Chapter 4

Materials and Constructional Details

4.1 Materials

4.1.1 Silicon Steel

The lamination of high - grade silicon or other sheet steel is used to form the magnetic core which are sometimes insulated from each other by varnish, frequently the surface coating of iron oxide is employed to minimize eddy - current losses in the core. The thickness of laminations are also influence the eddy current losses in the core. Two losses, due to the varying flux, occur in the iron core: the eddy current and the hysteresis losses. The silicon content of the iron and the nature of the annealing are very important in determining the hysteresis loss. The silicon content increases as the loss decrease. Up to 4 percent silicon is used in the best grade of annealed sheet. This makes the material very brittle and thus difficult to process.

For voltage transformer design the high permeability (low magnetizing current) is more important than low loss (low core loss current).

0.30 mm. thick of RG - 10 silicon steel was used for this lamination. Its properties are as follows;

Silicon content	4%
Lamination factor	96%
Density	7.65 grams/cu. cm.
Specific Resistance	47.5 (Micro - ohm - cm.)

The D.C. Magnetization and D.C. Permeability curves, Core Loss Curve and Exciting RMS. Current Curve of the RG - 10 silicon steel were shown in Fig. 4 - 1 to Fig. 4 - 3 respectively.

4.1.2 Magnetic wire

Magnetic wire is the name applied to single conductor insulated wires manufactured for the purpose of winding coils for electrical circuits. Round Magnet wire is made of soft annealed solid copper wire in sizes from No. 46 to No. 4/0. Square and rectangular - cross - section magnet wires are also available. Insulations which are used for magnet wire include baked films (enamel), cotton, silk, nylon yarn, paper, asbestos, fibrous glass, dacron - glass, or combinations of these materials. The temperature rating of magnet wires depends upon the insulation employed and is based upon the temperature limits.

The magnetics wire used in this transformer was round copper enamel wire (Trade name Poly - Vinyl. Formal Enameled Wire: SUMITOMO) The enamel has excellent resistance to moisture, heat and oil and posses high dielectric strength. The Enamel wire consists of a comparative thin even coating of high - grade organic insulating enamel applied directly to the bare wire.

Round copper enameled wire No. 32 SWG was used for high - voltage winding. Its dimensions are as follows;

The nominal diameter of bare conductor = 0.274 mm.

The nominal diameter of Insulated Conductor = 0.3070 mm.

The bare conductor cross - section area = 0.0589 Sq.mm.

Round copper enameled wire No. 15 SWG, was used for low - voltage winding. Its dimensions are as follows:

The nominal diameter of bare conductor = 1.83 mm.

The nominal diameter of insulated conductor = 1.90 mm.

The bare conductor cross - section area. = 2.63 sq.mm.

4.1.3 Paper Insulation

Paper is such an important part of the insulation in modern transformers that it deserves some special mention. Paper can be classified as a natural product. Many kinds of fibers are found in nature from which good dielectric paper can be made

Kraft paper...............wood fiber.

Manila paper..............manila rope.

Kraft board...............wood fiber

Pressboard................wood and cotton.

Paper has excellent dielectric strength and low dielectric loss when it is dry, but it very readily absorbs moisture. In order to overcome this difficulty it must be dried and treated (Impregnated) in some liquid (oil, varnish, resins) to exclude moisture and maintain its dielectric strength. Such treatment fills the spaces between fibers and increases the dielectric strength.

The Kraft paper was used for insulating this transformer. (Pressphane - trade name) The thickness of the pressphane insulation in use were 0.05, 0.13, 0.25, 0.50 and 0.8 mm. The dielectric strength of the pressphane was shown in Fig. 4 - 4.

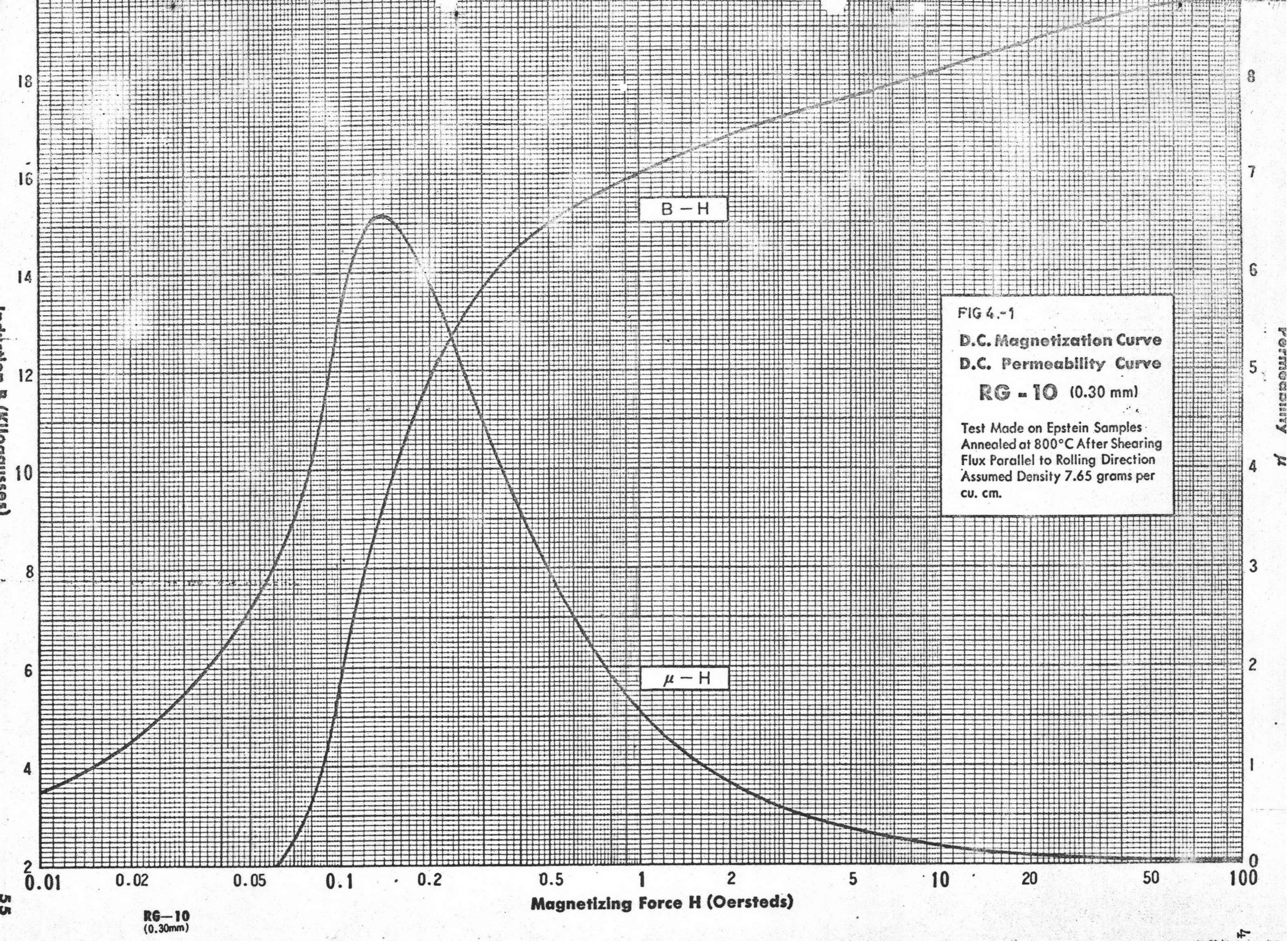


FIG 4.-1

D.C. Magnetization Curve

D.C. Permeability Curve

RG - 10 (0.30 mm)

Test Made on Epstein Samples Annealed at 800°C After Shearing Flux Parallel to Rolling Direction Assumed Density 7.65 grams per cu. cm.

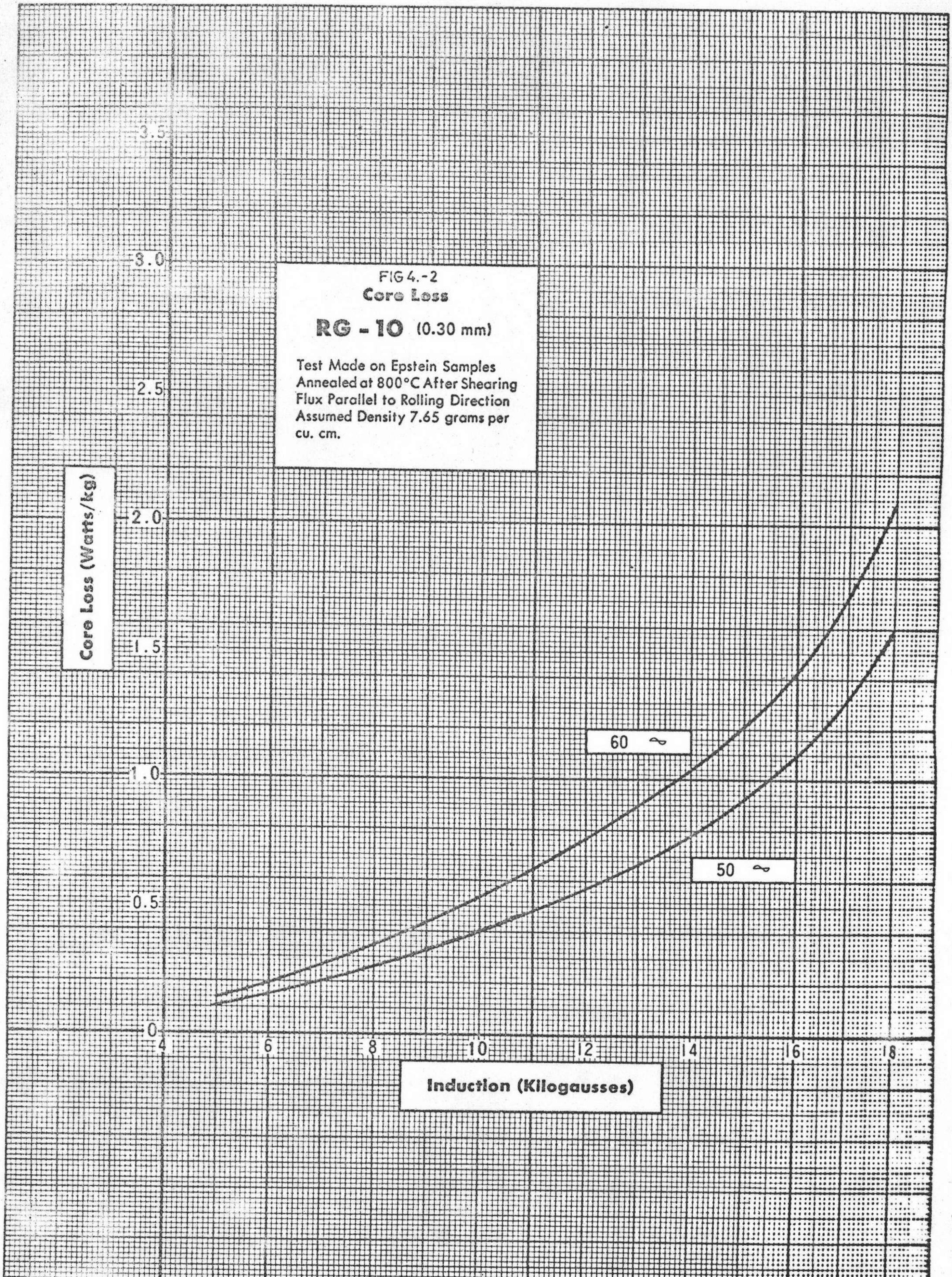


FIG 4.-2
Core Loss
RG - 10 (0.30 mm)
Test Made on Epstein Samples
Annealed at 800°C After Shearing
Flux Parallel to Rolling Direction
Assumed Density 7.65 grams per
cu. cm.
Core Loss (Watts/kg)
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
4
6
8
10
12
14
16
18
60 ∼
50 ∼
Induction (Kilogausses)

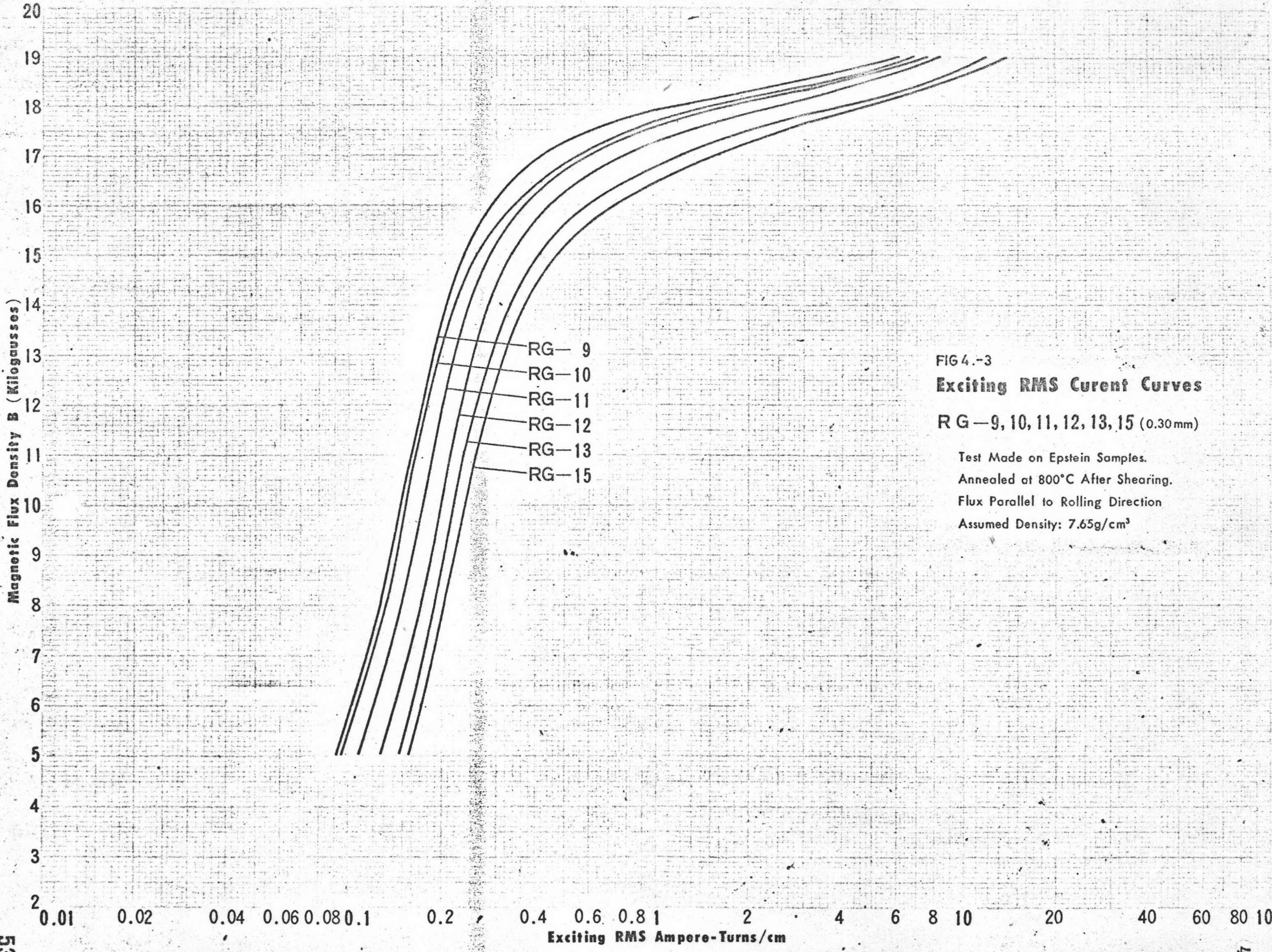


FIG 4.-3
Exciting RMS Curent Curves
R G—9, 10, 11, 12, 13, 15 (0.30 mm)
Test Made on Epstein Samples.
Annealed at 800°C After Shearing.
Flux Parallel to Rolling Direction
Assumed Density: 7.65g/cm³
RG— 9
RG—10
RG—11
RG—12
RG—13
RG—15
Magnetic Flux Density B (Kilogausses)
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
0.01
0.02
0.04
0.06
0.08
0.1
0.2
0.4
0.6
0.8
1
2
4
6
8
10
20
40
60
80
100
Exciting RMS Ampere-Turns/cm

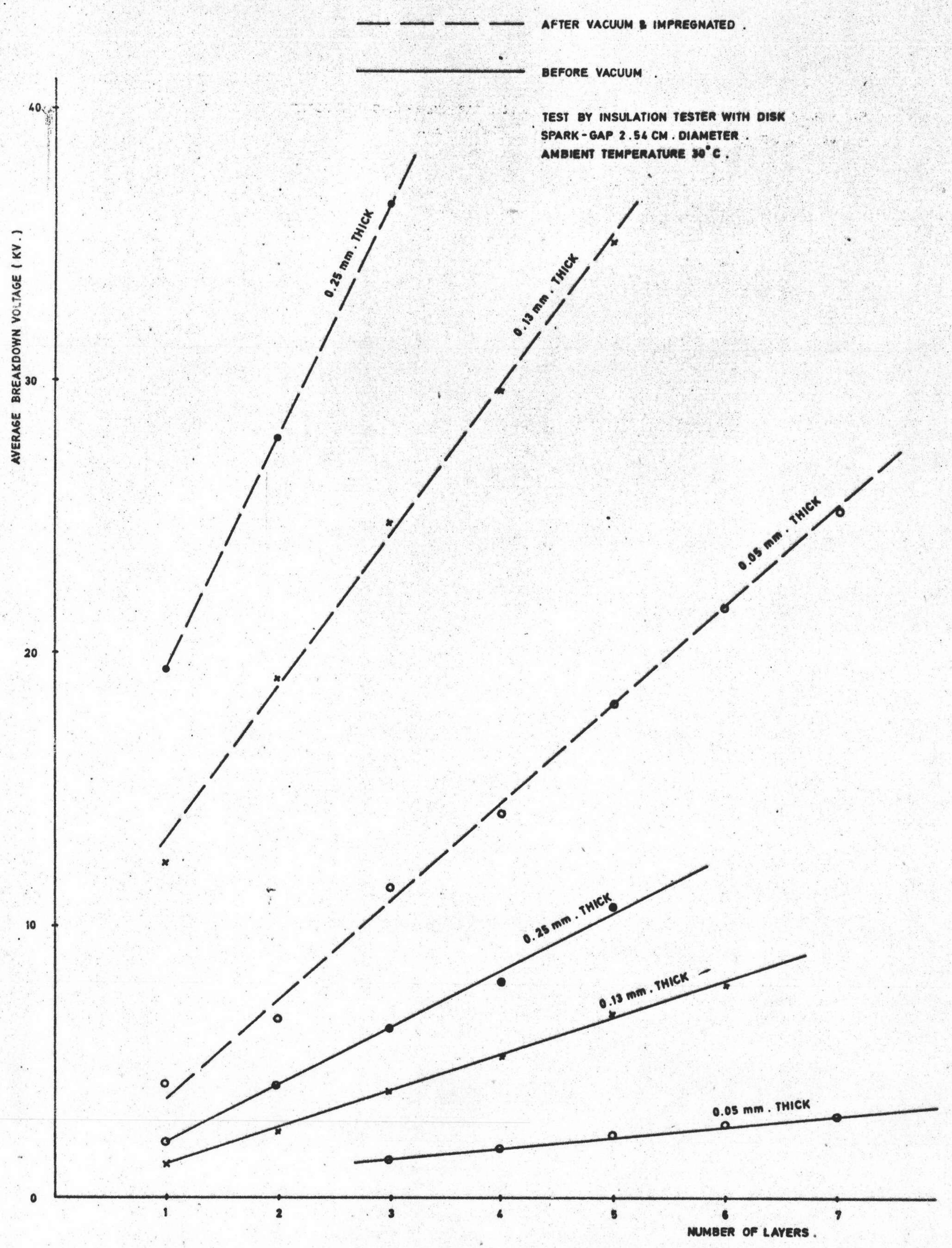


FIG. 4-4 THE DIELECTRIC STRENGTH OF PRESSPHANE INSULATIONS .

4.1.4 Bushings

Bushings are made of porcelain, although in high voltage transformer for indoor use, terminals built up of paper and bakelite varnish are occationally employed. The porcelain should be of the best electrical quality with a highly glazed surface. Generally speaking, the surface of the insulator should conform approximately to the shape of the dielectric field. In the case of transformers for indoor installation the porcelain contour should be as simple as possible. When they are for outdoor service, however, it is necessary to provide watersheds. Poreelain insulators for higher voltages are oil filled in order to take advantage of the higher permitivity and higher dielectric strength of oil, as compared with air.

When tappings are provided and the leads are brought to the outside of the tank, the bushing insulators are similar to those for the main phase leads, the only difference being that a number of tapping leads suitably insulated from one another may be brought through one insulator, as the voltages between tapping leads are relatively low.

Bushing insulators for very high voltages are sometimes of the capacitor type. These insulators consist of a number of alternate layers of paper, together with bakelite varnish and metal foil. The various dimensions are so propertioned that the capitance between adjacent layers of foil is stressed. The insulator is wound on to a brass tube which serves a tripple purpose, being the mandrel for winding, the inner plate of the first capacitor and the conductor. Insulators of this type are suitable for indoor service, but they may be rendered weather proof by providing an outer shell of porcelain having the necessary watersheds.

The high voltage bushing, outdoor type, was used for this voltage transformer as shown in Fig. 4 - 5 and the low - voltage bushing, indoor type, was used as shown in Fig. 4 - 6.

4.1.5 Transformer Oil

A generally more satisfactory method of cooling is to immerse the transformer working parts in oil, which serves the twofold purpose of facilitating the removal of heat from the core and winding, and at the same time has valuable insulating properties. The oil should have high dielectric strength, low viscosity, low freezing point, and high flash point and should be free from corrosive acids, alkalies, and sulphur. The oil should not oxidize or sludge. Unfortunately, the presence of very small amounts of moisture or suspended particles seriously affects the dielectric strength of the oil so that in large transformers special means are provided to prevent moisture from entering it.

The typical transformer oil characteristics was shown in table below.

1. Color.............nearly water white (by Union Colorimeter) 2 max.
2. Reaction............................ Neutral.
3. Neutralization number (milligrams of potassium hydroxide per gram sample)..................... 0.03 max.

4. Precipitation number................ Zero

5. Free sulfur or Corrosive Compounds.. None

6. Steam emulsion number (seconds)..... 25.0 max.

7. Flash point......................... (275°F) 135°c min.

8. Fire point.......................... (305°F) 152°c min.

9. Pour Paint.......................... -(50°F) 45.6°c

10. Viscosity at 38.8°c (100°F) SU...... 60.0 sec.max.

11. Viscosity at 0°c (32°F) SU.......... 280 sec.max.

12. Specific gravity at 15.5°c (60°F)... 0.898

13. Specific heat....................... 0.488 approx.

14. Coefficient of expansion at 0°c (32°F) 0.000725

15. Coefficient of expansion at 100°c (212°F) 0.000755

16. Interfacial tension (dynes/sq.cm.).. 40.0 min.

17. Dielectric constant................. 2.2

18. Dielectric strength (min. standard cup)

    at point of shipment................ 26,000 volts

    (min. standard cup) at point of delivery 22,000 volts.

19. Weight per gallon................... 7.5 lbs.

The Shell DIALA OIL D was used and its strength of the vacuum and non - vacuum were shown in Fig. 4 - 7, test by insulation tester. The Insulation tester spark gap has disk terminal 2.54 cm. in diameter.

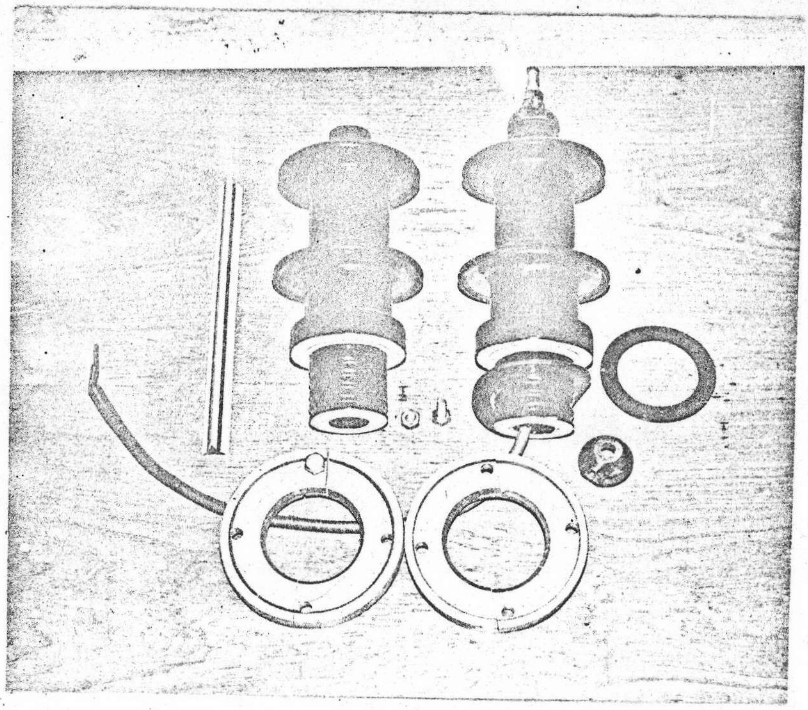


FIG 4.-5 HIGH-VOLTAGE BUSHING AND ACCESSORY.

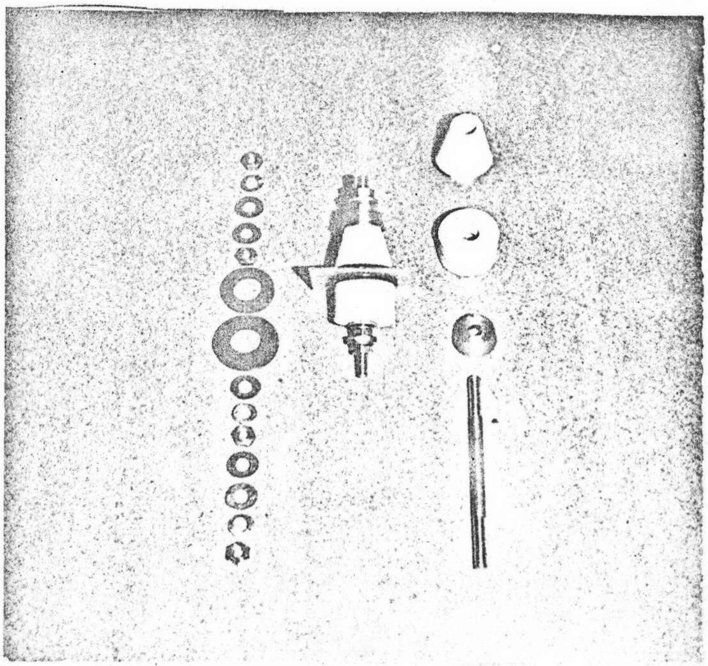


FIG 4.-6 LOW-VOLTAGE BUSHING AND ACCESSORY.

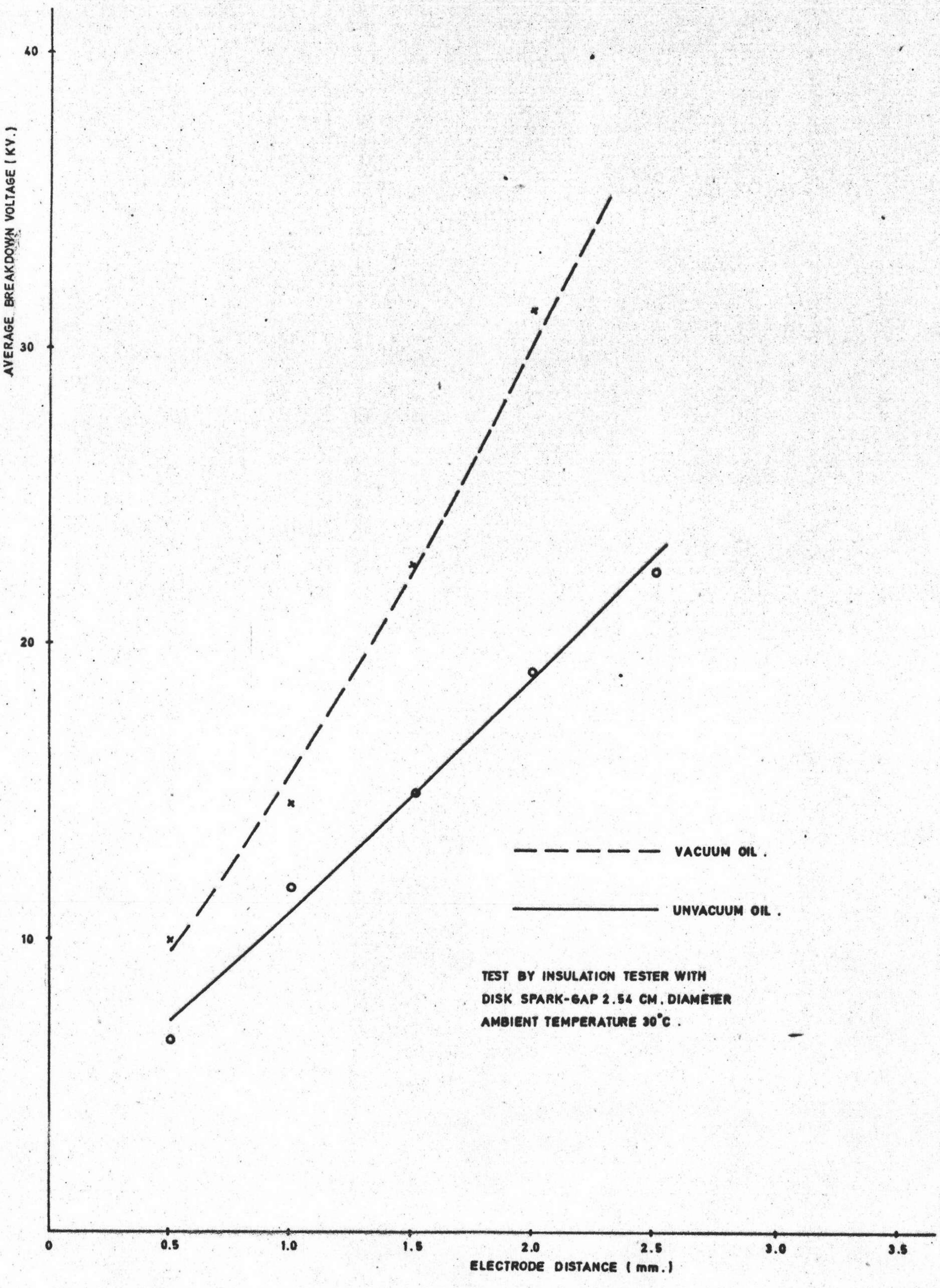


FIG.4 -7 TRANSFORMER OIL DIELECTRIC STRENGTH .

4.2 Constructional Details

4.2.1 Core and Laminations

The core is core type and one - step cruciform - shaped, the cross - section of the core was shown in Fig. 4 - 8.

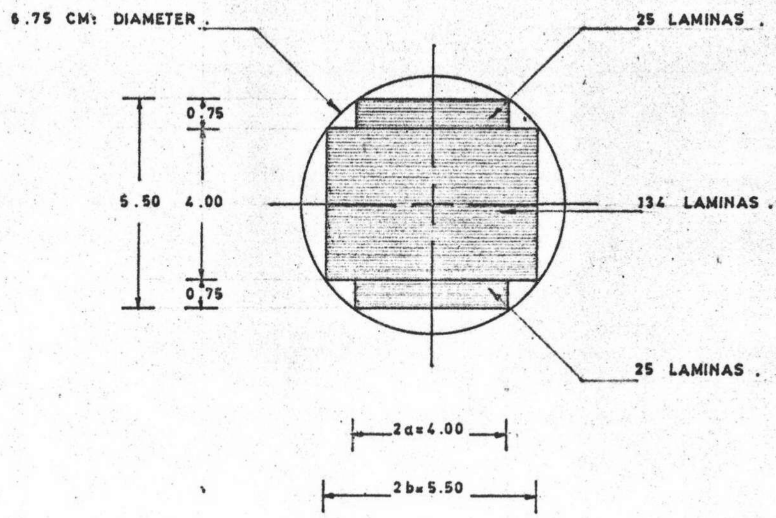


FIG.4-8. CORE LEG CROSS-SECTION.

The RG - 10 steel strip with 0.30 mm. thickness was used for this core.

From Fig. 4 - 8

The number of laminas of the middle laminations (4.00 cm. thick)

$$= \frac{4}{0.03} \quad = \quad 133.33 \quad = \quad 134 \quad \text{laminas.}$$

The number of laminas of the outer laminations (0.75 cm. thick)

$$\text{each} \quad = \quad \frac{0.75}{0.03} \quad = \quad 25 \quad \text{laminas.}$$

The dimensions and shapes of the lamination for the core's yokes and legs were shown in Fig. 4 - 9.

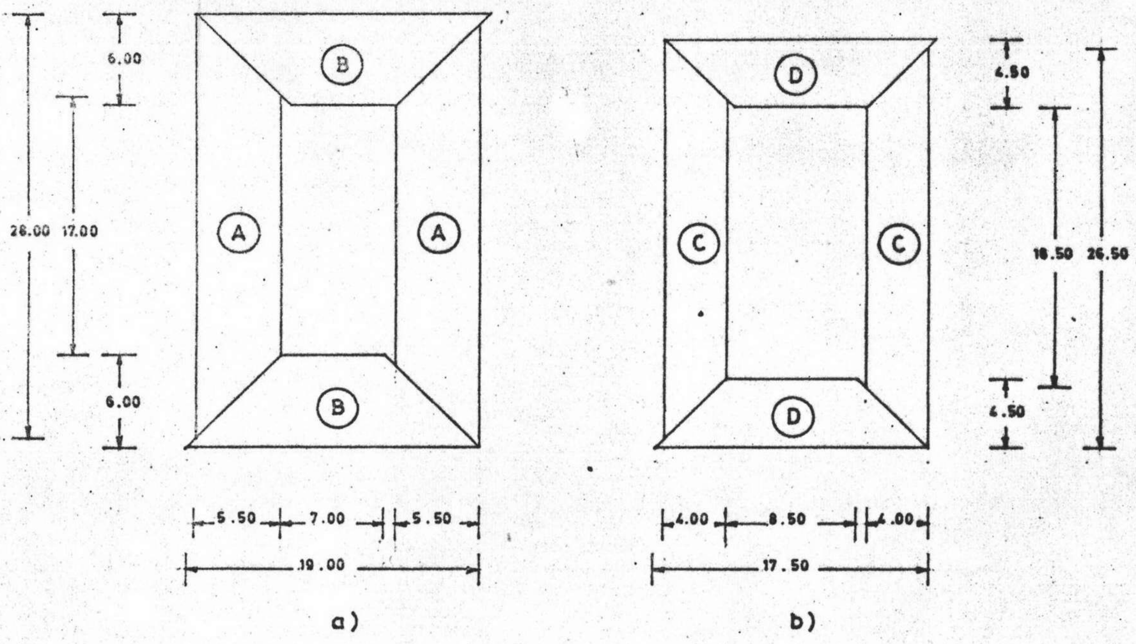


FIG. 4-9. THE DIMENSIONS OF THE LAMINATIONS FOR THE CORE.

a) THE MIDDLE LAMINATIONS AND

b) THE OUTER LAMINATIONS.

From Fig. 4 - 9 the number of the laminations are :

For core legs:

Dimension (A) = 268 laminas (each leg 134 laminas)

Dimension (C) = 100 laminas (each leg 50 laminas)

For core yokes:

Dimension (B) = 268 laminas (each yoke 134 laminas)

Dimension (D) = 100 laminas (each yoke 50 laminas)

The single straight strips of lamination were assembled with the joints cut at 45 degree angles and overlapped in alternate layers as shown in Fig. 4 - 10.

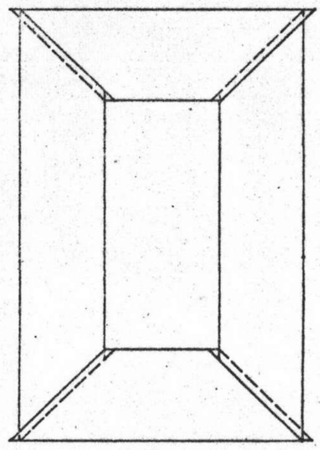


FIG. 4 – 10. CORE OF LAMINATIONS SHOWING MODIFIED LAP JOINTS .

WITH CORNER CUT DIAGONALLY .

The yokes of the assembled core was fastened by the L - Shape iron clamps as shown in Fig. 4 - 11. After assembling the core had to be varnished.

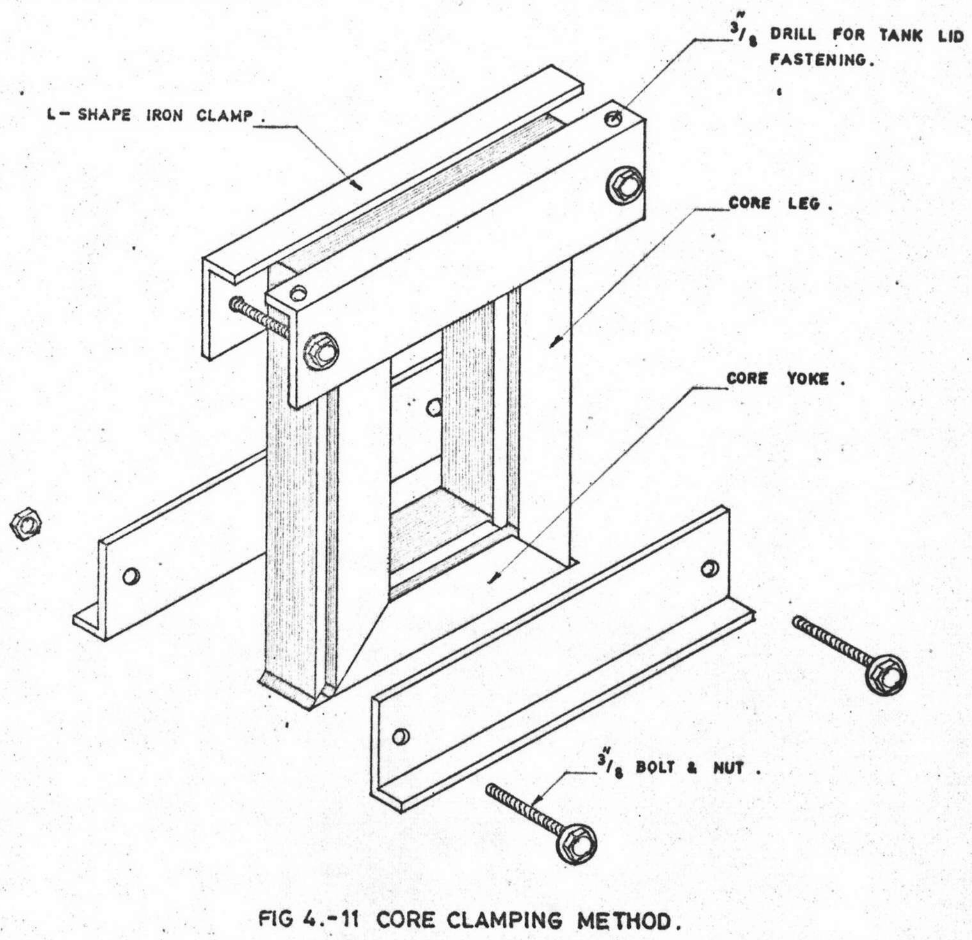


FIG 4.-11 CORE CLAMPING METHOD.

4.2.2 Coils Construction

Low and high - voltage coils were wound together in one coil (for small coil only). The coil winding machine and the wooden bobbin were shown in Fig. 4 - 12 the diameter of the wooden bobbin was 6.75 cm. In real practice, a little difference diameters in bobbin had to be provided for the adventage of easier removed of the coil after finishing winding (about 2 mm. differed in diameter for this wooden bobbin).

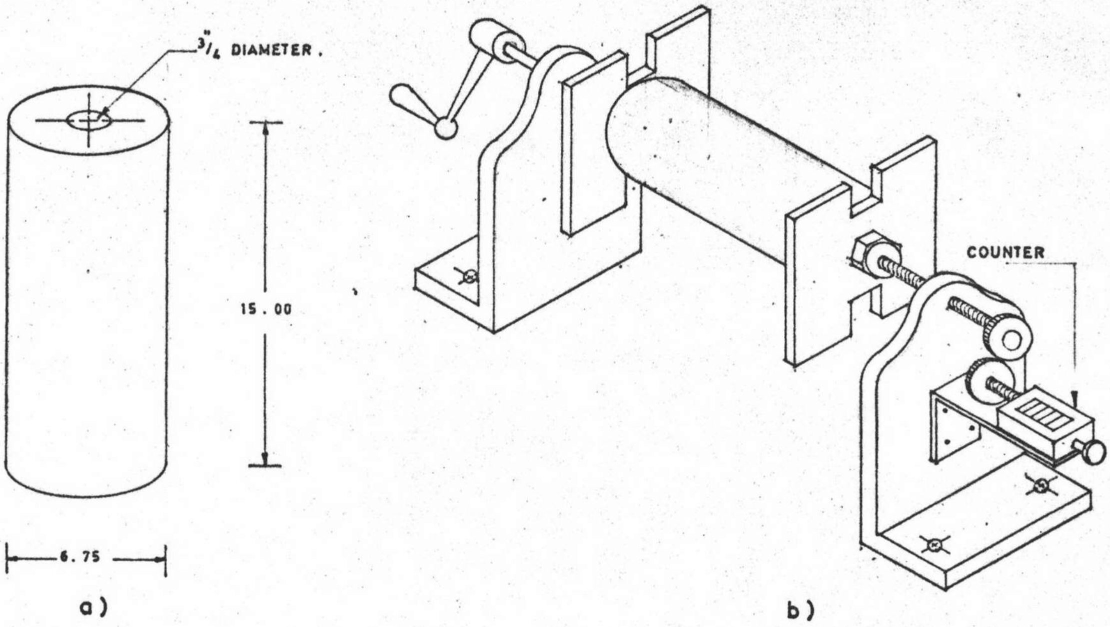


FIG.4-12. a) WOODEN BOBBIN AND b) COIL WINDING MACHINE.

4.2.2.1 Low - voltage coils forming

To form the low - voltage coils, the wooden bobbin was attached to the coil winding machine. At first the 0.50 mm. thick pressphane insulation had to be wound around the wooden bobbin for 6 layers as shown in Fig. 4 - 13 The method of winding was shown in Fig. 4 - 14. It also shown how to wind the coil with no slipping appeared at the beginning and ending of the operation.

4.2.2.2 High - voltage coils forming

After the low - voltage coil winding was completed. The pressphane insulation was cover around it for one turn and then the strips of pressphane insulation of 0.50 cm. thickness were placed to form vertical oil duct as shown in Fig. 4 - 15 and Fig. 3 - 2. Pressphane insulation was covered again for 6 turns (0.30 cm. thick). The high - voltage winding was started.

At the beginning and the ending of the high - voltage winding the wire was soldered to the flexible cord to prevent the wire - breaking when connected, because the high - voltage wire was so thin (No. 32 SWG). There were 27 layer in high - voltage coil and each layer was insulated by pressphane insulation with thickness 0.13 mm.

The method of winding the high - voltage coils and the method to prevent the wire at beginning and the ending from slipping was shown clearly in Fig. 4 - 16. When the last layer of the high - voltage coil was finished, it would be wound by the white cloth from the bottom to the last bending point, pressphane insulation was covered around this coil again, let the flexible cord come out through the pressphane at the last bending point.

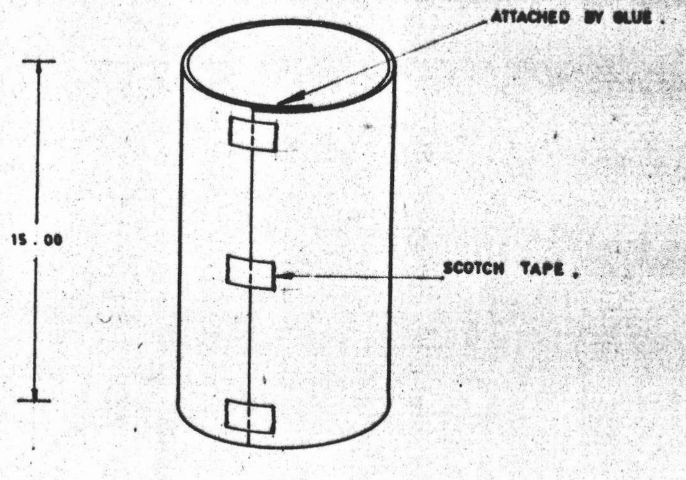


FIG. 4-13. THE INSULATION BETWEEN CORE AND LOW-VOLTAGE COIL .

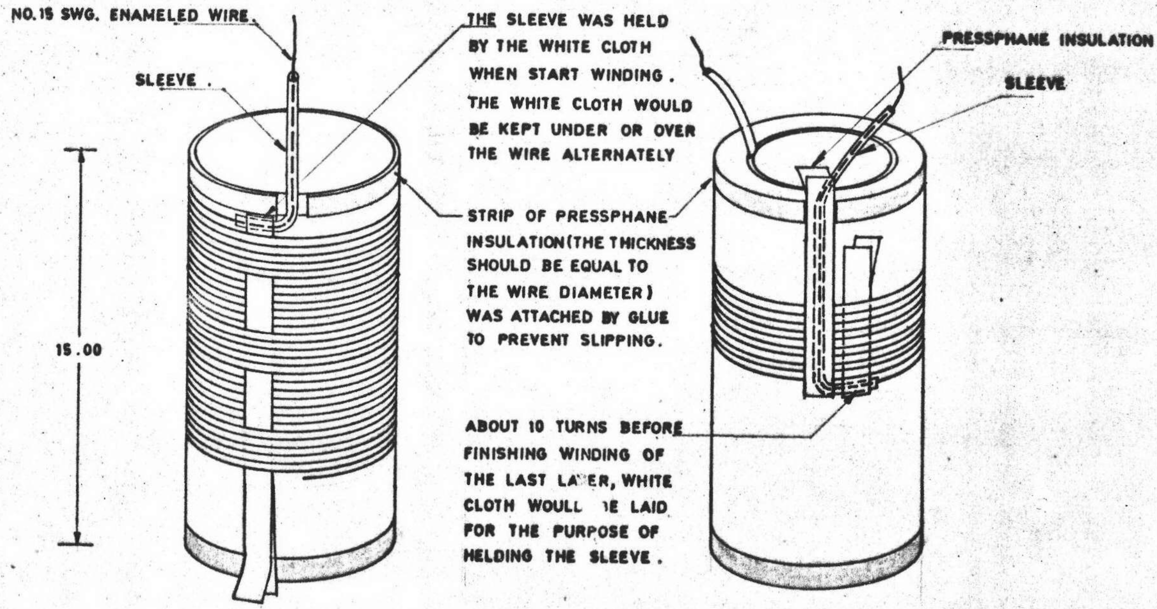


FIG. 4-14. THE LOW-VOLTAGE COIL WINDING METHOD .

a) AT THE BEGINNING AND

b) AT THE ENDING OF THE WINDING .

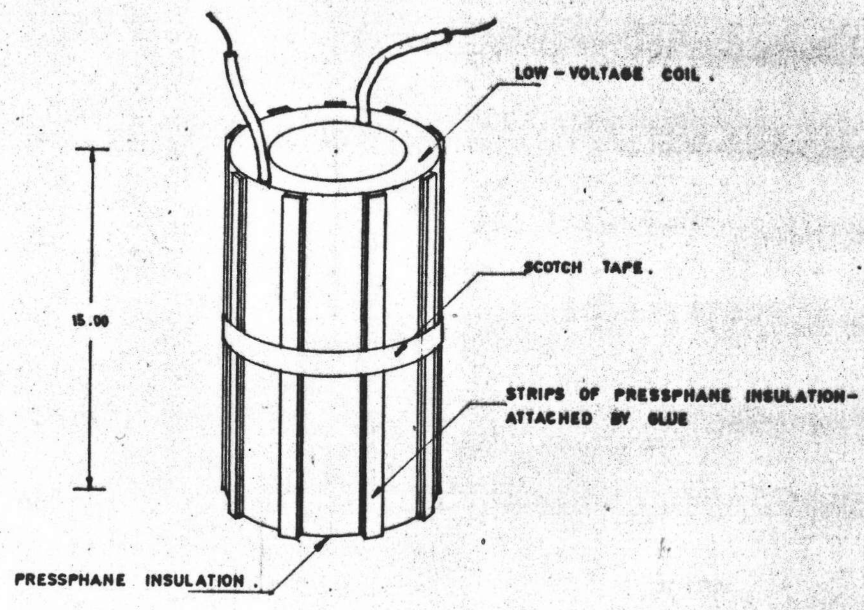


FIG.4-15 OIL DUCTS BETWEEN HIGH-VOLTAGE AND LOW-VOLTAGE COIL .

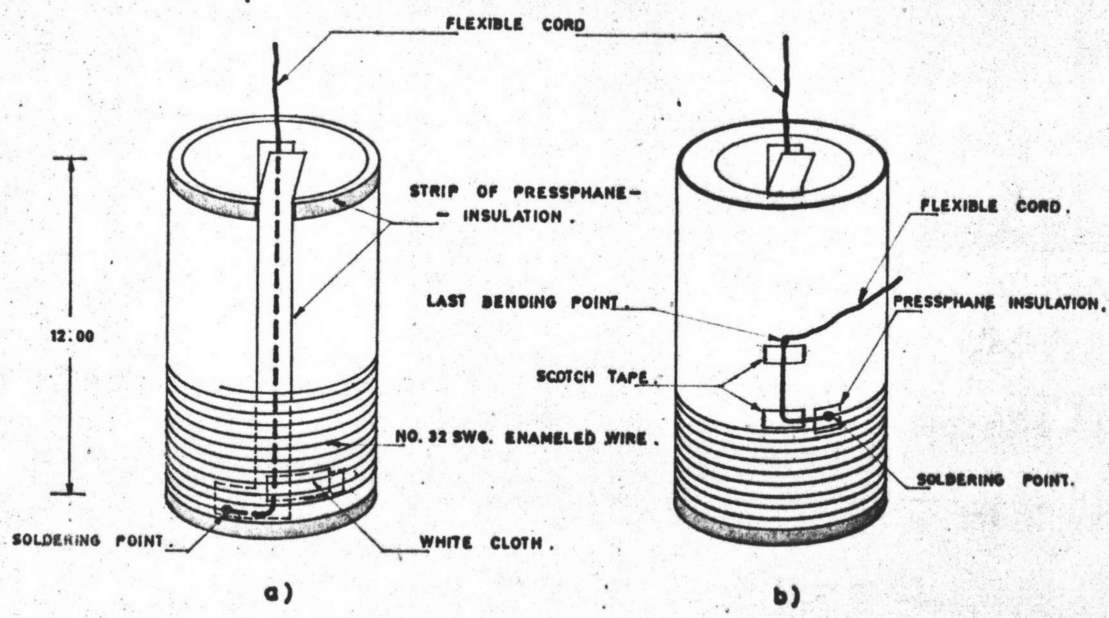


FIG.4-16. THE HIGH-VOLTAGE COIL WINDING METHOD .

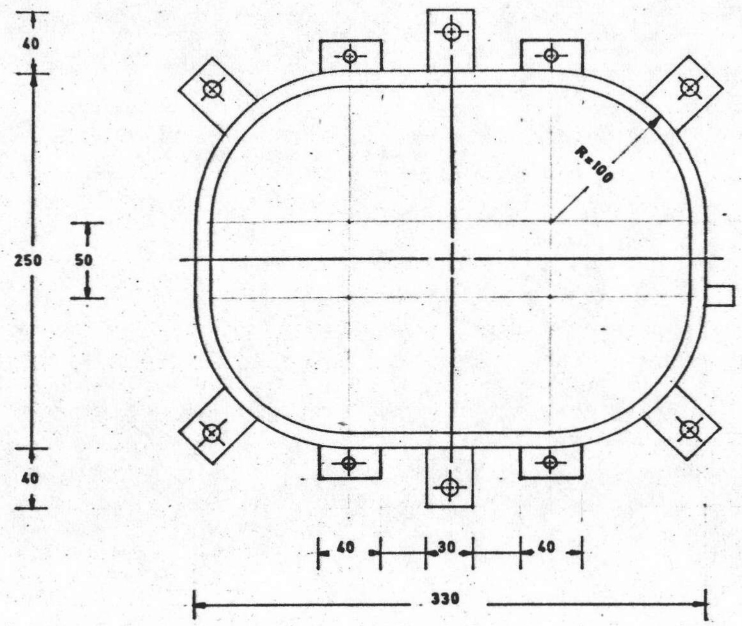
a) AT THE BEGINNING AND

b) AT THE ENDING OF THE WINDING

4.2.3 Tank

The tank was made of plain - sheet steel, the thickness of the sheet steel varies on it application, 2.40 mm. thick for the wall and 3.00 mm. thick for the bottom and lid.

The specification of the tank and tank lid were shown in Fig. 4 - 17 and Fig. 4 - 18 respectively. The inside surface was coated with varnished and the outside surface was painted with rustproof paint for the first painting and then with grey color.



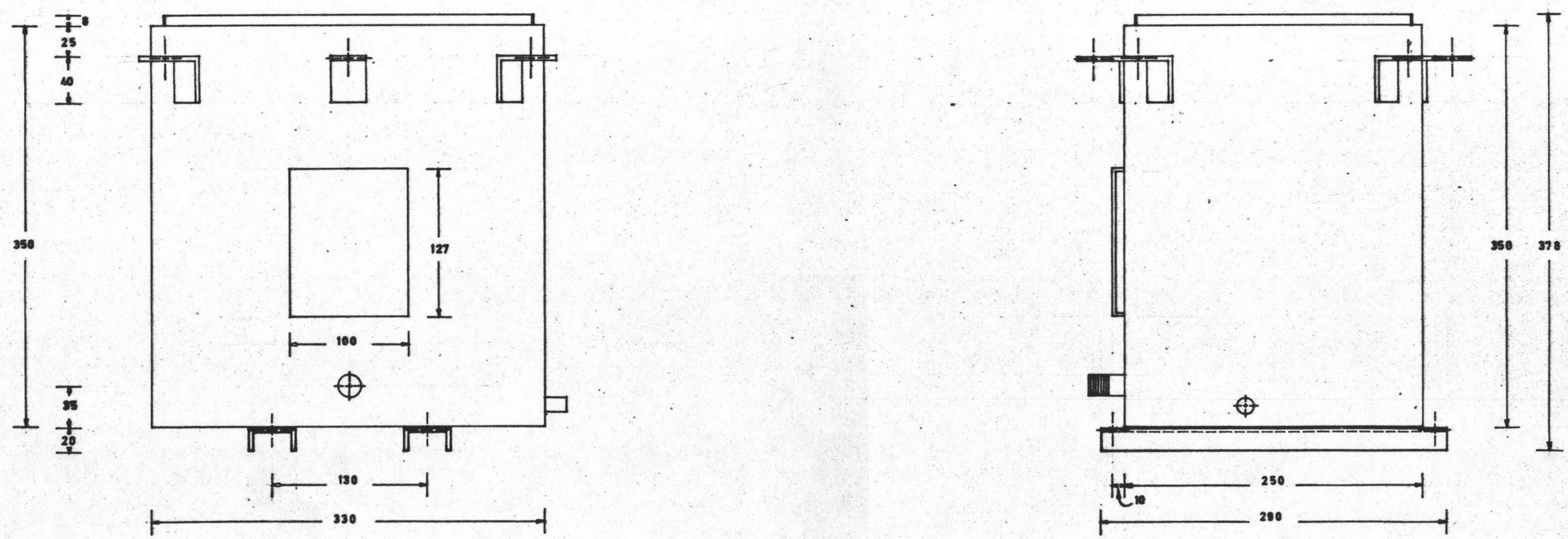
TOP VIEW.

NOTES.

1. PLAIN-SHEET STEEL WITH THICKNESS 2.40 mm. WAS USED FOR TANK WALL AND 3.00 mm. FOR THE BOTTOM.

2. ALL STEEL WAS JOINED TOGETHER BY WELDING.

3. ALL DIMENSIONS ARE IN mm.

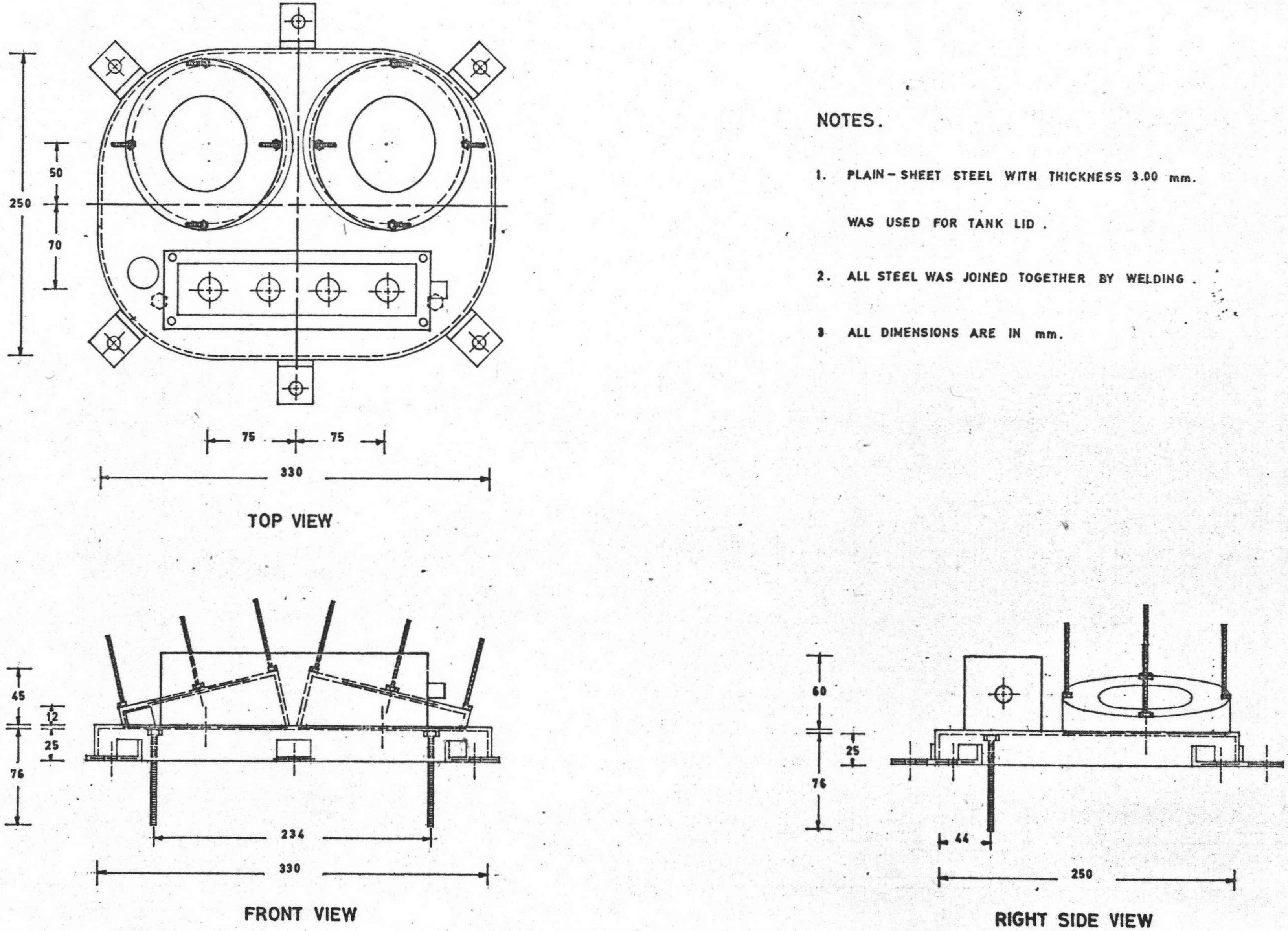


FRONT VIEW.

RIGHT SIDE VIEW.

FIG. 4–17. TANK SPECIFICATION.

SCALE 1 : 5



NOTES.

1. PLAIN-SHEET STEEL WITH THICKNESS 3.00 mm. WAS USED FOR TANK LID.

2. ALL STEEL WAS JOINED TOGETHER BY WELDING.

3 ALL DIMENSIONS ARE IN mm.

FIG 4.-18. TANK LID SPECIFICATION
SCALE 1:5

4.2.4 The Assembly

4.2.4.1 Coils inserting

To insert the finished coils around the core legs, the upper yoke had to be removed, the ring type pressboards insulation with 3.00 mm. thick would be inserted to the bottom and head of the coils. Then inserted the coil and pressboard onto the core legs. The upper yoke was laminated to form a complete core type and clamped with L - Shape iron clamps. The high - voltage coils were fitted tightly to the yokes by the strips of bakelite inserted between the coils and the ring type pressboards at the upper and lower yokes. The low - voltage coils would be supported tightly by pressboard insulation to the yokes to ensure the oil circulation between the low and high - voltage coils.

Tank lid would be placed tightly on the head by mean of screws and nuts connected to the L - Shape iron clamps which attached to the upper yoke and the tank lid. The terminals of the ended wire of each high - voltage winding would be connected together and insulated with paper insulation tube 2.5 mm. thick.

The high and low - voltage bushings were assembled in the tank lid. The high - voltage windings were connected to the high - tension leads of the high - voltage bushings and insulated with paper insulation tubes 3.00 mm. thick. The low - voltage windings were insulated with sleeve and connected to the low - voltage bushings.

There would be 4 terminals to be connected in series or parallel at the low - voltage coils and the secondary voltage obtained were 240 and 120 volts respectively. The connection diagram for low - voltage coils was shown in Fig. 4 - 19.

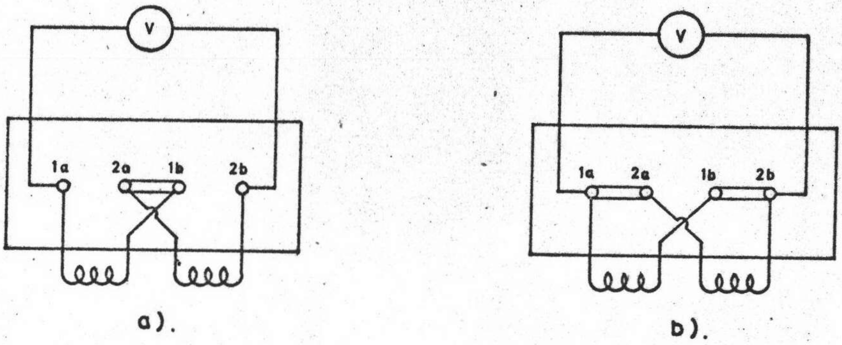


FIG.4-19.CONNECTION DIAGRAM OF LOW-VOLTAGE COIL.

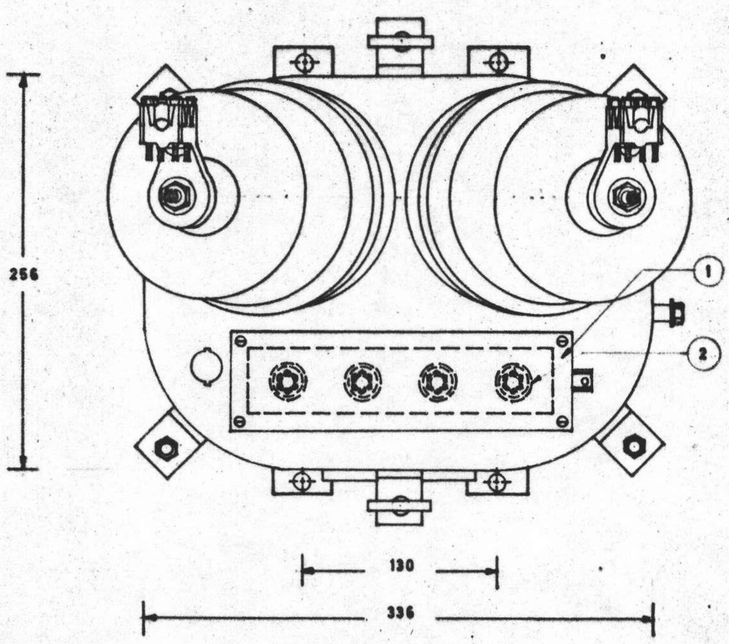
a). SERIES CONNECTION.

b). PARALLEL CONNECTION.

4.2.4.2 Transformer oil filling process

After assembling the coils, the unfinished transformer had to be baked and vacuum in the vacuum chamber. Baking process would be operated first by increasing the temperature of the vacuum chamber to about 75 degrees celsius and then started the vacuum process. The temperature and vacuum pressure were controlled at 105 degrees celsius and 760 mm. Hg. respectively. The baking and vacuum would be operated about 8 hours continuously at this temperature. After this operation fitting of the assembled coil would be checked to make sure that it was fitted tightly. After checking it would be inserted into the tank. The 10 x 10 mm. square rubber seal (for the tank and lid sealing) was used, then fastened with 3/8 inch bolts and nuts at the fastening hinges as shown in Fig. 4 - 20.

Before starting the second baking and vacuum one high - voltage bushing had to be removed, the rubber tube connected from the vacuum - transformer oil pipe was put to this hole. Then the second operation was started, the operations traced as the previous operations. After 8 hours treatment (at 105 degrees celsius) the temperature in vacuum chamber was reduced to 70 degrees celsius and the vacuum - transformer oil was transfer through the bushing hole into the transformer tank until the oil immersed the transformer core (reading from flow - meter), the reason for filling the vacuum - transformer oil during the vacuum process was that to prevent the transformer from moisture in the air. The transformer was removed from the vacuum chamber, then the oil was filled again until the tank was fulfil, the high - voltage bushing was assembled. All screws and nuts were checked again for their fittness. The set was completed. Its figure and dimensions were shown in Fig. 4 - 20.

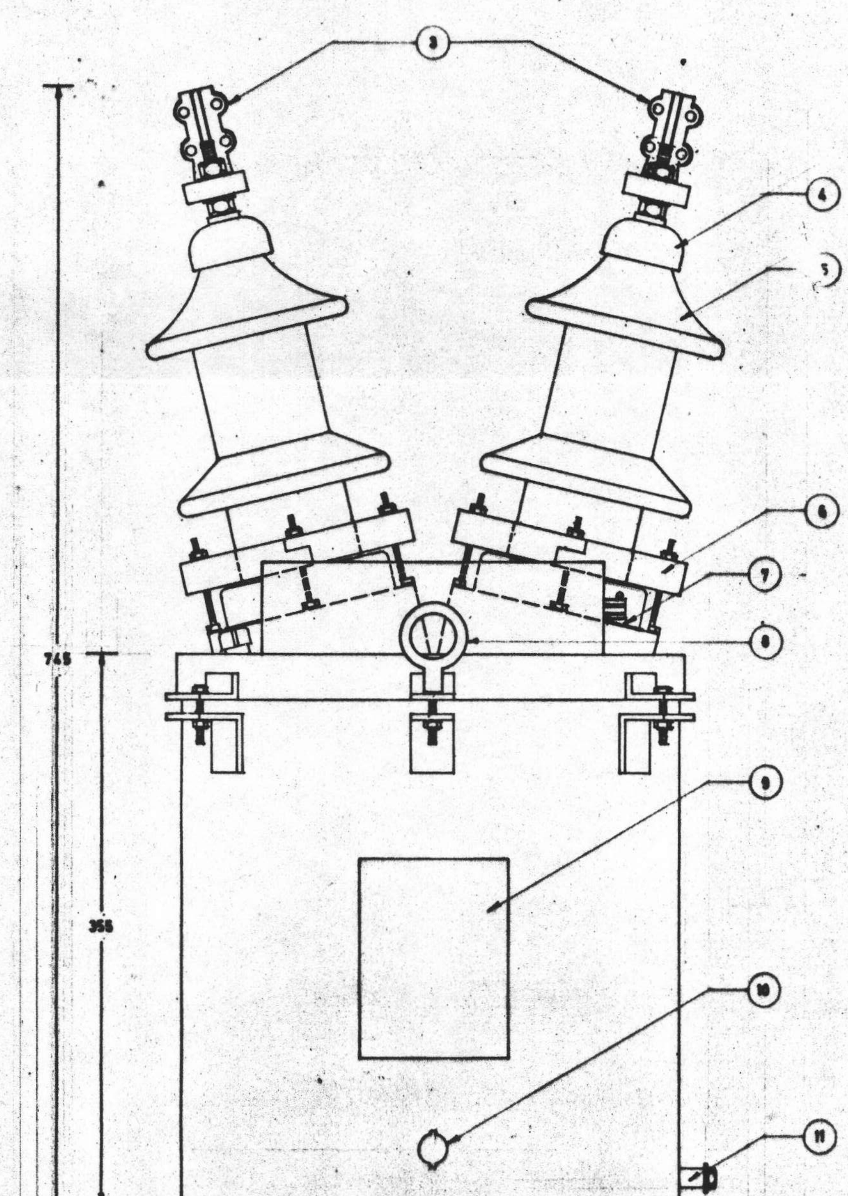


TOP VIEW.

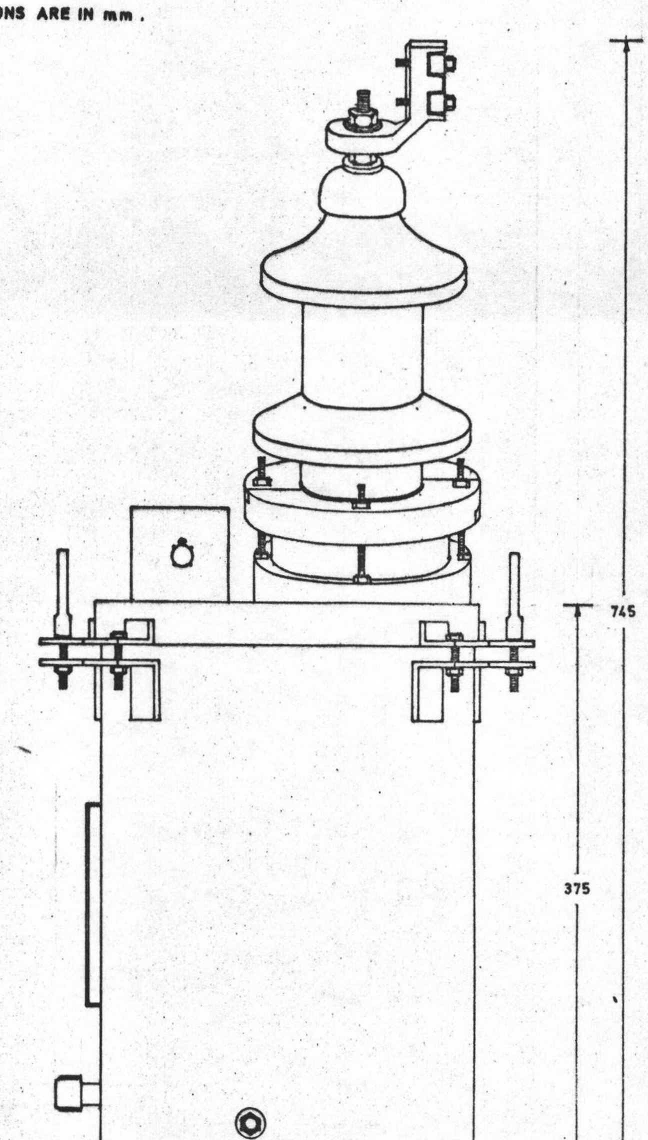
1	SECONDARY TERMINAL BOX .	
2	LOW - VOLTAGE TERMINAL CONNECTION .	
3	HIGH - VOLTAGE TERMINAL CONNECTION .	
4	HIGH - VOLTAGE BUSHING CAP .	
5	HIGH - VOLTAGE BUSHING .	
6	" " " CLAMP .	
7	" " " RUBBER SEAL .	
8	LIFTING LUG .	
9	NAME PLATE .	
10	DRAIN PLUG .	
11	EARTH TERMINAL .	

NOTE :

1. ALL DIMENSIONS ARE IN mm .



FRONT VIEW .



RIGHT SIDE VIEW .

FIG 4.- 20 12 KV. VOLTAGE TRANSFORMER .

SCALE 1 : 5

4.2.5 Cost of Materials

	Baht
1. Silicon Steel 16 Kgs. @ ฿.25.00	400.00
2. No. 15 Copper Wire 2.5 Kgs. @ ฿.75.00	187.50
3. No. 32 Copper Wire 3.5 Kgs. @ ฿.90.00	315.00
4. 2 x High - Voltage Bushing and Accessory @ ฿.500.00	1,000.00
5. 4 x Low - Voltage Bushing and Accessory @ ฿.25.00	100.00
6. Pressphane 1 Kg. @ ฿.45.00	45.00
7. Plain - Sheet Steel 15 Kgs. @ ฿.5.00	75.00
8. Transformer Oil 20 Litres @ ฿.15.00	300.00
9. Paint	100.00
10. Clamps, Screws, Bolts and Nuts etc.	100.00
11. Name Plate	100.00
Total	2,722.50