following dimensions of the Low Voltage coil:

Radius of the coil, R = 40 cm.

Number of turn, N_1 = 10 turns

Spacing distance between turns = 1 cm.

rectangular wire for L.V. coil, a = 0.5 cm.

b = 1.0 cm.

the design of the wooden-frame is shown in Fig.2-8 with a total height of 22 cm. Fig.2-9 shows the winding procedure for Low Voltage coil.

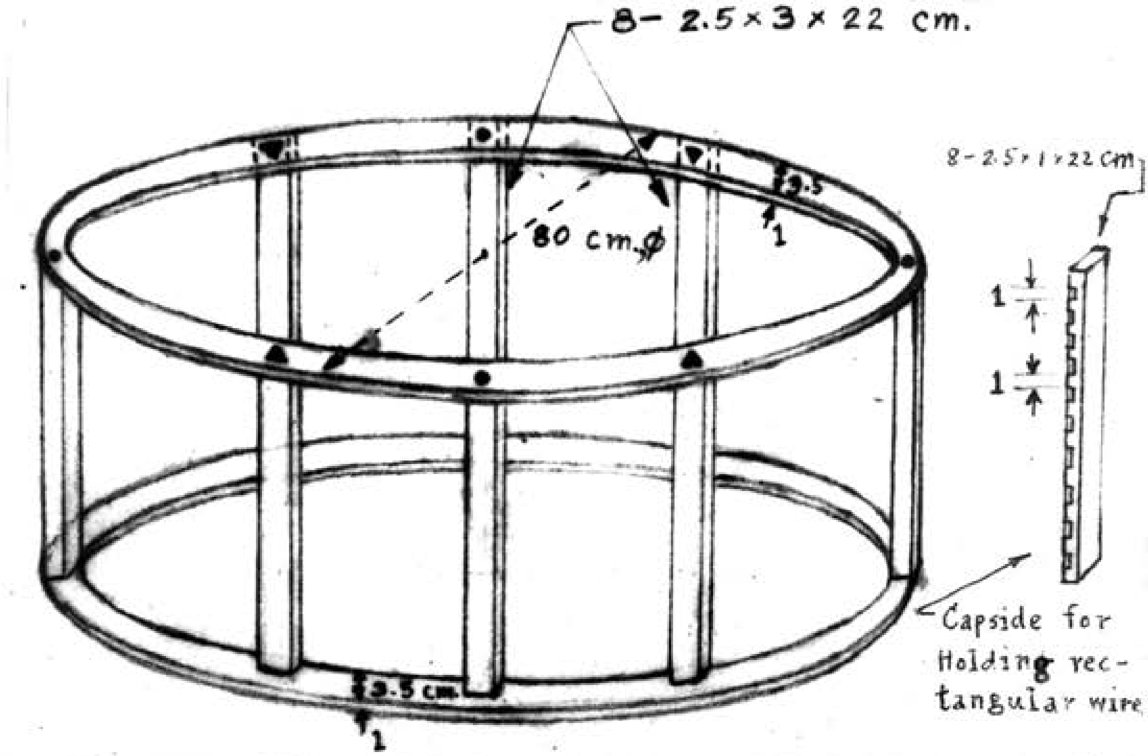
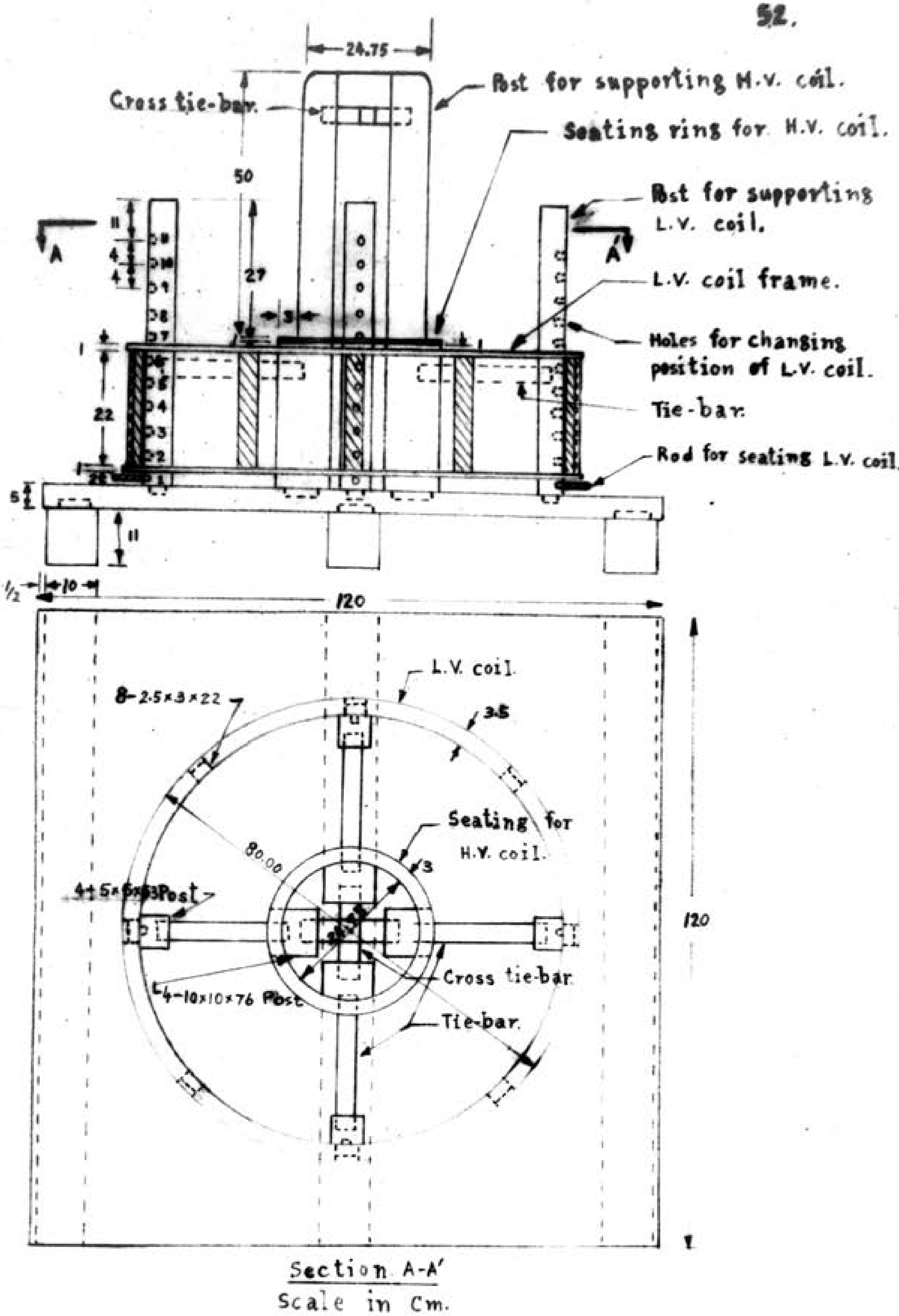


Fig.2-8 Wooden-frame for winding of the Low Voltage coil.

Fig.2-9 Winding of the Low Voltage coil.



Section A-A'
Scale in Cm.

Fig. 2-10 Design and dimensions of Wooden-base

2-4 Lay-out and Construction of the Basement, Design and Construction of the Basement

The Base for supporting the two coils of the Tesla Transformer must be made of non-ferromagnetic materials ($\mu_r > 1$). Wood in this case is choosen as a material for the Base. The design and dimensions is shown in Fig.2-10.

The construction of the Basement is shown in Fig. 2-11. The varnish is used for insulating material and have two coats on the wooden-base.

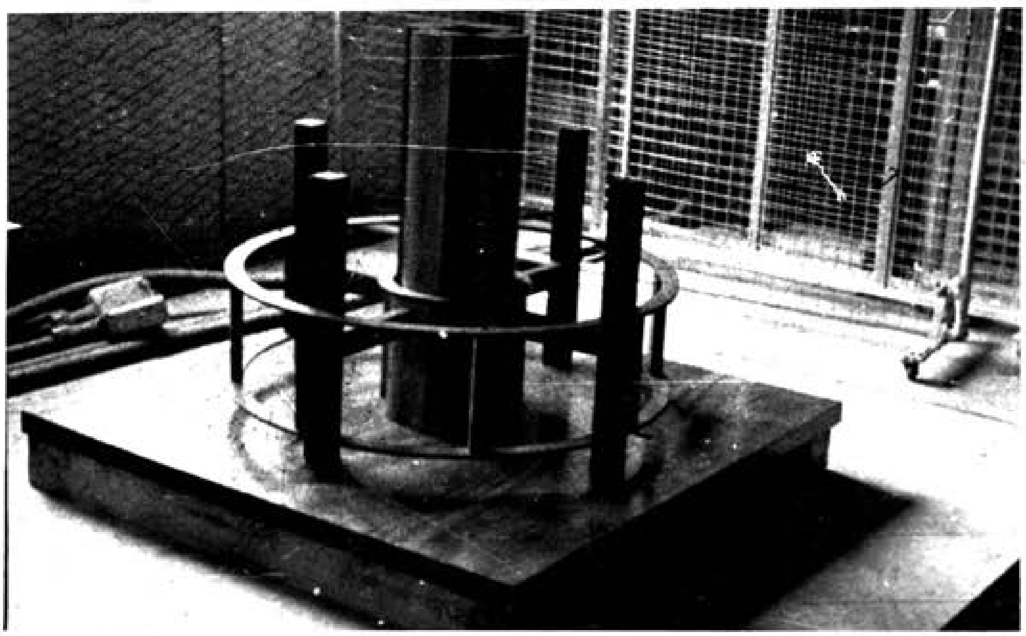


Fig.2-11 Construction of the Basement for L.V. and H.V. coil.

2-5 Lay-out and Construction of other components of the Tesla Transformer

The other components of the Tesla Transformer are the output and input terminals of the Low Voltage coil, the grounding system, and the copper sphere on the top of the High Voltage coil.

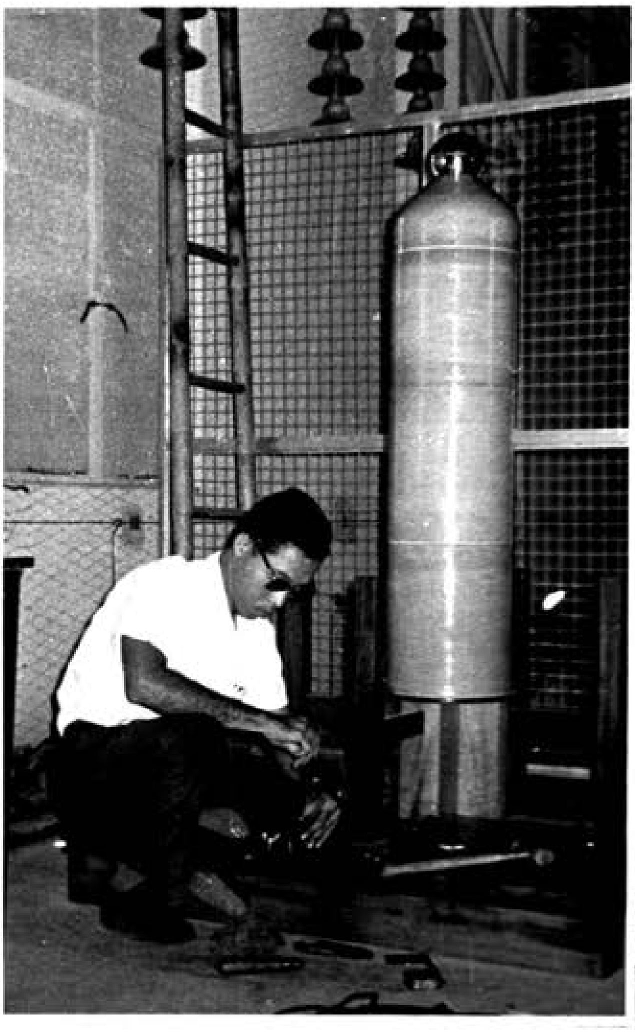


Fig.2-12 Connection procedure of the grounding system.

Two screws are used as the terminals for the Low Voltage coil by drilling and screwing through each terminal of the rectangular wire of the Low Voltage coil. The lower terminal connected to the grounding terminal by the grounding lead and the upper one left for incoming source.

The grounding system connected by soldering firmly. The copper sheet is used for the ground plate between the two coils. The lower terminal of the H.V. coil is connected to the ground plate and the other one to copper sphere placing on top of the porcelain former. The copper sphere has a diameter of 13 cm. The equivalent circuit of the grounding system is shown in Fig.2-13.

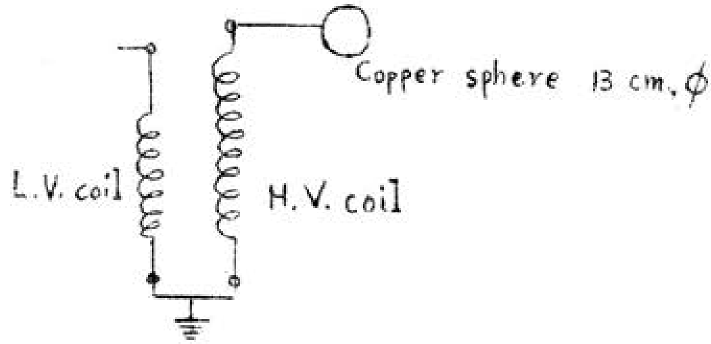


Fig.2-13 Equivalent circuit of H.V. and L.V. coil for grounding system.

2-6 Current limiting resistance for 250 Kva. base, transformer

Reference to Fig.2-7, if the current limit-ing resistance, R is used, the size of this resistance would be calculated.

If the voltage across the capacitance of the L.V. coil is 50 Kv. and the current is limited at 1 ampere. Then, the current limit-ing resistance, R based on 250 Kva. transformer is

$$R = \frac{50 \times 10^3}{1} \text{ ohm}$$

$$= 50 \text{ Kilo-ohms.}$$

$$\text{Power dissipated} = \frac{U^2}{R} = \frac{(50 \times 10^3)^2}{50 \times 10^3} = 50 \text{ Kilo-watts}$$