STUDY OF SOLID AND LIQUID DIELECTRICS, BY NON-DESTRUCTIVE TEST, USING SCHERING BRIDGE.

BY

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A THESIS

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JULY, 1977.

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EXAMINERS:-

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ABSTRACT

The present work deals with the study of different commercial dielectrics at high voltages to observe their dissipation factor (tangent of the dielectric loss angle) and capacitance behaviour under different condition. The Schering Bridge was used for the purpose. This is a very useful non-destructive method of testing dielectrics. A schering Bridge, with some of the auxiliary apparatus, lying unused and in a damaged condition, had to be repaired and brought to proper working condition for this study. The thesis deals with (i) the general theory of schering Bridge, and (ii) interpretation of variation of the dissipation factor and capacitance as obtained in the study.

High-frequency polyethylene cable, 11-KV 3 core PILC cable and transformer oil were tested under varying conditions such as repeated stress, long duration stress, change of temperature, etc. From the results attempts were made to evaluate the condition of the dielectric from the point of view of its breakdown strength.

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CHAPTER-I.

INTRODUCTION:

The different properties of electrical engineering materials —conductor, insulator and others—should be precisely known for their proper utilization. Moreover, the properties of the different materials are not independent of the environmental conditions. That is, the properties change with such factors as composition, presence of impurities, temperature, humidity, etc. Hence it is very important to gather as much information about these materials as possible under the different conditions. The necessity of newer materials required to suit the different conditions become important as research and developement of the electrical engineering science tends to produce articles and equipment for the greater benefit of users. The enormous advances that have taken place in the different branches of electrical engineering are largely due to careful experimental researches, being based on a fairly complete mathematical and physical theory, in which the various electric, magnetic and other relevent properties involved have been precisely measured.

Insulating materials, or dielectrics, as a class, are required to stop the passage of electric current at places where it is not required to pass; in other words, it should possess almost an infinitely high insulation resistance. They surround conductors in electrical equipment forming electrical insulation between parts across which a voltage exists. Air acts as an insulator for overhead transmission lines. Oil-impregnated paper—and other types of dielectrics also — is required for underground cables. Then there are other sorts of materials to suit the respective conditions. Thus transformer oil, in addition to its cooling purpose, serves also as an insulation. In short, there is no piece of electrical equipment that does not depend on insulation in some form to maintain the flow of current in the proper channel.

For dielectrics — like other materials — their required properties should be preserved as far as possible under the different conditions for their proper utilization; and hence the need arises for measurements of their different properties under different environmental conditions.

The electrical properties of dielectrics which are very important are the insulation resistance, breakdown strength, permittivity, dielectric loss angle (the tangent of this angle is known as loss tangent or dissipation factor), conductivity, etc. Of the above mentioned properties this work deals with the investigation and study of two properties —— loss-tangent or diddipation factor and capacitance (dependent on the permittivity of the dielectric).

It is a proven fact that the properties of the different materials is dependent on their molecular structure. The molecular structure of the dielectrics studied in the investigations reported in the thesis are different. Thus while polyethylene and transformer —oil are non-polar materials, paper is a polar material[21]. Also, there are physical differences between these; while polyethylene is a solid, transformer oil is a liquid, and oil-impregnated, paper is a solid-liquid combination.

As has been mentioned earlier, two important properties of these dielectrics have been investigated to some extent. These are the loss tangent and capacitance. The angle by which the current in any dielectric is not in quadrature with the applied a-c voltage is known as dielectric loss angles. The tangent of this angle is called the loss-tangent or the dissipation factor. This defect in the quadrature angle (for ideal case) arises from the fact that no dielectric is perfect, and thus it possesses some conductivity. This cuases an absorbtion of electric energy by the dielectric. This absorbed energy is dissipated as heat, The loss tangent is a very important parameter of the dielectric; its impertance as an index of the perfection of a dielectric cannot be over-emphasized, since it is the best single test which can be made, without the destruction of the dielectric, to determine the suitability of the dielectric for a particular purpose, as well as the state of the dielectric at any time.

Every dielectric material poseesses the property of storing electric energy within it, and this property is called the capacitance of the dielectric. This capacitance depends, besides the bulk of the dielectric, upon its permittivity, E, which is a measure of its ability to store electric energy within it. Thus, the greater the permittivity, the greater is the capacitance of any dielectric or insulating material, --the bulk, of course, remaining the same.

With the above in view, the following types of tests, and other experiments have been performed and reported in the thesis.

(1) Testing the behaviour of high-frequency, low voltage polyethylene cable at high voltages and power-frequencies

(2) (a) An oil-impregnated paper cable was tested with repeated and excessive stressing to observe their harmful effect, if any on the dielectric

(b) This dielectric of the same type of cable was next tested a few days after its breakdown which was made to take place after the repeated stressings, as stated above.

(3) Samples of transformer oil were studied to observe the effect of elevated temperatures on their loss tangent and capacitance.

The Schering Bridge provides a very useful and convenient means to study (and measure) the capacitance and dielectric loss angle of dielectrics. This bridge is superior to other types of bridges in many respects. Details about the different methods of measuring the capacitance and loss tangent can be found in B. Hague's "A-C Bridge Methods[2]. In Appendix G are given some bridge networks that are satisfactory for the measurement of dissipation factors and capacitance. Since the Schering bridge had been used in the investigations, some relevant details are given in the next chapter (chapter 2).

CHAPTER-2.

THE SCHERING BRIDGE

2.1 INTRODUCTION:

The Schering Bridge was invented in 1920 by H.Schering and is named after him[2]. This bridge was desribed at an earlier date by Phillips Thomas in "United States Patent"No. 1,166,159 which was accepted in Dec. 1915. High-voltage testing in America tended to be restricted to the use of Wein Bridge. The bridge was entirely developed in Europe, and was used by H.Schering and his associates. This bridge could be designed for use at high-voltages, and also for measurements at different frequencies ranging from 20 H_z to 1 MH_z. Low-voltage testing on small capacitors with very high precision is also possible. For a detailed discussion on the different aspects of this bridge, one is referred to Hague's book[2] "Alternating current Bridge Methods".

The Schering bridge proves very easily operative for making measurements of capacitance and loss tangent of dielectrics at high-voltages.

2.2. THE SIMPLE SCHERING BRIDGE:

The Schering Bridge in its simplest form is shown in fig.2.1 below:-

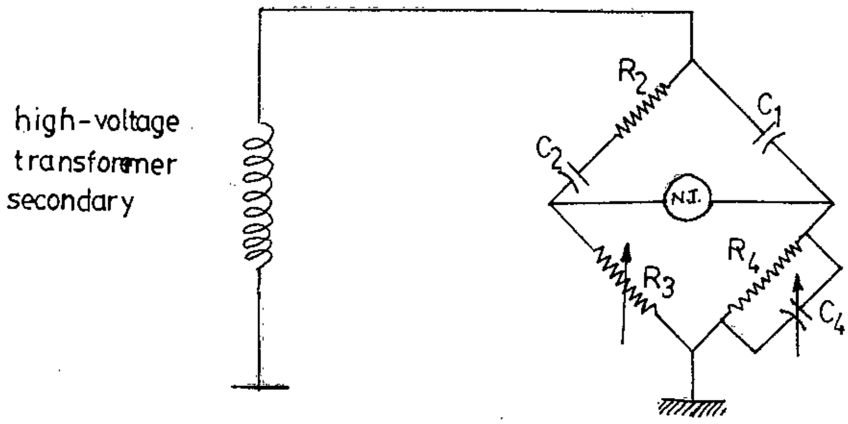


Fig. 2.1 : Simple Schering Bridge.

In the figure, C_2 is the effective capacitance and R_2 the equivalent loss resistance of the imperfect dielectric. Evidently, no dielectric medium is fully insulating; it will have some conductivity, though very very small. C_1 represents the standard air-capaciter. C_4 is a variable capacitor. R_3 and R_4 are non-inductive resistors. The impedances of the various branches are:

$$Z_1 = 1/ jwC_1 ;$$

$$Z_2 = \left(\frac{1}{jwC_2} + R_2 \right)$$

$$Z_3 = R_3 ;$$

$$Z_4 = \frac{1}{\left(\frac{1}{R_4} + jwC_4 \right)}$$

When balanced, that is, with no current in the detector, we get[2]

$$Z_1 Z_3 = Z_2 Z_4$$

Putting in this equation, the circuit symbols for Z_1, Z_2, Z_3 and Z_4, we get

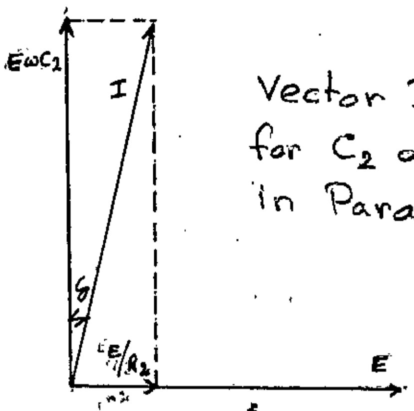
$$\frac{1}{j\omega C_1} \cdot R_3 = \left(\frac{1}{j\omega C_2} + R_2 \right) \left(\frac{1}{1/R_4 + j\omega C_4} \right)$$

$$\text{or,} \quad R_3 \left(1/R_4 + j\omega C_4 \right) = j\omega C_1 \left(1/j\omega C_2 + R_2 \right)$$

from which, after simplifications, we have

$$R_2 = \frac{C_4}{C_1} R_3 ; \quad \text{and} \quad C_2 = \frac{R_4}{R_3} C_1 ;$$

For a parallel representation of the dielectric, as is shown in the figure below, we have the following equations.



Vector Diagram for C_2 and R_2 in Parallel.

For arm 1, $Z_1 = - \frac{j}{wC_1}$

For arm 2, $Z_2 = \frac{R_2}{(1 + jwC_2 R_2)}$

arm 3, $Z_3 = R_3$

arm 4, $Z_4 = \frac{R_4}{(1 + jwC_4R_4)}$

Under balance condition

$$Z_1/Z_2 = Z_4/Z_3$$

or,

$$\frac{R_2}{R_3(1+jwC_2R_2)} = \frac{-j/wC_1}{\frac{R_4}{1 + jwC_4R_4}}$$

$$= \frac{-j}{wC_2R_4}(1+jwC_4R_4)$$

Rationalyzing, we have

$$\frac{R_2 (1-jwC_2R_2)}{R_3(1 + w^2C_2^2 R_2^2)} = \frac{-j}{wC_1R_4}(1 + jwC_4R_4)$$

Equating real terms,

$$\frac{R_2}{1 + w^2 C^2_2 R^2_2} = \frac{C_4 R_3}{C_2}$$

Now, from the vector diagram shown below, for an applied voltage E,

$$\cos\delta = \frac{E_w C_2}{E \sqrt{\frac{1}{R_2^2} + w^2 C_2^2}} = \frac{w C_2 R_2}{\frac{w C_2 R_2}{\sqrt{1 + w^2 C_2^2 R^2_2}}}$$

or $$\cos^2\delta = \frac{w^2 C_2^2 R_2^2}{1 + w^2 C_2^2 R_2^2}$$

Substituting $\cos^2\delta$ in the equation of real terms obtained above, we have

$$\frac{\cos^2\delta}{w_2 C_2^2 R_2} = \frac{C_4 R_3}{C_1} \qquad C_2 = \frac{C_1 \cos^2\delta}{w^2 C_2 C_4 R_3}$$

From Fig.2.2, showing the complete vector diagram for the bridge network under balance conditions,

$$\tan\delta = w C_4 / \frac{1}{R_4} = w C_4 R_4$$

$$\text{and also, } \tan\delta = \frac{1/R_2}{w C_2} = \frac{1}{w C_2 R_2}$$

$w C_4 R_4 = 1/w C_2 R_2$ or, $R_4 = 1/ w^2 C_2 C_4 R_2$

Substituting R_4 in the expression for C_2 gives $C_2 = \frac{C_1 R_4}{R_3} \cos^2\delta$

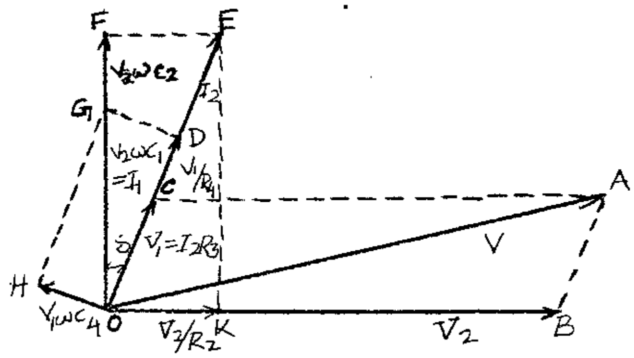


Fig.2.2- Vector Diagram for ~~Sk~~ Schering Bridge under Balance Conditions

The vector diagram of Fig.2.2 needs, perhaps, some explanation. Vector OA represents the voltage applied to the bridge from the supply transformer. OB is the voltage drop V_2 across arm 2 which, when no current flows in the ~~main~~ null indicator branch (i.e. under balance conditions), is equal in magnitude and phase to the voltage drop across arm 1. Vector OC is the drop V_1 across arm 3, which is equal in magnitude and phase to that across arm 4. The vector sum of OB and OC obviously gives the total bridge voltage OE. The current I_1 flowing in arm 2 and 3 is represented by vector OE, while OG represents the current I_2 flowing in branches 1 and 4 . OF and OK represent the component parts of current I_1 when split up between the capacitance C_2 and resistance R_2 . In the same way OD and OH represent the components of the current I_2 when split up between R_4 and C_4.

The magnitudes of some of the vectors, e.g. OC, are exaggerated for the sake of clearness. V_1 will, in reality, be very small compared with V_2 and V.

2.3 MODIFICATIONS OF THE SCHERING BRIDGE TO SUIT DIFFERENT CONDITIONS:

The simple Schering Bridge has to be modified to include certain precautions, to use it for testing short lengths of cables, porcelain insulators where charging currents are usually small, about 30 milliamperes. Near breakdown, when the current becomes excessive, this method is not very suitable because it is difficult to design non-reactive variable resistors, for use in arm R_3, which can carry large currents. This defect is eliminated by using the circuit shown in figure 2.3 below:

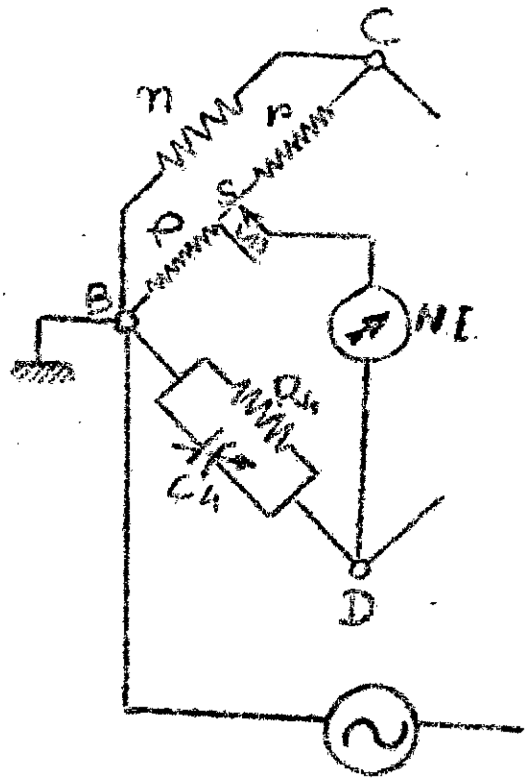


Fig-2.3: Mofidications of the Schering Bridge for large Charging Current.

2.3.1 MODIFICATIONS OF THE SCHERING BRIDGE FOR LARGE CHARGING CURRENT:

In the figure, n is a fixed low resistance, r is a fixed resistance of higher value in series with slide wire ; the sum $(n + r + \rho)$ is a constant,—usually equal to 100 ohms. The resistance ρ is a non-reactive decade box upto 1111 ohms. P and C_3 are adjusted to secure balance, and by moving the potential contact on the slide wire, a suitable value of n can be chosen. This resistance combination can be converted into its equivalent star, and it can be shown that balance occurs when

$$C_1/C_2 = S(n + r + s + \rho) / n(\rho + \sigma)$$

$$= (100 + \rho)/n(\rho + \sigma)$$

$$\tan\delta = wSC_3 - wSC_2\frac{r+6-\sigma}{+} \cong wSC_3$$

$$\cong 0.1\,C_3 .$$

where $(n + r + s) = 100$ ohms; $S = 1000/\pi$ and C_3 is in microfarads. The second term in the expression for tan δ is usually small, and can be neglected.

The arrangement shown in figure above has been used to measure capacitance upto 5 mf at high voltages; to extend to capacitance range, it is required that the low-resistor n should be of very small a value. When this is done, the residual inductances of the resistances and their connecting leads,especially in n, have enough effect to distort the measurements of the capacitance and the dielectric loss angle; the simple theory given has to be modified to include certain modifications. Some workers, Zickner and P festorf (2) have worked ourt the necessary corrections. They have shown that large condensors can be measured with good accuracy when precaution are taken.

2.3.2 - SCHERING BRIDGE WITH EARTHED SPECIMEN:

In the case where one electrode of the specimen is necessarily at ground potential, such as in cable testing where the lead sheath is earthed and in testing high voltage bushings where the central ring is fixed to the earthed tank of a switch or transformer. In such cases it is not allowed to earth B, as had been done in previous circuits; and another method is adopted.

The earth point is shifted to point A, giving the so-called "inverted" schering bridge. It has been introduced by Bormann and Seiler. A shield g joined to the high-voltage corner B defines the stray capacitances between the high-voltage parts of the bridge and the low voltage sides of C_1 and C_2 and shown in figure (2.4) below. It is seen that the adjustable arms of R_3 and C_4 are at the full test voltage above earth, and must be provided with fully insulated control handles to avoid danger to the operator. This greatly complicates the constructional features of the bridge, but inspite of this difficulty satisfactory apparatus has been made for testing of bushings and cables "in situ"; double sheilding is used, an earthed sheild enclosing the high-voltage shield shown in the diagram.

These difficulties are removed by transferring the earth point to C^*. Referring to figure 2.4(b), earth capacitances from the corners D, B and A act as shown. The capacitance C_D Shunts detector and does not affect the balance : C_A is in parallel with C_1 and C_B with R_3; these introduce errors. By means of a safety gap, it is ensured that B never rises more than a few hundred volts above earth, so that the effect of C_B on R_3 is very small and can be eliminated by balancing the bridge as shown, obtaining values of C_o and tan $_o$ for the combination in the branch AC. Now remove the test specimen and rebalance, giving C_A and $\tan\delta_A$. Then it can be found that approximately,

$$C_1 \cong C_0 - C_A$$

$$\text{and, } \tan\delta_1 \cong \frac{(C_0 \tan\delta_0 - C_A \tan\delta_A)}{(C_0 - C_A)}.$$

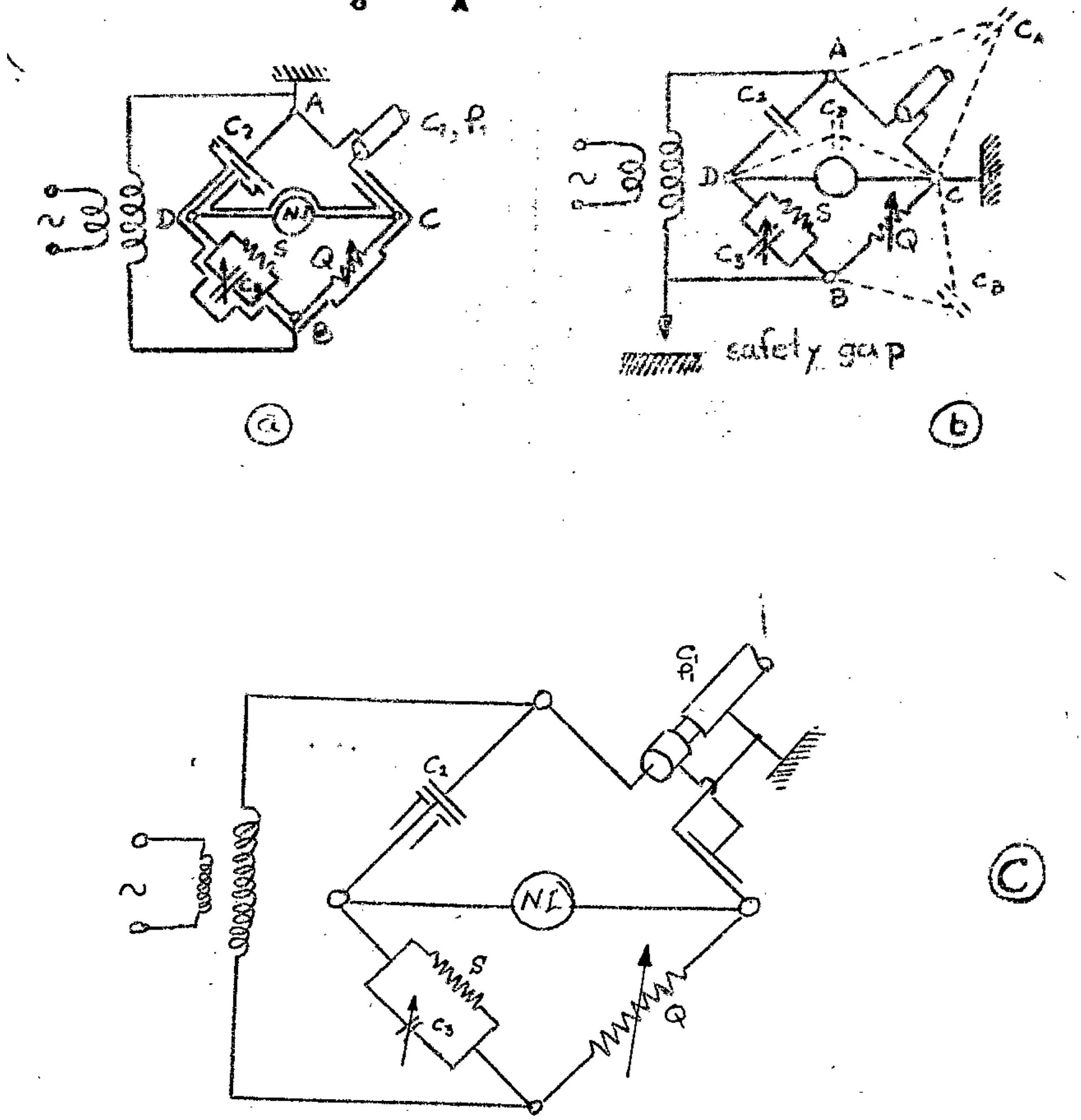


Fig. 2.4 : Schering Bridge with earthed test specimen.

It is necessary that the earth and inter-capacitances remain definite and this can only be secured by proper shielding. Fig 2.4.(c) shown diagrammatically and arrangement of shields intended to define and localize the capacitances and leakances between the bridge arms and between the primary winding, secondary winding and the tank of the supply transformer. Dielectric losses between the secondary winding and the insulated tank are considerable, and can be eliminated from the bridge measurements by enclosing the primary winding in an earthed shield and the secondary in a shield joined to the low-voltage corner B; the tank is joined to this corner also.

2.4 -THE SUBSTITUTION METHOD OF USING THE SCHERING BRIDGE:

Here the bridge arms consist of elements arranged as shown in figure 2.5 (1). The components are the bridge are equal ratio arms R_A and R_B, a standard air-capacitor C_N, and a balancing capacitor C_T. This method is used becuase of its greater accuracy. The specimen is connected in parallel with the standard air-capacitor, and the bridge balanced; then it is disconnected and the bridge rebalanced. The parallel capacitance C_p of the specimen is the difference of the two readings of the standard capacitor (readings with the specimen disconnected being primed)

$$C_p = \Delta C = C_N' - C_N$$

The resistive balance of the bridge can be made in three ways : by a variable resistor of low value in series with the standard capacitor C_T (series-resistance bridge), by a variable capacitor in parallel with the ratio R_B (Schering Bridge). For the Schering Bridge the dissipation factor (loss tangent) D of the specimen is

$$D = \frac{C_N'}{\Delta C} \Delta D$$

where $\Delta D = D - D' = R_B W (C_B - C_B')$. The total capacitance C_N' in the capacitance arms should be as small as possible so that the change in dissipation factor ΔD may be as large as possible, especially for low-loss materials.

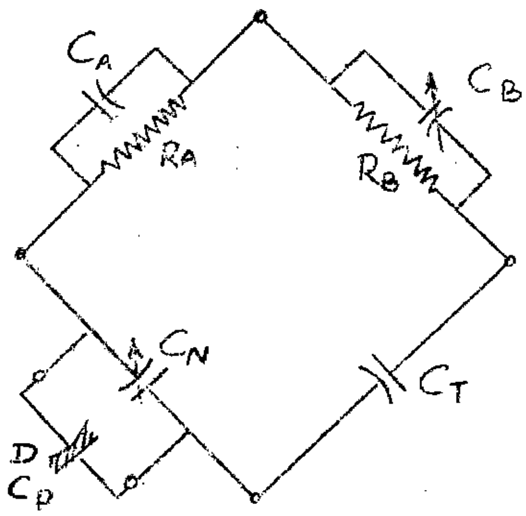


Fig-2.5 : The Substitution Method of Using The Schering Bridge.

The balance equations of the simple Schering bridge are not concerned with the parallel capacitances of the two capacitance arms; rather, they are concerned with the series capacitances. This fact, in combination with the fixed stray capacitance C_A across ratio arms R_A — this produces a dissipation factor reading D_A — causes cross terms to appear in the balance equations when high losses are measured. The complete equations are

$$C_p = \Delta C \frac{1 + aD}{1 + D^2}$$

$$D = \frac{C'}{\Delta C} \frac{\Delta D}{1 + aD}$$

where $a = D' - \frac{C}{\Delta C}\Delta D = D\frac{C'}{\Delta C}\Delta D$, and the dissipation factor readings D and D' have been increased by D_A.

2.5 -THE MODIFIED SCHERING BRIDGE USED IN THE STUDY:

INTRODUCTION:

The bridge circuit, Fig.2.6 [8] consists of four arms; the high-voltage arms AB and BC and the low-voltage arms AD and CD. In addition are suitable shield and guard arrangements and an adjustable low-voltage source. This bridge unit provides the two low-potential arms, shield and guard adjustment circuits.

The elements of the different arms are : AB — high-voltage standard air-capacitor C_1; BC — test specimen in a suitable holder, C_2 : CD — six decade dial resistor suitable for alternating current, R_3; AD-adjustable capacitor, C_4, shunted by resistor, R_4, from which a centre tap connects through an adjustable air capacitor, Ca, to the grounded shield.

This particular bridge is designed to measure the dielectric loss angle and capacitance upto a maximum of 25 kilovolts, which can be varied from zero to that value. The range of capacitance measureable accurately is from 40 to 20,000 PF, using a 100 PF air capacitor as standard, and the tangent of the dielectric loss angle ($\tan\delta$) from 0.0001 to 1.00. The maximum permissible specimen current is 75 milliamperes.

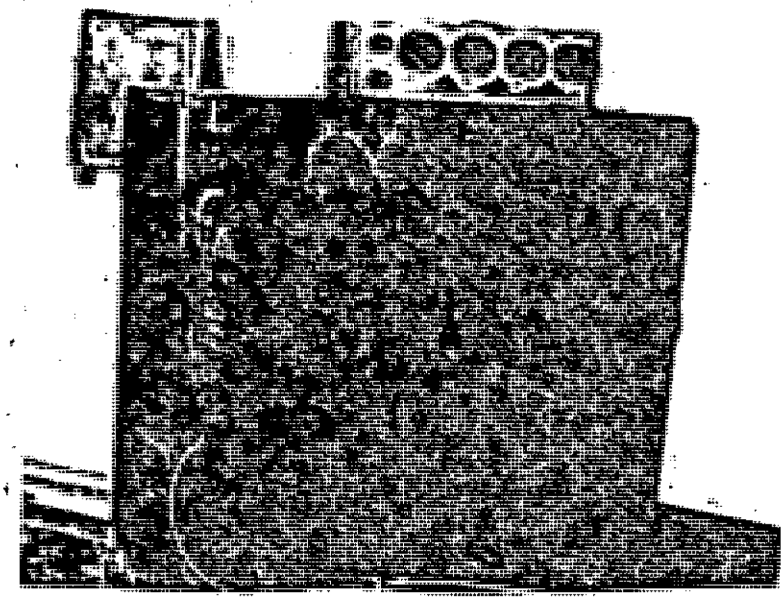


FIG. FRONT PANEL OF THE MODIFIED SCHERING BRIDGE.

FIG. BELOW INTERIOR VIEW OF THE MODIFIED SCHERING BRIDGE.

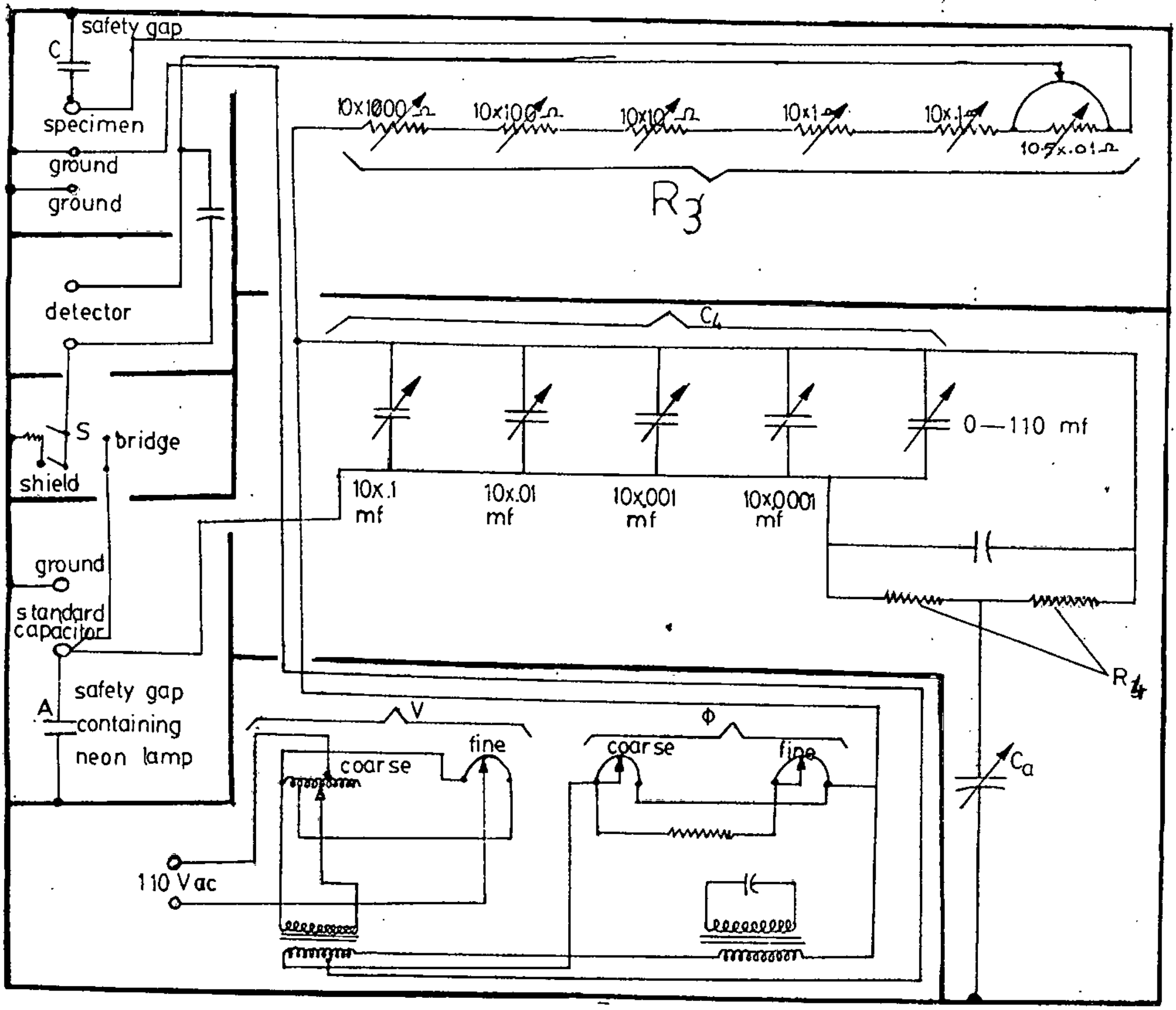


FIG. 2.6.a. MODIFIED SCHERING BRIDGE

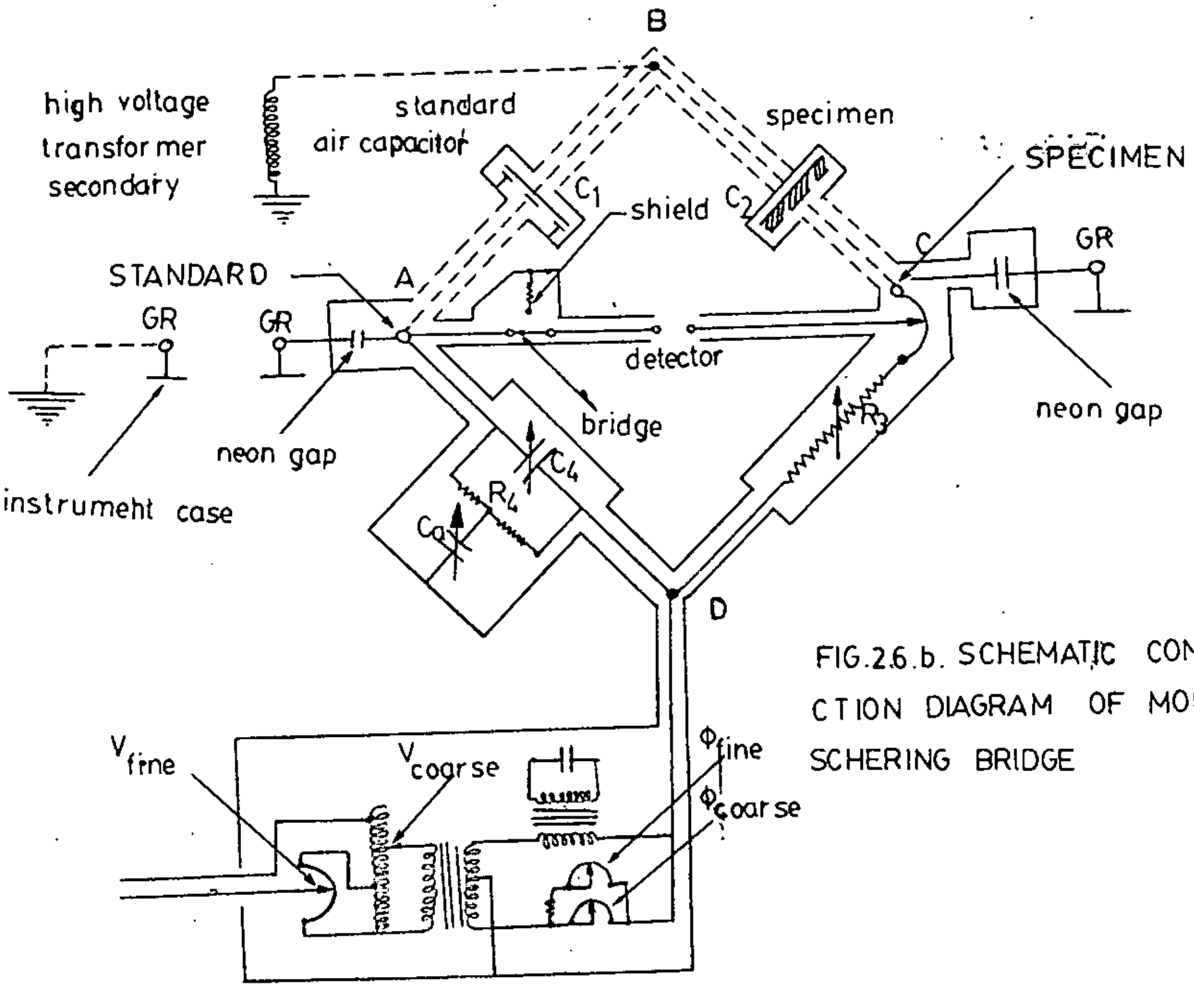


FIG.2.6.b. SCHEMATIC CONNECTION DIAGRAM OF MODIFIED SCHERING BRIDGE

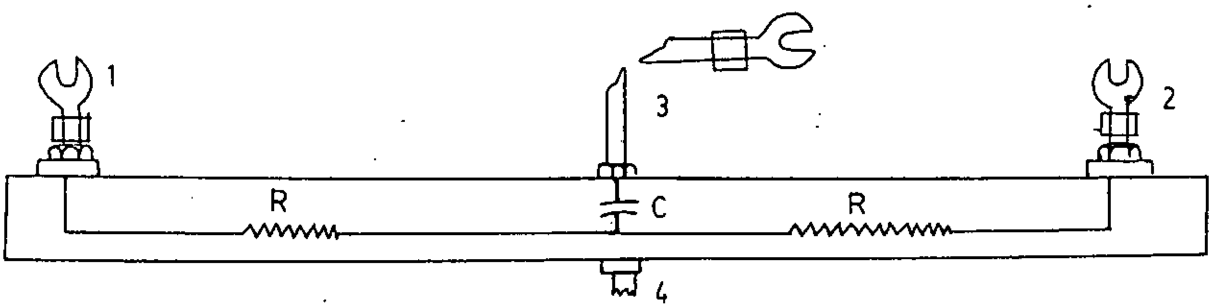


FIG. 2.7. TESTING UNIT

2.5.1 - VOLTAGE SOURCES:

The bridge requires two voltage sources[4], connected in series as is shown in Fig.2.7 : one is an adjustable low-voltage source and the other a high-voltage source. The bridge is connected to an earthed common shield which is connected to the common terminal of both sources and is equipotential with respect to the detector branch. The shield and detector branches are equipotential when

$$V_h/V_l = \frac{Z_1}{Z_2} = \frac{Z_4}{Z_3}$$

where V_h is the voltage of the high-voltage source, and V_l that of the low - voltage source. The equipotential condition is obtained by adjusting the low-voltage V_l both in magnitude and phase.

This sort of arrangement completely eliminates any unwanted coupling and provides equipotential protection for the detector. The guard ring of the high-voltage capacitor is maintained at the potential of the guard electrodes, for which reason its value is rendered definite in magnitude. The capacitance of the bridge arms do not affect the balance condition, since they either "act" haw between the equipotential points (the capacitances lumped at the points A and C) or shunt the two sources(the capacitances humped at the points B and D).

2.5.2 THE LOW VOLTAGE SOURCE[4]:

The low-voltage is regulated by a circuit shown in fig. 2.8 which consists of a continuously adjustable auto-transformer(AT) and a parametric phase-shifter using a transformer T_1 and a capacitor C, connected via another transformer T_2 (this being done to increase the effective capacitance), and variable resistors R'

and R''. The continuously adjustable auto-transformer and the voltage divider at its input vary the magnitude of the low-voltage; its phase is adjusted by variations of R' and R''.

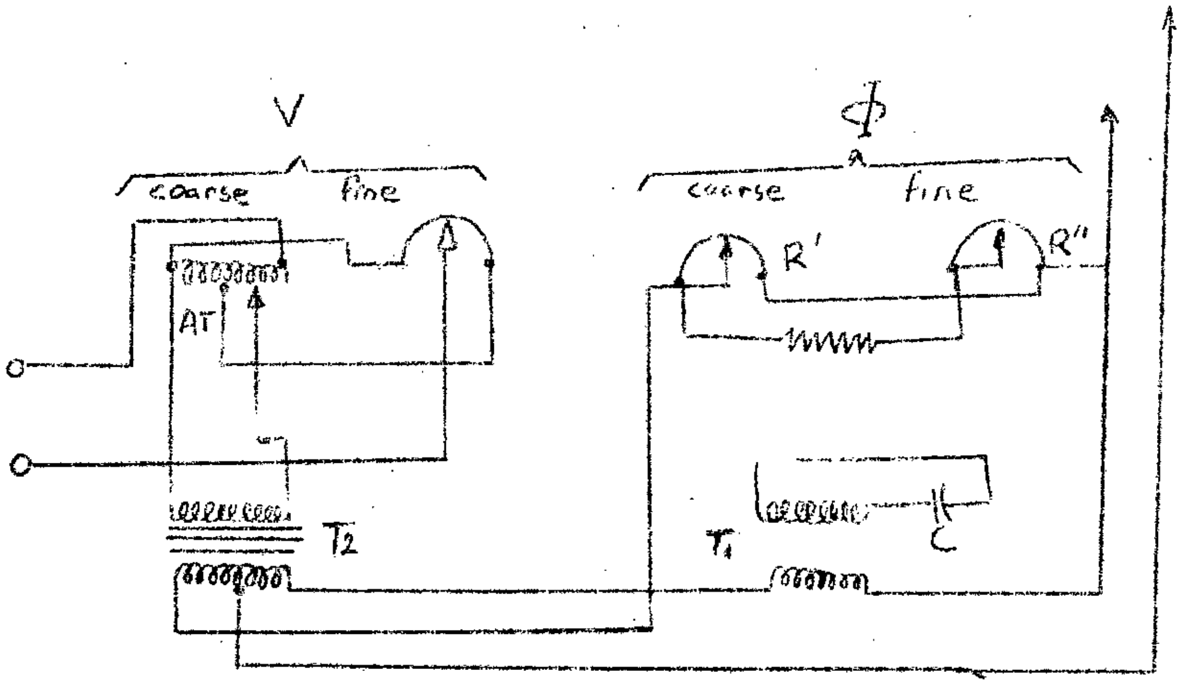


Fig. 2.8 : Low Voltage Source

2.5.3 THE RESISTANCE ARM, R_3 :

The resistance branch of the bridge, R_3, has *five* dials, each dial contains six coils per decade. This arrangement, designed by Behr(9), is shown in figure (2.9) below. The value of each coil is twice the decade units. One of the coils is stationary. This is connected between two brushes to the next decade. The remaining coils are connected in series, and arranged on the rotor as shown in the figure. In the position shown in the left band arrangement, the current does not go through any coil.

This is the zero position of the decade. In the next position of the rotor in the counter-clockwise direction, the first coil on the rotor is arranged in parallel with the fixed coil and the resulting resistance is 1 unit. In the next rotor position; the fixed coil is shorted and the first rotor coil is in the circuit along, the resistance being two units. In the third position, the

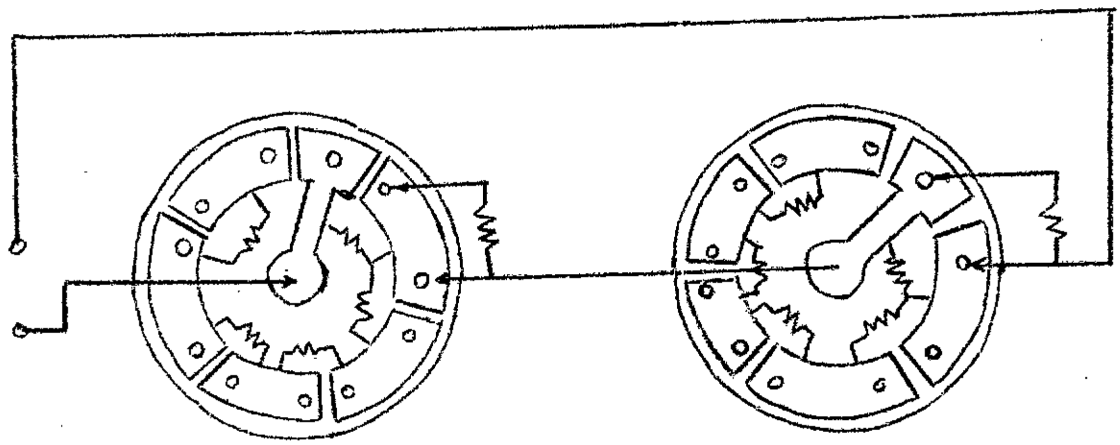


Fig-2.9: Resistance Coil Arrangement.

first rotor coil is in series with the parallel combination of the fixed coil and the second rotor coil, the total resistance being 3 units, etc. With suitable shield arrangements, the time constants of this decade are quite low for all dial settings. Measurements on a 1000 ohms decade at 50 KHz gives for 1 X 1000 ohms a time - constant of -1×10^{-8} seconds and for 10 X 1000 ohms one of -7×10^{-8} seconds[2].

2.5.4 THE CAPACITANCE ARM, C_4:

There are five dials in this branch, with four having grouped capacitors in each, and the other consisting of a variable air-capacitor. Each group contains four capacitors. Two of the dials which show higher values of capacitances each contain four mica capacitors properly sealed with wax, and shielded. The two other dials, each contain four air-capacitors, sealed in air-tight containers and shielded. These capacitors are arranged in a manner such that each consecutive setting results in a change of $1/_{10}$ of the total capacitance of each dial.

2.5.5 THE CAPACITANCE, Ca :

The variable capacitor Ca serves to balance the phase components of the arms R_3 and R_4. It is equivalent to an inductance connected in parallel with R_4. To obtain such balance prior to a series of measurements, the capacitances C_1 and C_2 are replaced by two identical impedances $Z_1 = Z_4$, then C_4 is set to zero, R_3 is made equal to R_4, and Ca and the low-voltage are varied until the bridge is brought to balance at balance $Z_1 Z_3 = Z_2 Z_4$. Since $Z_1 = Z_4$, then $Z_2 = Z_3$ or $R_2 + jwL_2 = R_3 + j\omega L_3$, where L_2 and L_3 are the effective impedances of the arms[4].

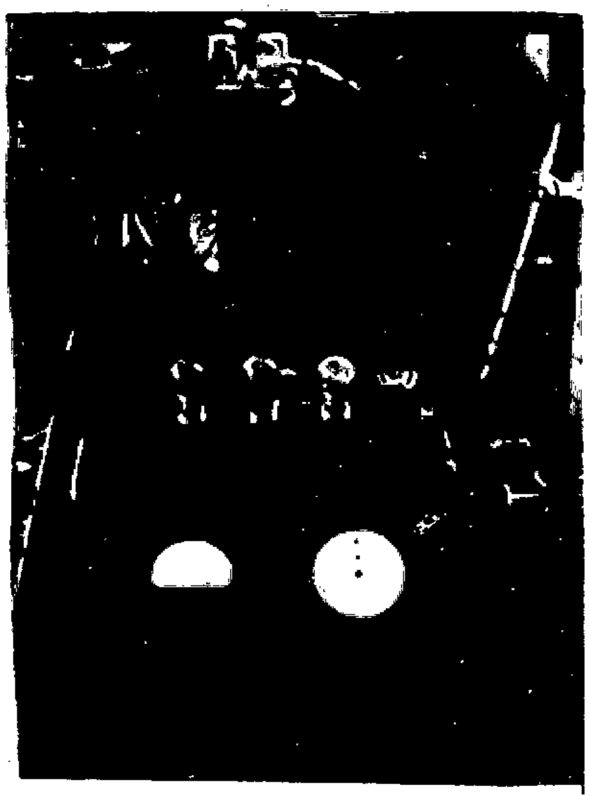
2.6 AUXILIARY APPARATUS :

2.6.1 STANDARD AIR-CAPACITOR( ):

The standard air capacitor supplied with the bridge has a maximum voltage rating of 35 kilovolts. The nominal capacitance rating is 100 microfaradSs while the actual rating in, micro-microfarads, is

FIG. (a) STANDARD AIR CAPACITOR AND (b) POLYETHYLENE SAMPLE.

FIG. AT RIGHT (a) THE HIGH-VOLTAGE SOURCE, (b) POLYETHYLENE SAMPLE (c) AMPLIFIER.



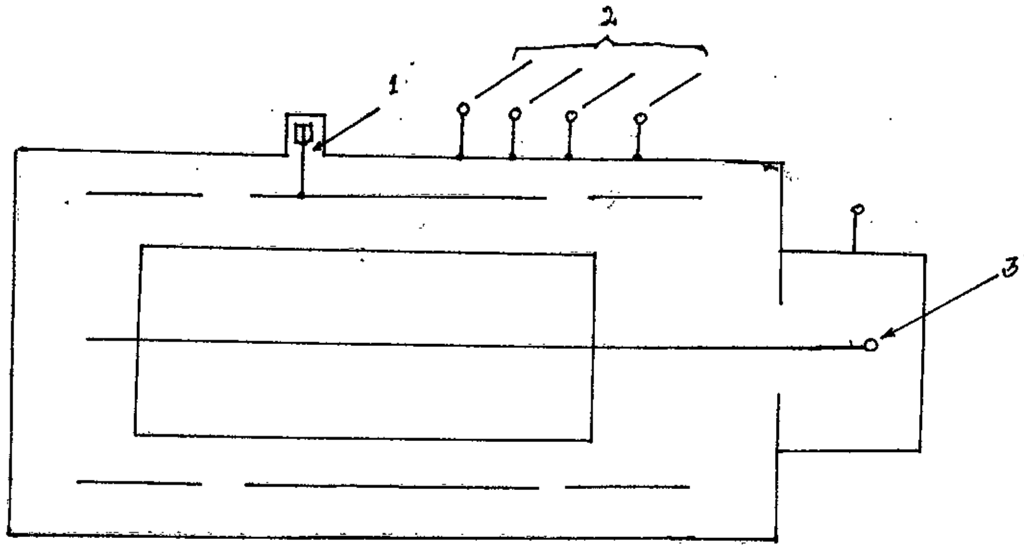


Fig. 2.10 : Schematic Diagram of Standard Air-Capacitor.

This capacitér is of the connectric cylender design, intended for use as a three lead capacitor where the low voltage electrode is opeated at or near the potential of the shield of the capacitor. The low voltage terminals 1, figure 2.10.., has a shield cap over it as does the high voltage terminal 3. The shield of the capacitor is equipped with four terminals, each marked; 2 and the shield cap over the high-voltage terminal is equipped with a terminal.

The standard capacitor is provided with means to protect it from atmospheric humidity.

2.6.2 THE REQUIREMENTS OF STANDARD AIR CAPACITORS

Gases, or air, when used as dielectric, provide a medium which is "completely" loss free. A properly designed air-capacitor is the closest approach to a perfect capacitor. The following are some of the properties that should be present in standard capacitors.

(i) They should be true capacitors; that is, the current taken by them when supplied by a sinusoidal voltage should lead on the voltage by an angle of $\pi/2$ and should be free from harmonic

(ii) They should be free from losses and absorption effects in the dielectrics

(iii) The capacitance should be constant and the standard should be compact for a given value of capacitance in order that inaccuracy due to earth capacitances may be very small.

(iv) The capacitance should be independent of frequency, wave form and temperature

(v) The insulation resistance should be great and the capacitors should be capable of with standing high-voltages.

The air capacitors used are specifically built to withstand the high-voltage. The dimensions are such that the dielectric breakdown field strength is not approached, while simultaneously losses due to brush discharges and corona are avoided by adequate spacing and by well rounding all edges. This results in the air-cpacitor being bulky and of small capacitance.

The standard capacitors with their low voltage electrode and guard ring surrounding the high-voltage electrode have the defect of much larger earth capacitances, with a consequent dependence on surrounding objects and their potentials. To overcome this defect, the capacitor is enclosed in an earthed shield.

The advantages of standard air capacitors over resistors, when used as standard impedance, are the following[2] :

a) Their construction is simple; they can be easily shielded from extraneous capacitive effects;(b) heating is absent; there is no limit to the voltage for which these capacitors can be built, provided only that the necessary space is available to accomodate their considerable bulk.

2.6.2 SPECIMEN HOLDER[8]:

The specimen holder is designed for use with liquid die-electrics. It consists of two shells. The outer shell constitutes the high-voltage electrode and the inner shell constitutes the low voltage electrode. The low-voltage electrode is surrounded by a guard ring, so that the specimen capacitance and dissipation factor measurements are not affected by extraneous effects. The guard electrode is connected to ground terminal on the main bridge. The top covers are made of glass, so that the specimen is visible from outside. The cell has a capacitance in air of about 75 $\mu\mu F$. The spacing between the electrodes is 80 mils. The volume of the specimen required is approximately 75 cc or 4.5 cubic inches.

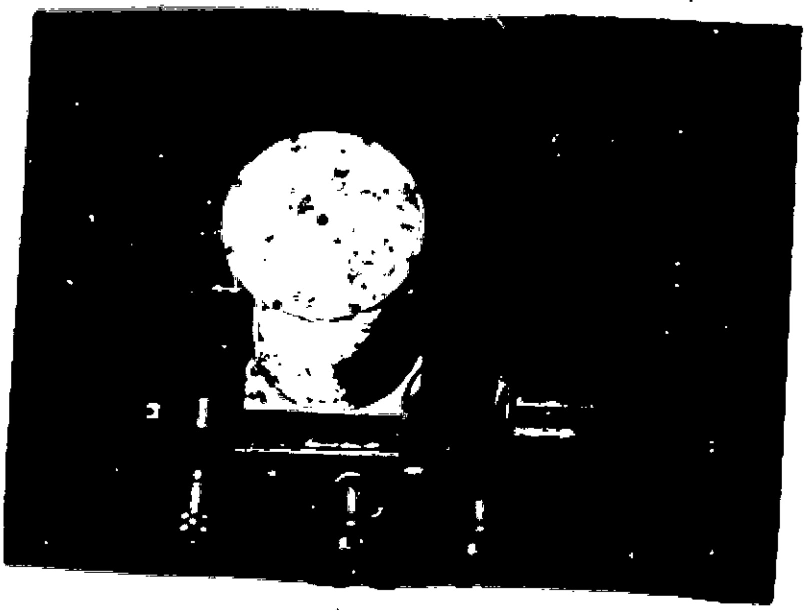
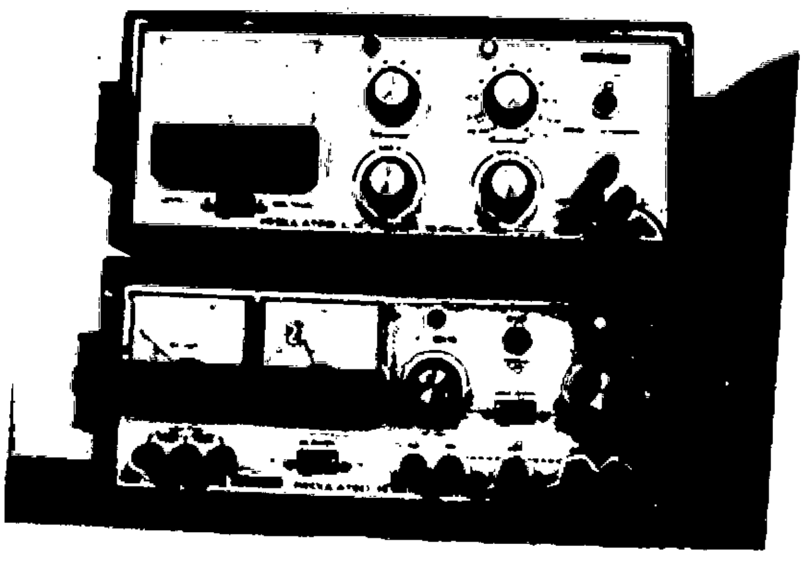


FIG. ABOVE INSIDE THE AMPLIFIER.
BELOW AMPLIFIER POWER SUPPLIES.



2.6.3 COMMERCIAL FREQUENCY AMPLIFIER[8]:

The amplifier, provided with the bridge is battery operated (power supplies can be used instead). It requires two D.C. sources:- one a 6.0 volt supply, the other a 90 volt supply. This amplifier is designed to be used for frequencies between 25 to 60 Hz. It is electrostatical and magnetically shielded.

Further description of the amplifier is given in the "Bridge Mannal".[8]

2.6.4 NULL DETECTOR:

The bridge is supplied with a vibration galvanometer, including a lamp and scale arrangement. However, this was not used in the experimental studies due to some difficulties. It is also possible to use a D.C. micro-ammeter, in conjuction with a metallic rectifier. Actually, use was made of of a sensitive cathode ray oscilloscope, becuase it proves superior to the D.C. micro-ammeter arrangement.

In the schering Bridge, the voltage developed accross the low-voltage arm is approximately VwC_1R_4( ). If $\Delta\delta$ is the smallest change in loss-angle to which the detector is required to respond, then the sensitivity must be $VwC_1R_4\Delta\delta$ . .

For $V = 1KV_1$ $C_1 = 100$ PF; $R_4 = 3182$ ohms, $\Delta\delta = 10^{-4}$ and $W = 314$ radians/second, then the sensitivity must be 9 μV.

2.7 PRELEMINARY ADJUSTMENTS:

These adjustments are made—prior to taking measurements— to balance out the residual capacitance in the bridge network. They need be made only once before each set of measurements on test samples[8].

These adjustments are made by connecting the testing unit to the standard and specimen terminals; terminals 1 and 2 of the testing unit (or vice versa) are connected to these terminals. Lead 4 of the unit is connected to the secondary of a transformer, supplying 6.00 volts. The other end of the transformer is grounded. Terminal 3 of the testing unit is connected to a ground terminal on the bridge panel board. The bridge is then grounded. The amplifier, with the null detector connected to its output, is connected to the terminals "DETECTOR" on the bridge panel board. 110 Vac are supplied to the bridge low-voltage terminals.

The value of Ca, the mean of two sets of readings taken with connections 1 and 2 of the testing unit interchanged, is obtained after adjustments of R_3, Ca, Vcoarse, Vfine Φcourse and Φfine (C_4 is kept at zero). These are varied in order to obtain the balance point. The final value of Ca is such that it is unaffected by the bridge voltage, when precise measurements are required. The details of the above procedure are to be found in the bridge manual(8).

2.8 SHIELDING OF CONNECTIONS AND THE LOW-VOLTAGE ARMS OF THE BRIDGE:-

The connections from the A.C. source to the measuring circuit must be screened, and thus protected from external electrical fields, by a metallic tube or other metallic screens. The connections from the specimen to the bridge must also be screened likewise.

2.8.1 SOURCES OF ERRORS:

When tests are made on short lengths — 1 yard or more — considerable error may arise from end effects( ). The avoid this, the earthed sheath is always stripped back some little distance, laying bare the insulation; it has been observed that the losses in the cable end may easily swamp the true losses in the cable itself when short lengths of specimen are tested. These losses may result from (i) leakage over the high surface resistivity of the bared insulation, and in the distributed capacitance between this and the core of the cable; (ii) non-uniformity of the electric field near the end of the earthed sheath; (iii) ionization of the air near the end by influence of neighbouring high-voltage conductors.

Accurate measurements can be made if suitable guard rings of a length not less than eight times—and never less than four inches—the thickness of the insulation are applied to the end to by-pass the surface effects from the bridge[12].

2.8.2 GUARD RINGS AND THEIR EFFECT:

In its simplest form the guard ring is made by cutting a gap in the lead sheath. The cable portion under test is protected completely and effectively by using an electrostatic screen. In this connection,[12] it must be mentioned that a 1" or ½" wire mesh which will effect complete capacitance screening, will not, in general, effect complete loss-current screening, especially if the tests are carried out in the neighbourhood of any high-voltage corona or other discharge. Thus for highly accurate measurements, the screen must consist of a continuous metal, although in particular cases it may be possible to use wire-meshes, if it can be demonstrated that the condition of the experiment are such that no loss current arrives at the detector points. This screen is connected to the guard ring (or electrode), and this in turn is connected to a ground terminal on the bridge so that end currents do not enter the bridge arms, but are passed via the shields.

2. 8 : 3 -THE EFFECT OF LENGTH ON THE ERRORS:

The errors due to end-effects and to incomplete screening are inversely proportional to the lenth of the cable under test, and may be negligible on long lengths,-say about 200 yards. For intermediate lengths a guard ring 1" wide, close to the end of the sheath, may be found to be sufficient. The errors, however, depend on the voltages and on the arrangement of the equipment. The requirement can only be ascertained by experiment.

Errors due to end-effects are not necessarily positive, but may make a negative contribution to thea apparent power factor.

For measurements on liquid dielectrics, suitable shielded cells are designed to contain the specimen.(Detailed explanation is given in the bridge manual[8]).

2.9 : SAFETY:

In the bridge, very little voltage develops across the arms AD and CD, becuase their impedances are very small in comparision with those of the arms containing the standard air-capacitor and the specimen. If the impedance of the specimen is about 30 Mohms at 50 cps then balance can be obtained with R_3 having a value of a few thousand ohms. The voltage that is developed across the resistance arm is thus about one ten-thousandth of the applied high-voltage. Thus under normal conditions, the points A and C are at a potential of a few volts above ground. Thus, there is no danger to the operator, when adjusting R_3 and C_4. As an additional precaution, R_3, C_4 and R_4 are enclosed in a metal casing, which is earthed, and the adjusting knobs are made of carefully selected insulating materials.

Although the bridge is safe under normal conditions, a hazardons situation would arise if the specimen C_2 were to breakdown. This will result in the application of the full voltage to the resitance arm R_3 - a consequent danger to the operator. To avoid such a situations, the branches AD and CD are shunted by over - voltage safety devices consisting of neon glow damps, placed at A and C. This safety device is arranged to operate when the potential difference across the adustable branches rise to about 200 volts, so that the bridge is put out of action long before a dangerous situation arises.

CHAPTER - III

STUDY OF SOLID DIELECTRICS

3.1 CO-AXIAL POLYETHYLENE CABLE:

To study solid dielectric mediums, a polyethylene cable was taken. This cable is used in high-frequency applications. It is not designed for used at high-voltages and power-frequencies. However, it was tested at power-frequencies and high-voltages, so that the behaviour of the dielectric under these conditions could be ascertained. The dielectric was tested to study the behaviour of its two properties-capacitance and dissipation factor(loss-tangent)- with voltage. Evidently, the capacitance is dependent on the dimensions while the loss tangent is independent of the dimensions. The dissipation factor or loss tangent is a property of the medium analogous to permittivity.

Since the specimen is a concentric cable, its capacitance, C, can be obtained from the formula for a cylindrical capacitor (14).

$$C = \frac{0.039K}{\log_{10} D/d} \text{ microfarads per mile.}$$

where K is the permittivity of the dielectric

D = diameter of the outer conductor

d = " " " inner conductor.

That the dielectric loss-angle, δ, is independent of the dimensions of the medium can be found out in the manner given below :

Let the total length of thespecimen be L.

Let r = resistance per unit length

C = capacitance per unit length.

For length L, then

total capacitance $= CL$

total resistance $= r/_L$

The total capacitance current $= VwcL = I_C$;

The total resistive current $= \frac{V}{r/_L} = \frac{VL}{r} = I_R$.

$$\tan\delta = \frac{I_c}{I_R} = \frac{VwcL}{VL/_r} = Wcr$$

But $c = C/_L$ and $r = RL$

$$\therefore \tan\delta = \frac{WC}{L} \cdot RL = WCR$$

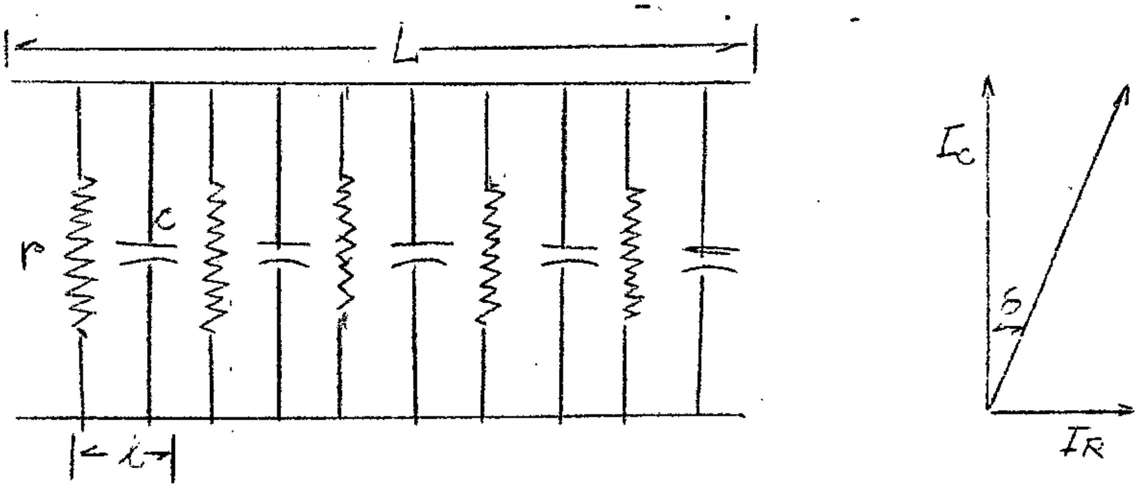


Figure-3.1- Schematic diagram of an Actual Dielectric and the current through it.

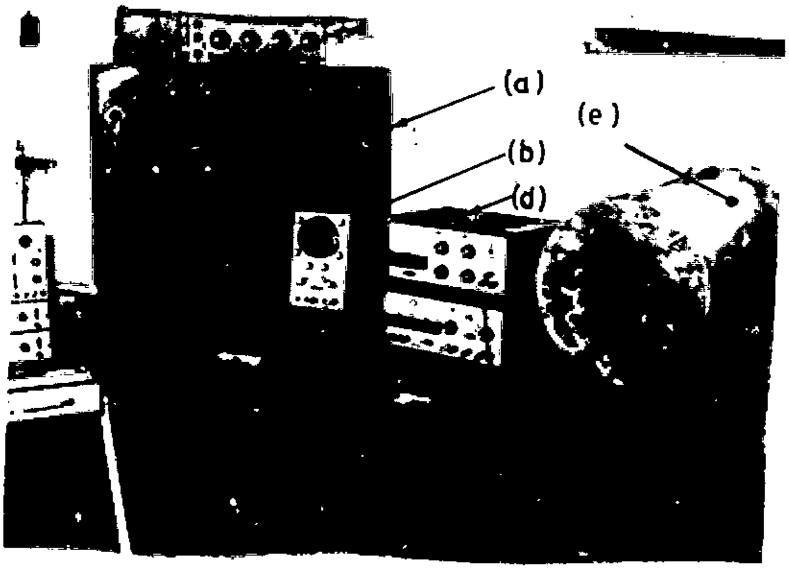
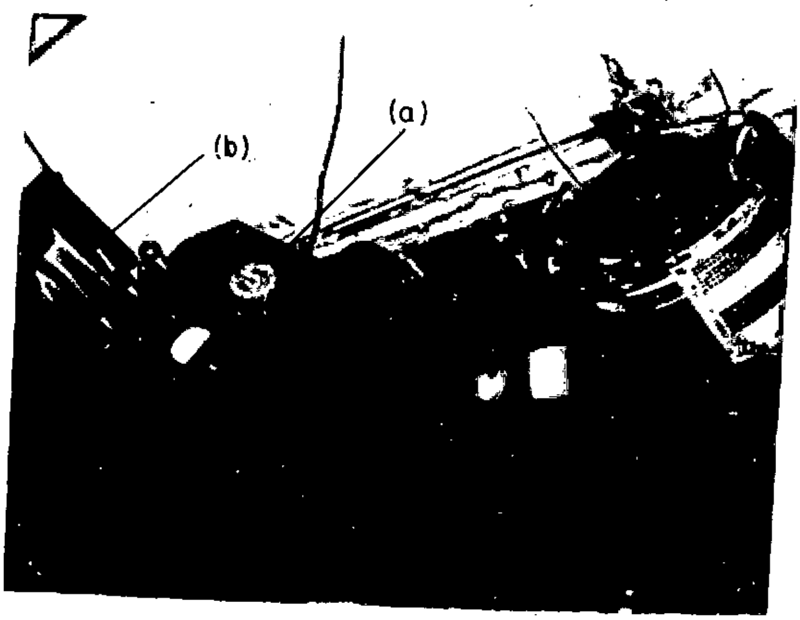


FIG. ABOVE THE EXPERIMENTAL SETUP SHOWING (a) SCHERING BRIDGE, (b) THE DETECTOR, (c) AMPLIFIER, (d) AMPLIFIER POWER SUPPLIES, (e) STANDARD AIR CAPACITOR.

FIG. BELOW (a) THE HIGH VOLTAGE SOURCE. AND (b) SPECIMEN.



3.1.1 CONDITIONS OF MEASUREMENT:

Going back to the actual specimen, a length of 141.7 cm, or 4.649 ft, of the cable was tested. This length excludes the portion cut out for making guards rings at both ends. The overall length of the cable is 158.3 cms.

For complete shielding from extraneous effects, the portion under test was enclosed in a metallic screen. The provision of this sort of screen is very effective in nullifying the stray capacitive effects and loss-currents. The screen and guard rings are connected to a ground terminals (GR) on the bridge.

The capacitance per foot of the cable is 32 micro-microfarads, this being marked on the cables. For a length of 4.649 ft, the total capacitance is approximately 148.77 $\mu\mu f$.

The inner conductor is made the high-voltage electrode, and the outer conductor the low-voltage electrode. Cellophane tape is provided at the ends of the high-voltage terminal(both at the specimen end and near the transformer end) to minimize corona discharges; otherwise terminal discharges affect the actual measurements on the specimen.

Readings were taken under normal conditions, at different voltages,—from 1.00 kilovolt onwards upto 9.00 kilovolts. Higher voltages could not be reached because the intencity of the discharges increased so much so that hissing sounds (due to discharges) could be heard at about 10 kilovolts. After this value of voltage, the discharges from the high-voltage conductor caused an arc to the guard ring.

THE FORMULA UTILISED:

The capacitance of the specimen is obtained from the formula[8]

$$C_2 = C_1 \frac{R_4}{R_3} \cos^2 \sin^{-1} P.F.$$

where P.f. denotes the power factor.
When the settings of the C_4 dials is less than 0.1 microfarads (as in this case), the capacitance can be found from the equation

$$C_2 = C_1 \frac{R_4}{R_3}$$

Here C_1 = capacitance of standard air-capacitor

= 100 μ μ f.

R_4 = 3188 ohms.

R_3 = is obtained from thedial setting in ohms.

The dial settings of C_4 on the bridge panel in microfarads, gives directly the value of the loss tangent, tan δ.

TABLE-1.

SPECIMEN: POLYTHENE CO-AXIAL CABLE :

LENGTH : 4.649 ft.

VOLTAGE K.V.	R_3 ohms.	C_4, μ f. tan δ = C_4. μ.f	$C_2 = \frac{R_4}{R_3} C_1$. μμf
1.00	2277.5	$0.0010 + 14 \times 10^{-6}$	139.98
2.00	2276.3	$0.0014 + 10 \times 10^{-6}$	140.052
3.00	2275.4	$0.0016 + 10 \times 10^{-6}$	140.107
4.00	2274.1	$0.0020 + 10 \times 10^{-6}$	140.187
5.00	2273.2	0.0022 + 000	140.243
6.00	2272.0	$0.0024 + 8 \times 10^{-6}$	140.317
7.00	2271.2	$0.0025 + 70 \times 10^{-6}$	140.366
8.00	2270.4	$0.0026 + 40 \times 10^{-6}$	140.416
9.00	2269.6	$0.0027 + 96 \times 10^{-6}$	140.484

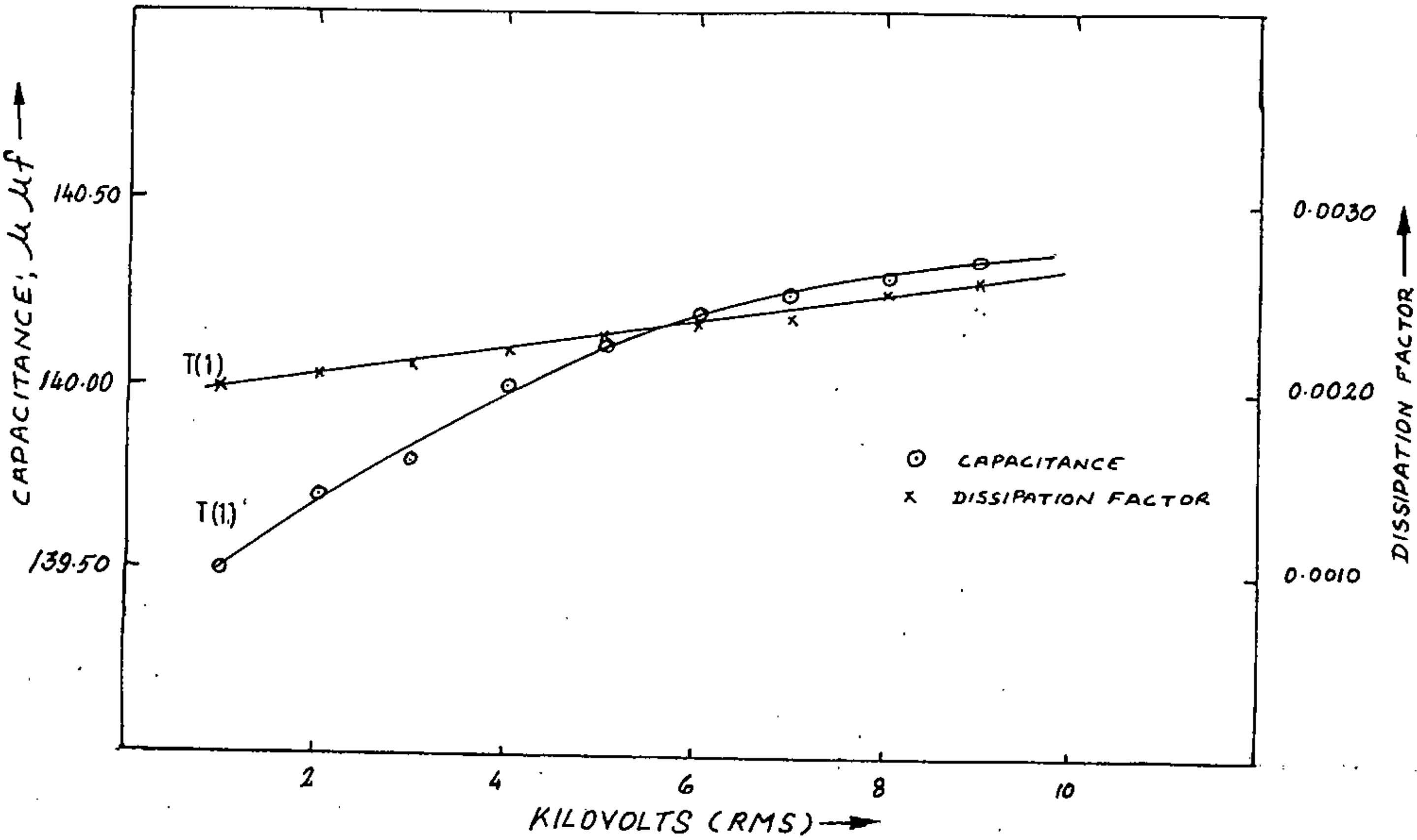


FIG. 32. VARIATION OF CAPACITANCE AND DISSIPATION FACTOR WITH VOLTAGE FOR A HIGH-FREQUENCY POLYETHYLENE CO-AXIAL CABLE (AT POWER FREQUENCY).

3.2 DISCUSSION ON THE DATA :

3.2.1 DISSIPATION FACTOR:

From the data, it seen that at 1.00 kilovolts, the dissipation factor is about 0.0020, which begins to increase gradually, and slowly, as the voltage is increased, at 9.00 kilovolts it is about 0.0025. The increase could be due to discharges taking place in the voids; and could also be due to the presence of additives, which are added to it. The increase could be due to shouting of discharging voids. The rate of increase is approximately linear. (Details about this is given in Appendix C)....).

3.2.2 CAPACITANCE BEHAVIOUR:

The capacitance is also found to increase with voltage,-the increase being much more rapid as compared to that of the dissipation factor. Moreover, in this case, the rate of increase is not very linear. This confirms the theory that as discharges take place in the voids, however small they may be, they short circuit the air space in the voids, and thus result in the increase of the capacitance. Since the number of discharging voids increase with the applied stress, the capacitance increase will depend directly on it.

CHAPTER-IV.

THE STUDY OF THREE CORE 11-K.V. PAPER INSULATED LEAD COVERED (PILC) CABLE:

4.1 INTRODUCTION:

A 3-core 11-K.V paper insulated lead covered cable was taken to study the behaviour of oil-impregnated paper insulation under different conditions of stressings. The cable was studid to investigate into the behaviomr of the dissipation factor and capacitance with the application of high-voltage.

Experiments were performed to study the variations with voltage of the core to core and core to sheath dissipation factor (loss-tangent) and capacitance.

Study was done under three different conditions: (i) before any sort of stressing, and normal conditions; (ii) after application of stress in excess of four to four and a half times the normal working voltage; readings were taken immediately after stressing and 20 and 45 hours after stressing; and (iii) a few days after the breakdown of the oil-impregnated paper insulation. The application of stresses on different occasions were for different durations.

4.2 PREPARATION OF THE SAMPLE :

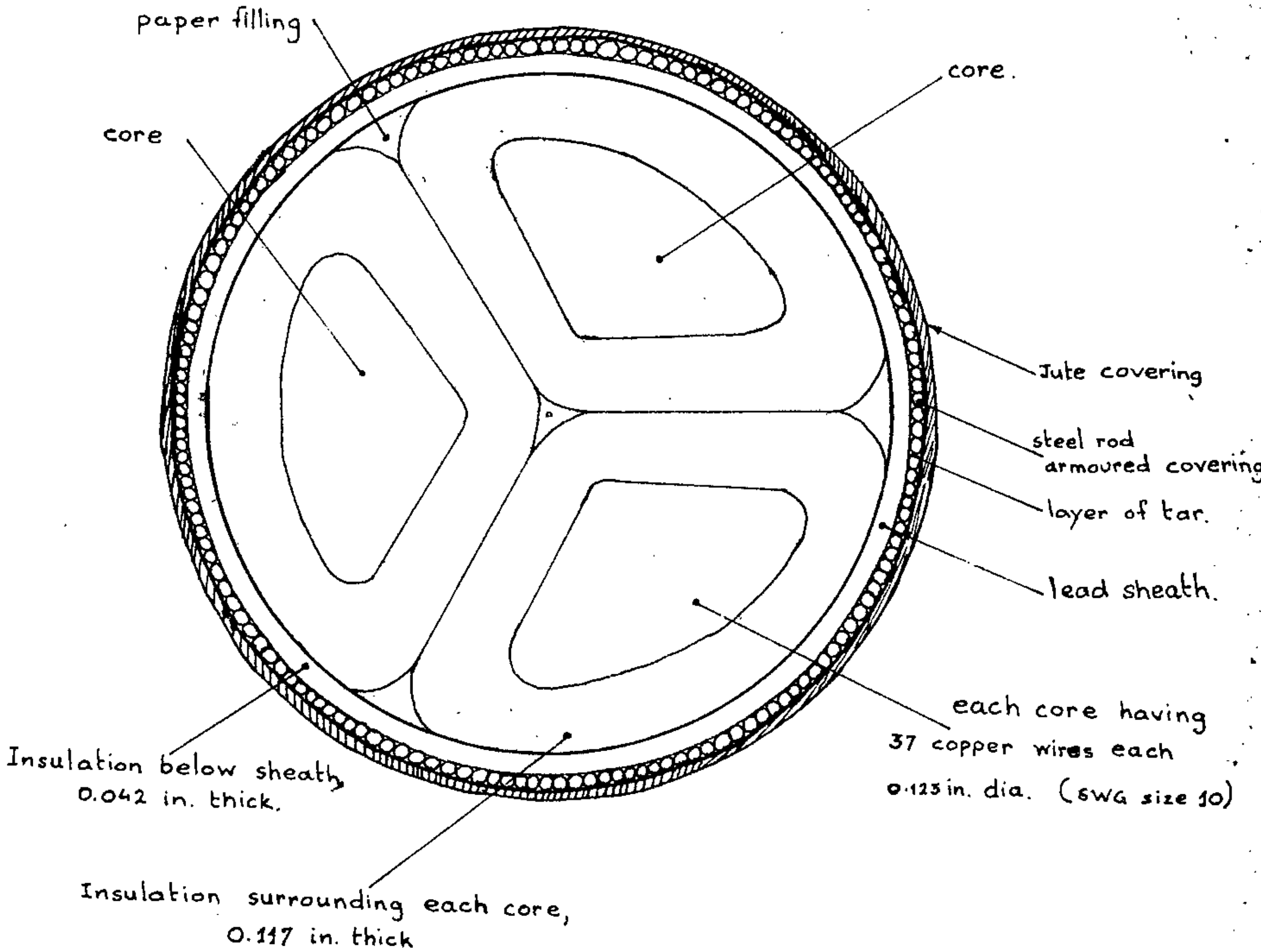
To study the behaviour of oil impregnated paper insulation, a length of 2.10 metres or .... ft, of a three-core calbe was taken. (A greater length could not be used becuase the charging current exceeded the maximum current limits of the high-voltage transformer secondary; earlier a length of 26 feet was tried.)

To make connections to the cores, a portion of the armoured steel and lead sheath was stripped off; then the outer paper covering the cores was removed. The three cores were then separated, by turning their ends in different directions, so that no discharges take place between them. The terminals were converd with wax. The insulation was then covered with oil resisting plastic tape to avoid the ingress of moisture into the insulation (paper is very hygroseopic), as this would increase the dissipation factor and lower the breakdown voltage. Similarly, some portion of the lead sheath was stripped off the other end, the cores separated by bending them in different directions. Plastic tape was applied carefully, and the ends were covered with wax, so as to stop the entrance of moisture from this end, and also to avoid discharges from conductors between them and to the sheath.

4.2.1 GUARD RINGS AND SCREENING:

To obtain accurate data, it is required that suitable guard rings be provided at the end of the lead sheath; and also that the sample under test be screened completely in order to avoid extraneous effects.

For the purpose of making a guard ring, a gap-about one inch wide - is cut in the lead sheath. The length of the guard rings obtained is about six inches. (The guard ring should be at least eight times the thickeness of the insulation, and nwver less than 4 inches). The gap is then covered with a plastic tape so that moisture does not enter the cable. The length of the cable under test was enclosed in a metal screen. This screen is kept



CROSS SECTIONAL VIEW OF A 3-CORE PILC CABLE (not to scale).

apart from the cable by surrounding portions of the cable with jute. The metal screen is connected to the guard ring.

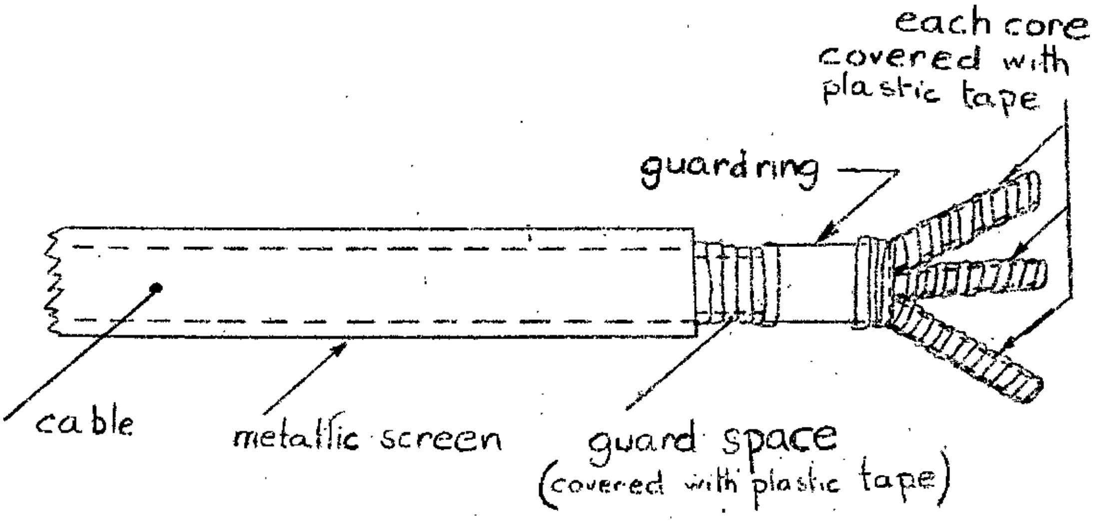


Fig-4.1 ;Schematic diagram showing cable with screen and guard ring.

4.2.2 CONNECTIONS AND GROUNDING:

The low voltage terminal of the specimen (the sheath for core to sheath measurements; and one of the cores for core to core measurements)was connected to the SPECIMEN terminal of the bridge with a shielded wire, the shield at the bridge ends was connected to a GR terminal next to the SPECIMEN terminal and the other end of the shield (at the specimen) was connected to the guard rings.

The low-voltage terminal of the standard air-capacitor is next connected to the SPECIMEN terminal. This is done with a shielded wire, in the manner similar to that in the case of specimen.

The high-voltage terminal of the specimen (any ofthe cores; each is marked separately for identification) is next connected to the secondary of the high voltage transformer. This is done with a shielded wire; the shield at the transformer end is connected to ground, while that at the specimen end connected to the guard rings.

The high-voltage terminal of the standard capacitor is next connected to the secondary of the high-voltage transformer. This is done with a shielded wire with the shield at the transformer end connected to ground and that at the capacitor end connected to terminal 2 on the capacitor.

The ground connections for the shields at the transformer end, and the grounding of the transformer, are all taken to the same point.

The amplifier is next connected to the bridge at points marked DET. The shield of this connecting wire is connected to the GR terminal adjacent to the DET points.

An Oscilloscope, connected to the output of the amplifier, is used as the null detector.

Before making measurements, the bridge has to be balanced, for residual capacitance in the manner indicated in chap. 2. (The details of the procedure of making measurements is to be found in the bridge manual[8].)

4.3 MEASUREMENTS AND DATA:

The oil-impregnated paper insulation-PILC cable-was studied under varying conditions : at first, the dissipation factor and capacit for voltage upto 25KV. Then, the dielectric was stressed for different voltages——about four to four and a half times the working voltage—, and different durations——at times for 2 to 3 hrs, and at times for a few minites. All those have been elaborately given in the data.

The insulation between core (11) and sheath was made to breakdown by stressing the insulation for a long period. Cumulative heating and discharges lead to the rupture.

It may be mentioned, that attempts to take data at still higher voltages failed becuuse discharges started taking place at the terminal of the high-voltage transformer (and/or within the shielded cables from the transformer to the standard air capacitor and the specimen). Evidently, these discharges would affect the true dissipation factor of the specimen.

DATA FOR THE BEHAVIOUR OF OIL-IMPREGNATED PAPER INSULATION BETWEEN ONE CORE(CORE I) AND SHEATH UNDER STRESS.

TABLE-2. [T(2)]

DATA TAKEN UNDER NORMALCONDITIONS,WITHOUT ANY PREVIOUS STRESSING OF THE INSULATION.

APPLIED VOLTAGE, KV	R_3, Ohms	tan δ =C_4 mF	SPECIMEN CAPACITANCE, mmF	[illegible]
6.00	600.00	0.001	531.333	
7.00	598.50	.0025	532.665	
8.00	597.00	.0040	534.003	
10.	596.00	.0070	534.899	
11	595.20	.0074	535.618	
12	593.00	.0101	537.605	
13	590.00	.0120	540.339	
14	590.60	.014	539.790	
15	587.55	0.0170	542.592	
16	586.40	0.0190	543.656	
17	585.64	0.020	544.362	
18	583.39	0.023	546.461	

TABLE-3. [T(3)] b 37

THE INSULATION BEEN CORE I AND SHEATH, HAS BEEN STRESSED (IMMEDIATELY AFTER STRESSING) AT 50 KV (R.MS)FOR A FEW MINUTES.

APPLIED VOLTAGE, KV	R_3, ohms	tan δ = C_4, mF	SPECIMEN CAPACITANCE mmF	REMARKS
3.00	609.00	.0129	523.48	
5.00	608.80	.0128	523.65	
8.00	608.30	.0126	524.08	
9.00	608.30	.0147	524.08	
10.00	606.20	.0169	525.90	
11.00	579.1	.0270	550.51	
12.30	580.0	.0337	549.66	
14.00	579.00	.0370	550.74	
15.00	577.00	.0420	552.51	

TABLE-4. [T(4)]

READINGS TAKEN 20 HOURS AFTER THE ABOVE SET.

APPLIED VOLTAGE, KV.	R_3, ohms	tan δ = C_4, mF	SPECIMEN CAPACITANCE, mmF	[illegible]
8.00	639	.0026	498.90	
9.00	635.3	.0048	501.81	
10.00	632	.0087	504.43	
11.00	627	.0125	508.45	
12.00	623	.0164	511.72	
13.00	620	.0190	514.19	
14.00	616	.0214	517.53	
15.00	614.0	.0254	519.22	
16.00	611.0	.0285	521.77	

TABLE-5. [T(5)]

READINGS TAKEN 45 HOURS AFTER STRESSING THE INSULATION BETWEEN CORE I AND SHEATH.

APPLIED VOLTAGE, KV.	R_3, Ohms.	tan δ = C_4, mF	SPECIMEN CAPACITANCE, Mmf.	REMARKS
5.00	660	483.05	483.05	
9.00	~~66~~ 636.5	.0062	500.86	
10.00	633.4	.0075	503.32	
11.00	628.0	.0124	507.64	
12.00	625.0	.0145	510.08	
13.00	621.5	.0165	512.95	
14.00	616.3	.0195	517.28	
15.0	615.1	.0216	518.19	

TADLE-6. [T(6)]

THE INSULATION BETWEEN CORE-I AND SHEATH HAS BEEN STRESSED AT 45 KV FOR HALF HOUR.

APPLIED VOLTAGE, KV.	R_3, Ohms	Tan δ = C_4, mF	SPECIMEN CAPACITANCE, mmF.	REMARKS
7.00	646.8	.0019	492.8	
8.00	640.1	.0054	498.05	
9.00	635.4	.0084	501.75	
10.00	632	.0105	504.45	
11.00	629.0	.0143	508.45	
12.00	621.5	.0190	512.05	
13.00	617.4	.0217	516.36	
14.00	614	.0241	519.22	
15.00	611.	.0260	521.77	
16.00	608	.0290	524.34	

TABLE-7. [T(7)]

DATA TAKEN AFTER APPLYING 35 KV FOR TWO AND HALF HOURS BETWEEN CORE I AND SHEATH.

APPLIED VOLTAGE, KV.	R_3, Ohms	tan δ = C_4, mF.	SPECIMEN CAPACITANCE, mmf	REMARKS
7.0	644.5	.0038	494.65	
8.0	638.2	.0057	499.53	
9.0	633.9	.0110	503.47	
10.0	631.4	.0132	504.91	
11.00	627.0	.0176	508.45	
12.00	621.7	.0214	512.79	
13.00	619.0	.0246	515.02	
14.0	614.6	.0278	518.71	
15.0	611.0	.0293	521.77	
16.0	608.4	.0306	524	

TABLE-8. [T(8)]

READINGS TAKEN 45 HOURS. AFTER THE PREVIOUS SET.

APPLIED VOLTAGE, KV.	R_3, Ohms	tan δ = C_4, mfd.	SPECIMEN CAPACITANCE, mmF.	REMARKS
8.00	637.7	.0079	499.92	
10.00	631.7	.0125	504.67	
11.50	625.5	.0171	509.67	
13.00	621.0	.020	513.37	
14.50	616.4	.0243	517.20	
16.00	611.0	.0278	521.77	
17.00	607.5	.0304	524.77	

TABLE-9 [T(9)]

DATA TAKEN IMMEDIATELY AFTER APPLYING 41 KV(RMS) FOR 3 HOURS BETWEEN CORE I AND SHEATH.

APPLIED VOLTAGE, KV.	R, Ohms	tan δ = C_4, mf.	SPECIMEN CAPACITANCE, mmf.	REMARKS
7.00	648.7	.0064	491.44	
8.00	641	.0113	497.35	
9.00	633	.0175	503.63	
10.00	629	.022	506.84	
11.50	620.7	.0274	513.61	
13.0	610.4	.0320	522.28	
14.5	607.0	.0350	525.21	
16.0	602.0	.0362	529.57	
17.5	598.8	.0373	532.40	

TABLE-10. [T(10)]

MEASUREMENTS TAKEN AFTER STRESSING THE INSULATION BETWEEN CORE II AND SHEATH AT 45 KV FOR 2 HOURS. STRESSED ON 21.10.76 DATA TAKEN ON 26.10.76.

APPLIED VOLTAGE, KV.	R_{δ}, Ohms	tan δ = C_4, mf	SPECIMEN CAPACITANCE, mmf.	REMARKS
2.50	645.0	.0346	492.26	
3.00	642.0	.0327	496.57	
5.00	662.3	.0284	481.35	
6.00	670.0	.0264	475.82	
7.00	676.4	.025	471.32	
8.00	680.3	.023	468.62	
9.50	683.6	.0227	466.35	
11.00	683.2	.0279	467.51	
12.50	683.0	.031	466.76	
14.00	682.0	.033	467.42	
15.50	680.0	.0345	468.82	
17.00	677.3	.0355	470.69	

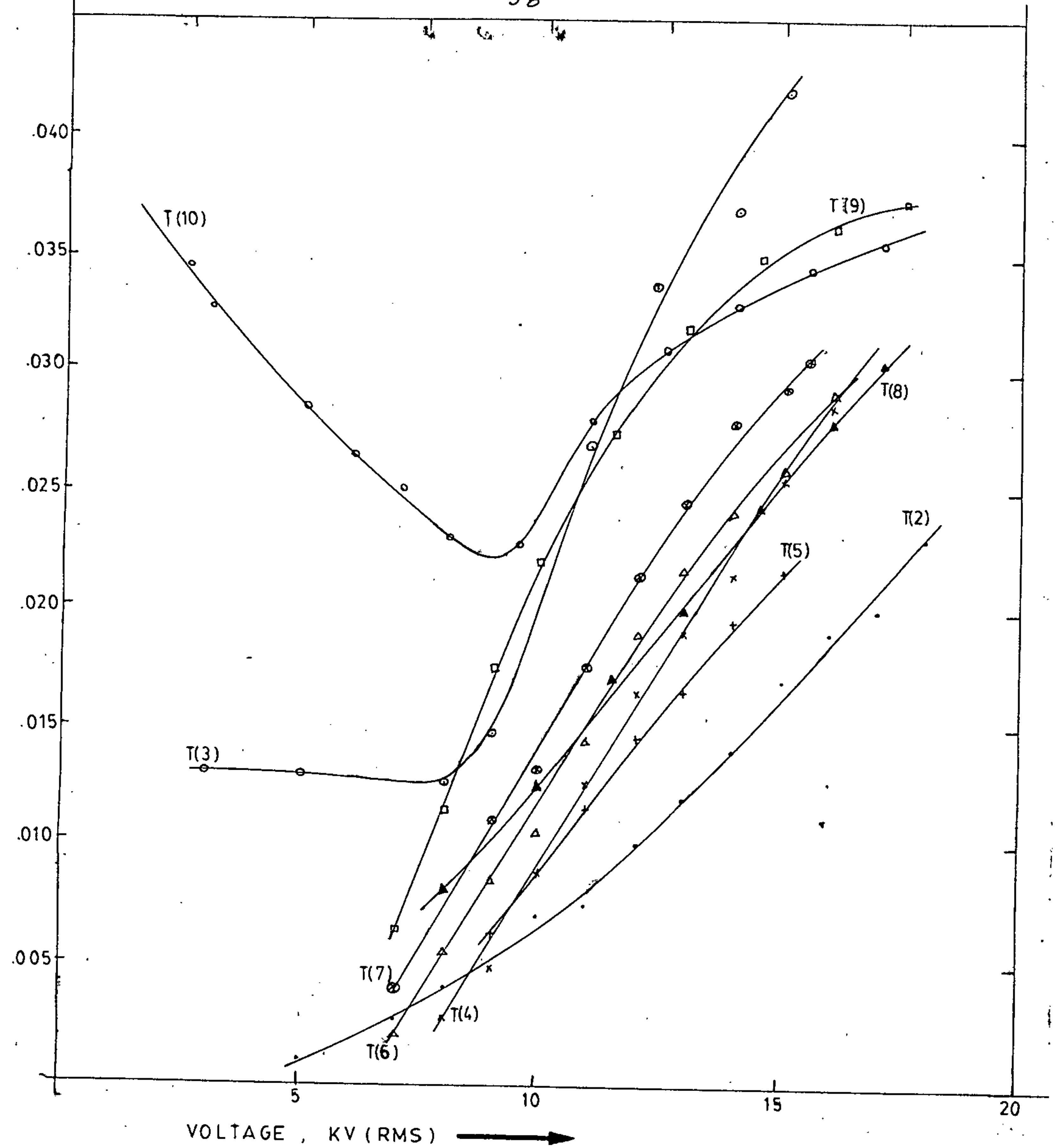


FIG.4.2.a. VARIATION OF DISSIPATION FACTOR WITH VOLTAGE FOR CORE I AND SHEATH INSULATION, UNDER DIFFERING CONDITION

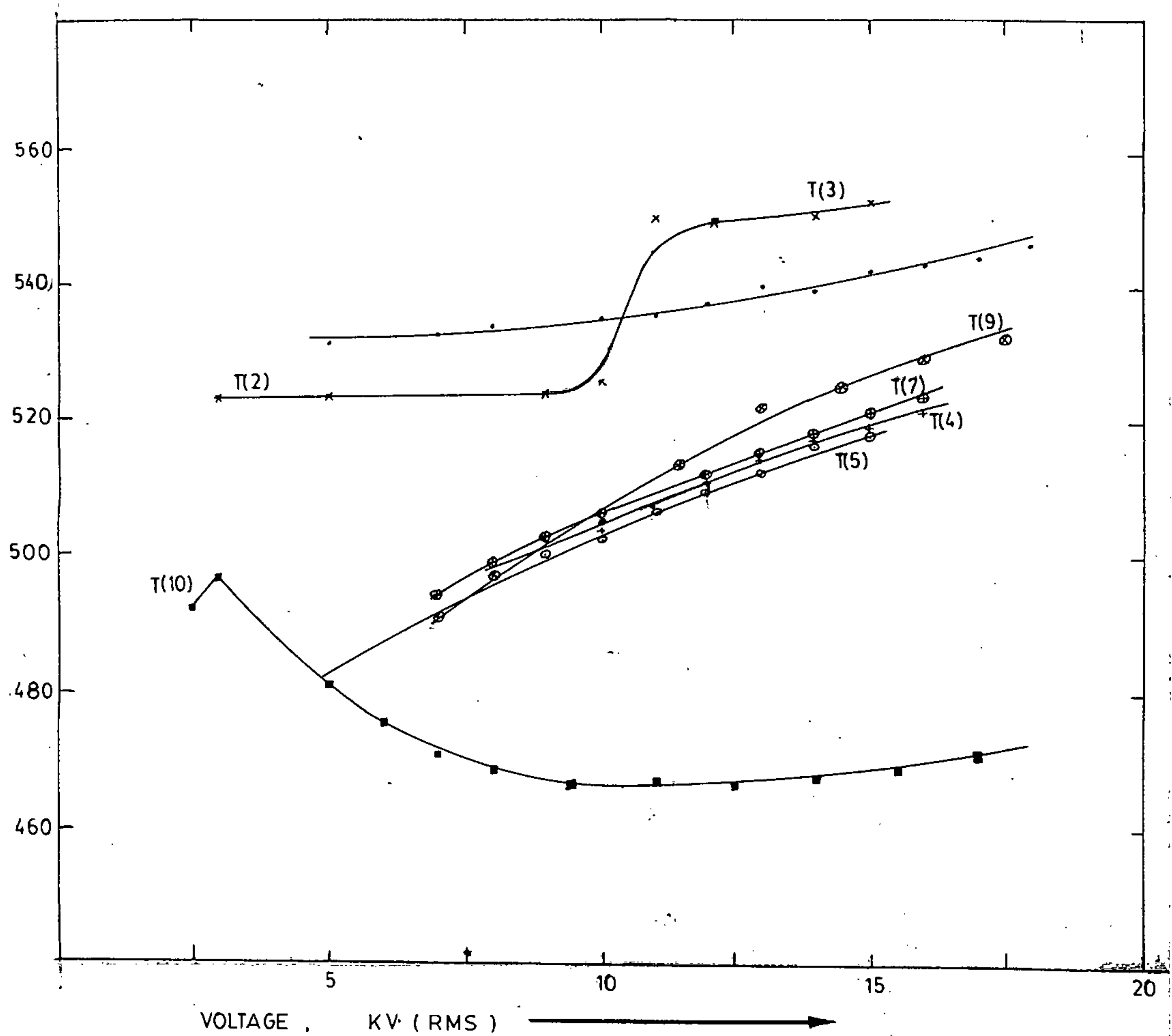


FIG.4.2.b. VARIATION OF CAPACITANCE WITH VOLTAGE FOR INSULATION BETWEEN CORE I AND SHEATH

DATA FOR INSULATION BETWEEN CORE II AND SHEATH TAKEN UNDER DIFFERING CONDITIONS.

TABLE-11 [T(11)]

READINGS ARE TAKEN TO INVESTIGATE INTO THE DIELECTRIC BEHAVIOR AT DIFFERENT VOLTAGES. THE DATA IS FOR THE INSULATION BETWEEN ONE CORE(CORE II) AND SHEATH.

APPLIED VOLTAGE, KV.	R_3, Ohms	tan δ = C_4, mf.	SPECIMEN CAPACITANCE, $C_2 = C_1 \frac{R_4}{R_3}$ (mmf) C_1 = 100 mmf.
3.10	634.3	0.0012	502.601
5.00	634.3	0.00125	502.601
6.00	634.2	0.00125	502.681
7.00	634.2	0.00130	502.681
8.00	631.7	0.00180	504.669
10.00	630.0	0.0061	506.032
11.00	629.3	0.00775	506.595
12.00	627.6	0.0110	507.967
13.00	625.6	0.0129	509.591
14.00	622.4	0.0152	512.211
15.00	620.00	0.0180	514.194
16.00	619.00	0.0190	515.024
17.00	618.5	0.0214	515.441
18.00	616.6	0.0220	517.029
19.00	614.7	0.0255	518.458
20.00	612.6	0.0267	520.405
21.00	610.0	0.0290	522.623
22.00	606.4	0.0303	525.726
23.00	604.0	0.0310	527.815
24.00	602.0	0.0320	529.568
25.00	600.08	0.0330	531.333

TABLE-12. [T(12)]

DATA TAKEN AFTER THE INSULATION BETWEEN CORE II AND SHEATH HAS BEEN STRESSED AT 50 KV (RMS) FOR A FEW MINUTES.

APPLIED VOLTAGE, KV.	R_3, Ohms.	tan δ = C_4, mf	SPECIMEN CAPACITANCE, mmf.
3.00	593	.016	538
5.00	593	.016	538
7.00	592	.017	540
10.00	588	.022	543
11.00	586	.026	546
12.00	580	.031	551
13.00	577	.036	554
14.00	574	.040	557
15.00	570	.046	563
16.00	566	.058	570

TABLE-13. [T(13)]

DATA TAKEN 20 HRS AFTER STRESSING THE INSULATION BETWEEN CORE II AND SHEATH AT 50 KV (RMS) FOR A FEW MINUTES.

APPLIED VOLTAGE, KV.	R_3 , Ohms.	tan δ = C_4, mf.	SPECIMEN CAPACITANCE, mmf.
2.00	591	.0185	539.42
3.00	590.8	.0195	539.61
5.00	590.5	.0202	539.88
6.00	590.1	.0201	540.25
7.00	591.0	.0202	539.42
9.00	589.7	.0214	540.61
10.00	588.9	.0227	541.35
11.00	589	.0246	541.26
12.50	580	.0268	549.66
14.00	578	.0314	551.56
15.00	575	.0372	554.43
16.00	570	.041	559.30

T.58

TABLE-14. [T(14)]

DATA TAKEN AFTER STRESSING THE INSULATION BETWEEN CORE II AND SHEATH AT 41 KV (RMS) FOR THREE HOURS.

APPLIED VOLTAGE KV.	R_3, Ohms.	tan δ = C_4, mF.	SPECIMEN CAPACITANCE, mmF.
7.00	636.8	.0016	500.63
8.00	630.9	.0043	505.31
9.00	626.3	.0083	509.02
10.00	624.0	.0094	510.90
11.00	620.8	.0124	513.53
12.00	617.3	.0143	516.44
13.00	614.6	.0166	518.71
14.00	610.0	.0190	522.62
15.00	607.0	.0234	525.21
16.00	604.1	.0266	527.33
17.00	601.3	.0291	530.18

TABLE-15. [T(15)]

DATA TAKEN 45 HRS AFTER STRESSING THE INSULATION BETWEEN CORE II AND SHEATH AT 41 KV(RMS) FOR THREE HOURS.

APPLIED VOLTAGE KV.	R_3, Ohms	tan δ = C_4, mF.	SPECIMEN CAPACITANCE mmF.
9.00	632	0066	504.43
10.5	626.4	0113	508.94
12.0	621.2	0148	513.20
13.5	616.4	0182	517.20
15.0	611.6	0217	521.26
16.5	607.0	0253	525.21

TABLE-16. [T(16)]

READINGS TAKEN IMMEDIATELY AFTER STRESSING INSULATION BETWEEN CORE I AND SHEATH AT 41 KV (RMS) FOR 3 HRS.

APPLIED VOLTAGE KV.	R_3, Ohms	tan δ = C_4, mF.	SPECIMEN CAPACITANCE mmF.
8.0	621.5	.0087	512.95
10.2	614.1	.0125	519.13
12.0	606.0	.0172	526.07
13.5	600.0	.0226	531.33
15.0	595.1	.0258	535.71
16.0	591.5	.0281	538.97
17.00	587.6	.0300	542.55

TABLE-17. [T(17)]

MEASUREMENTS TAKEN IMMEDIATELY AFTER APPLYING 45 KV (RMS) FOR 2 HRS ACROSS INSULATION BETWEEN CORE II AND SHEATH.

APPLIED VOLTAGE KV.	R_3, Ohms	tan δ = C_4, mF.	SPECIMEN CAPCACITANCE mmF.
8.00	639.6	.0103	498.44
10.00	631.2	.0152	505.07
11	624.6	.0197	510.41
12	618.5	.0270	515.44
13	614.4	.0300	518.88
14	611.3	.0332	521.51
15.5	603.3	.0342	528.43
17.00	598.1	.0350	533.02

TABLE-18. [T(18)]

READINGS OBTAINED 20 HOURS AFTER STRESSING CORE II - SHEATH INSULATION AT 45 KV FOR TWO HOURS.

APPLIED VOLTAGE KV	R_3, Ohms.	tan δ = C_4. mF.	SPECIMEN CAPACTIANCE mmF.
10.00	631.6	.010	504.75
11.00	627	.0135	508.45
12.50	619.3	.0185	514.77
14.00	612.0	.0255	520.92
15.5	606.5	.0301	525.64
17.0	601.3	.0325	530.18

TABLE-19. [T(19)]

DATA TAKEN FIVE DAYS AFTER BREAKDOWN OF THE INSULATION BETWEEN CORE(II) AND SHEATH.

APPLIED VOLTAGE KV.	R_3, Ohms.	tan δ = C_4. mF.	SPECIMEN CAPACITANCE mmF.
3	542.6	.0346	582.54
5	562.6	.030	566.65
6.5	569.0	.0241	560.28
8.0	577.0	.0210	562.26
9.5	579.0	.0225	550.60
11.0	582.5	.0257	547.30
12.5	580	.0278	549.66
14.0	579	.030	550.60

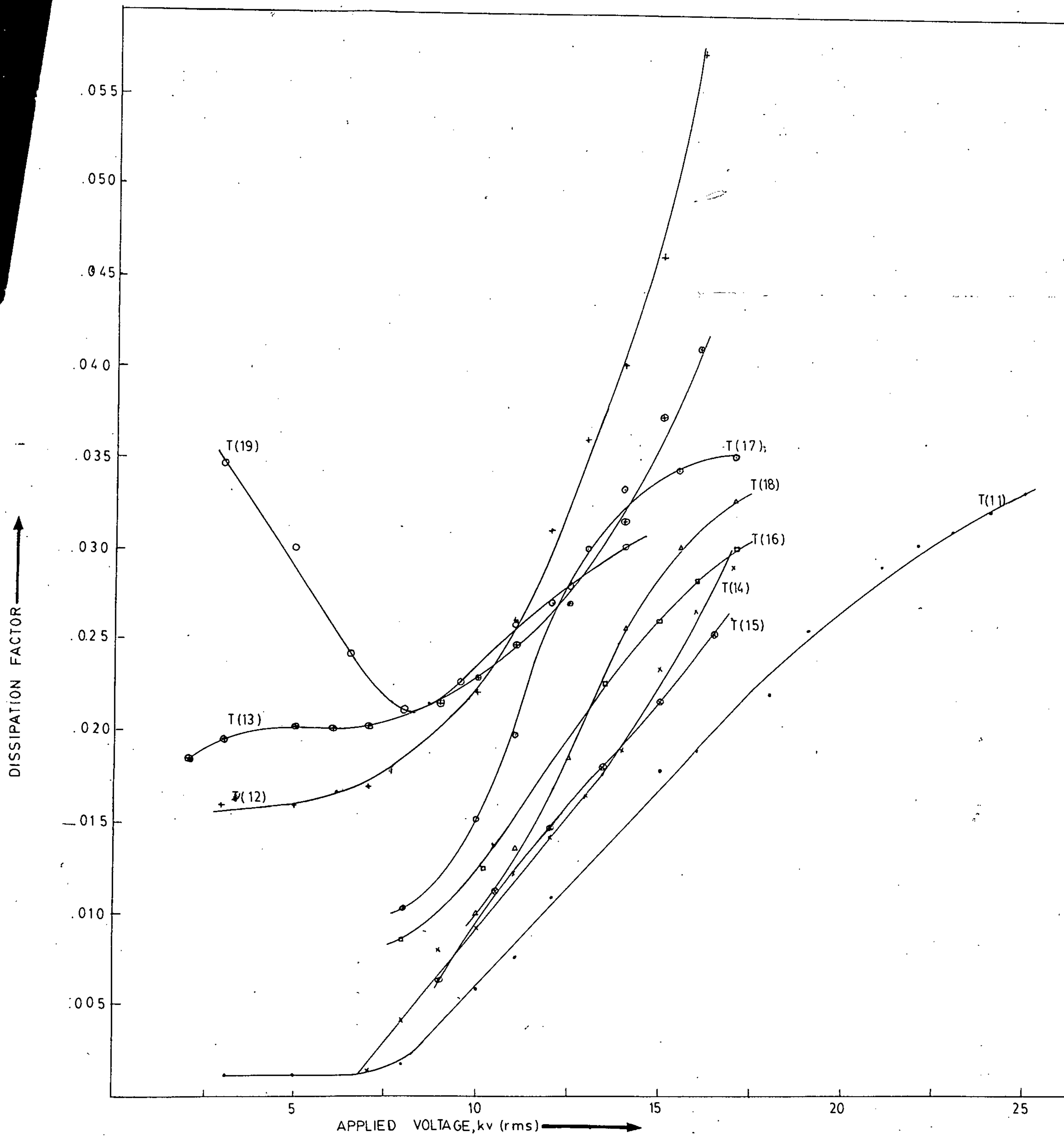


FIG.4.3.a THE VARIATION OF DISSIPATION FACTOR WITH VOLTAGE FOR THE INSULATION BETWEEN CORE II AND SHEATH UNDER DIFFERENT CONDITIONS.

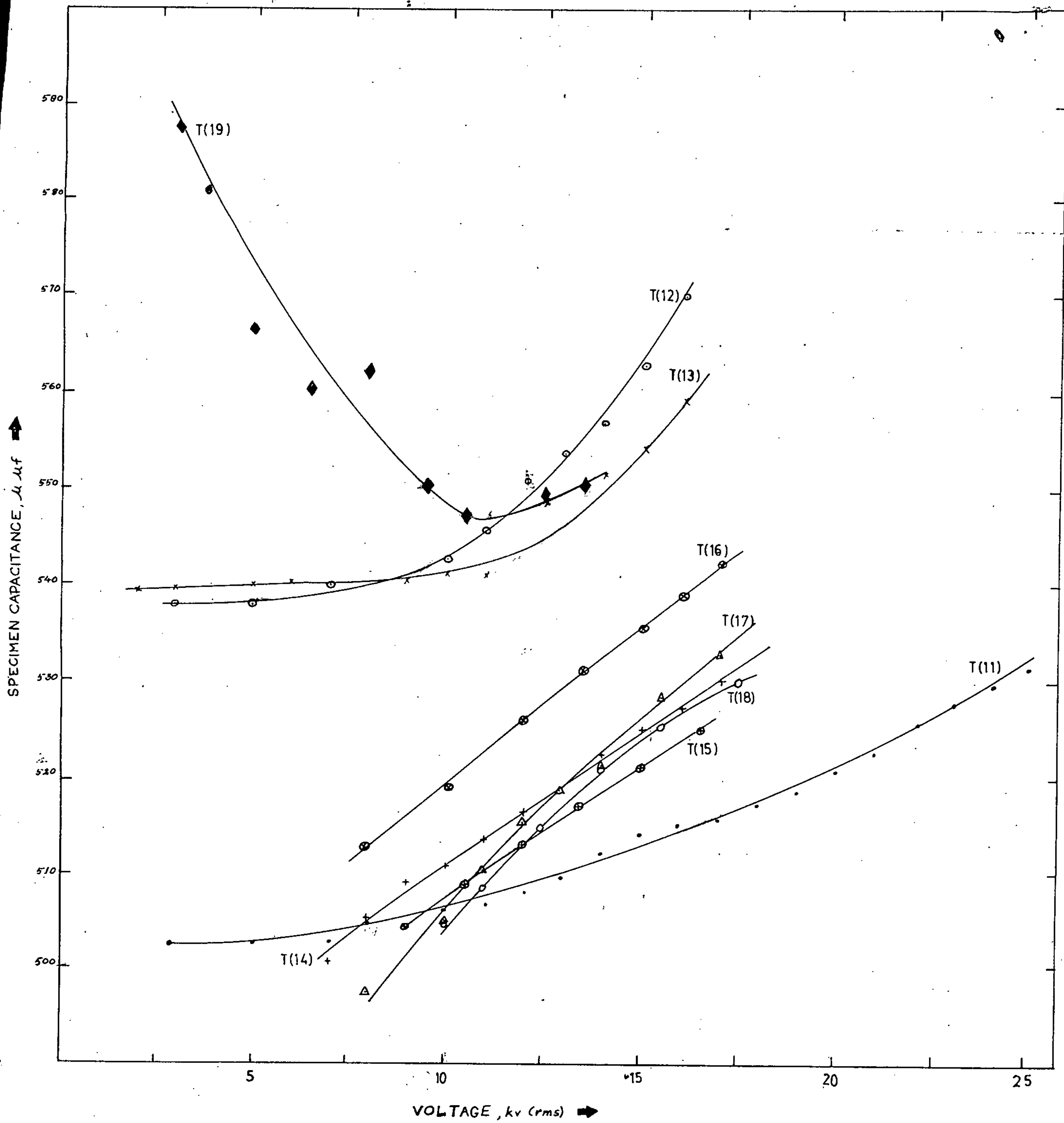


FIG. 4.3.b. VARIATION OF CAPACITANCE WITH VOLTAGE FOR INSULATION BETWEEN CORE II AND SHEATH

DATA TAKEN FOR THE INSULATION BETWEEN CORE-III AND SHEATH.

TABLE-20. [T(20)]

DATA TAKEN AFTER STRESSING THE INSULATION BETWEEN CORE II AND SHEATH AT 41 KV (RMS) FOR 3 HOURS.

APPLIED VOLTAGE KV.	R_3' Ohms.	tan δ = C_4. mF.	SPECIMEN CAPACITANCE mmF.
8.00	620.3	.0035	514.94
9.00	615.4	.0076	518.04
10.00	612.4	.0098	520.57
11.00	608.2	.0134	524.17
12.00	603.6	.0150	528.16
13.00	601.3	.0182	530.18
14.00	598	.0210	533.11
15.00	595	.0230	535.80
16.00	592	.0253	538.51

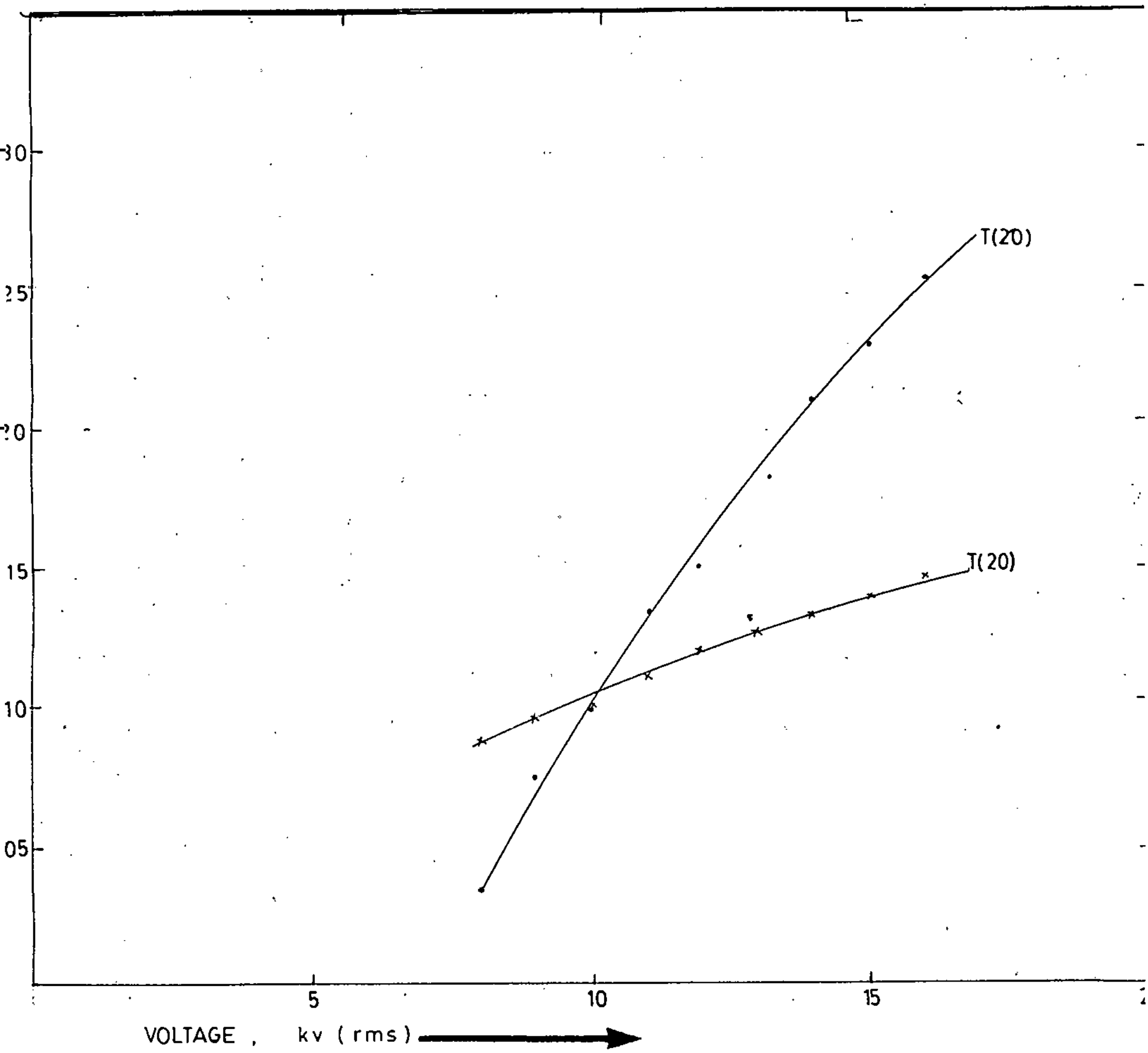


FIG. 4.4. THE VARIATION OF DISSIPATION FACTOR AND CAPACITANCE WITH VOLTAGE FOR INSULATION BETWEEN CORE III AND SHEATH.

DATA FOR INSULATION BETWEEN CORE-I AND II,

TAKEN UNDER DIFFERENT CONDITIONS.

TABLE-21. [T(21)]

DATA TKEN 20 HRS. AFTER STRESSING THE INSULATION BETWEEN CORE I AND SHEATH FOR A FEW MINUTES AT 50 KV(RMS).

APPLIED VOLTAGE KV.	R_3, Ohms.	Tan δ= C_4, mF.	SPECIMEN CAPACITANCE mmF.
9.0	2121.5	.0001	150.27
10.0	2118.0	.0009	150.52
11.0	2111.0	.0033	151.02
12.0	2099.0	.0090	151.88
13.0	2086.0	.0112	152.83
14.0	2075.0	.0154	153.64
15.0	2066.0	.0183	154.31
16.0	2058.0	0.0198	154.91

TABLE-22. [T(22)]

READINGS TAKEN 45 HRS AFTER STRESSING THE INSULATION BETWEEN CORE I AND SHEATH AT 50 KV FOR A FEW MINUTES.

APPLIED VOLTAGE KV.	R_3, Ohms.	tan δ= C_4, mF.	SPECIMEN CAPACITANCE, mmF.
3.0	2113		149.46
7.0	2112.0		150.95
10.0	2094.4	.0011	152.22
11.0	2085.5	.0054	152.87
12.0	2073.0	.0102	153.79
13.0	2054.0	.0120	155.21
14.0	2045.0	.0150	155.89
15.0	2042.0	.0200	156.12

TABLE-23. [T(23)]

DATA TAKEN A FEW MINUTES AFTER APPLYING 45 KV FOR $1/_2$ HRS BETWEEN CORE I AND SHEATH.

APPLIED VOLTAGE KV.	R_3, Ohms	tan δ = C_4, mF.	SPECIMEN CAPACITANCE, mmF.
7.00	2134		149.39
8.0	2129	.00025	149.74
9.0	2123	.00080	150.16
10.0	2113.9	.0032	150.81
11.0	2100.0	.0083	151.81
12.0	2092.5	.0112	152.39
13.0	2077.0	.0153	153.49
14.0	2068.0	.0187	154.16
15.0	2060	.0204	154.76
16.0	2050	.0210	155.51

TABLE-24. [T(24)]

DATA TAKEN 48 HOURS AFTER STRESSING AT 45 KV FOR 1/2 HOUR, THE INSULATIONS BETWEEN CORE-I AND SHEATH.

APPLIED VOLTAGE KV.	R_3, Ohms	tan δ = C_4, mF.	SPECIMEN CAPACITANCE, mmF.
8.0	2121	.0011	150.31
10.0	2112	.0034	150.93
11.0	2107	.0069	151.31
12.0	2093	.0112	152.32
13.0	2087	.0136	152.76
14.0	2069	.0165	154.08
15.0	2062	.0189	154.61
16.0	2056	.0210	155.06
17.0	2047	.0235	155.74

TABLE-25. [T(25)]

DATA TAKEN AFTER APPLYING 35 KV FOR $2^1/_2$ HRS.

BETWEEN CORE II AND SHEATH.

APPLIED VOLTAGE KV.	R_3, Ohms.	tan δ = C_4, mF.	SPECIMEN CAPACITANCE, mmf.
8.0	2178.5	.0005	146.34
9.0	2164.0	.0049	147.32
10.0	2157.3	.0076	147.78
11.0	2138.3	.0131	149.09
12.0	2126.0	.0164	149.95
13.0	2121.5	.0188	150.27
14.0	2105	.0214	151.45
15.0	2096	.0228	152.10
16.0	2087	.0246	152.76
17.0	2081	.0254	153.20

TABLE-26. [T(26)]

DATA TAKEN 48 HOURS AFTER STRESSING THE INSULATION BETWEEN CORE II AND SHEATH AT 35 KV FOR 2½ HRS.

APPLIED VOLTAGE KV.	R_3, Ohms.	Tan δ = C_4, mF.	SPECIMEN CAPACITANCE, mmF.
11.0	2135.1	0044	149.31
12.7	2110.9	0089	151.03
14.0	2098.9	0145	151.89
15.5	2058.8	0180	152.84
17.0	2079.0	0220	153.34

TABLE-27. [T(27)]

DATA TAKEN A FEW MINUTES AFTER APPLYING 41 KV BETWEEN CORE I AND SHEATH FOR 3 HRS.

APPLIED VOLTAGE KV.	R_3, Ohms.	Tan δ = C_4, mF	SPECIMEN CAPACITANCE, MmF.
10.0	2175	.0075	146.57
11.5	2147	.014	148.49
13.0	2126	.017	149.95
14.5	2110	.020	151.09
16.0	2100	.0215	151.81
17.0	2087	.0230	152.76

TABLE-28. [T(26)]

READINGS TAKEN IMMEDIATELY AFTER APPLYING 45 KV FOR 2 HRS ACROSS CORE II AND SHEATH.

APPLIED VOLTAGE KV.	R_3, Ohms	Tan δ = C_4, m F	SPECIMEN CAPACITANCE, mmF.
9.00	2200	0080	144.91
10.00	2192	0095	145.44
11.30	2164	.0160	147.32
13.00	2137	.0237	149.18
14.00	2122	.0250	150.24
15.5	2103	.0280	151.59
17.0	2091	.030	152.46

TABLE-29. [T(29)]

READINGS TAKEN 24 HRS AFTER THE STRESSING THE INSULATION BETWEEN CORE II AND SHEATH AT 45 KV FOR 2 HOURS.

APPLIED VOLTAGE KV.	R_3, Ohms.	Tan δ = C_4, m.F.	SPECIMEN CAPACITANCE mmF.
9.50	2188	.0019	145.70
11.00	2174.5	.0050	146.61
12.50	2160	.0120	147.59
14.00	2135.0	.0165	149.32
15.5	2117.0	.0220	150.59
17.0	2097.0	.0233	152.03

TABLE-30. [T(30)]

DATA TAKEN FIVE DAYS AFTER THE BREAKDOWN OF THE INSULATION BETWEEN CORE II AND SHEATH.

APPLIED VOLTAGE KV.	R_3, Ohms	Tan δ = C_4, m.F.	SPECIMEN CAPACITANCE, mmF.
3.00	2058	.0068	154.91
4.50	2076.3	.00496	153.54
6.00	2093.7	.0032	152.27
7.00	2103.1	.0022	151.59
8.00	2112.3	.0015	150.93
9.50	2118.3	.0010	150.50
11.0	2114.3	.0083	150.78
12.5	2106.0	.0133	151.38
14.0	2089.7	.0186	152.56
15.5	2078.0	.0196	153.42
17.0	2067.7	.0203	154.18

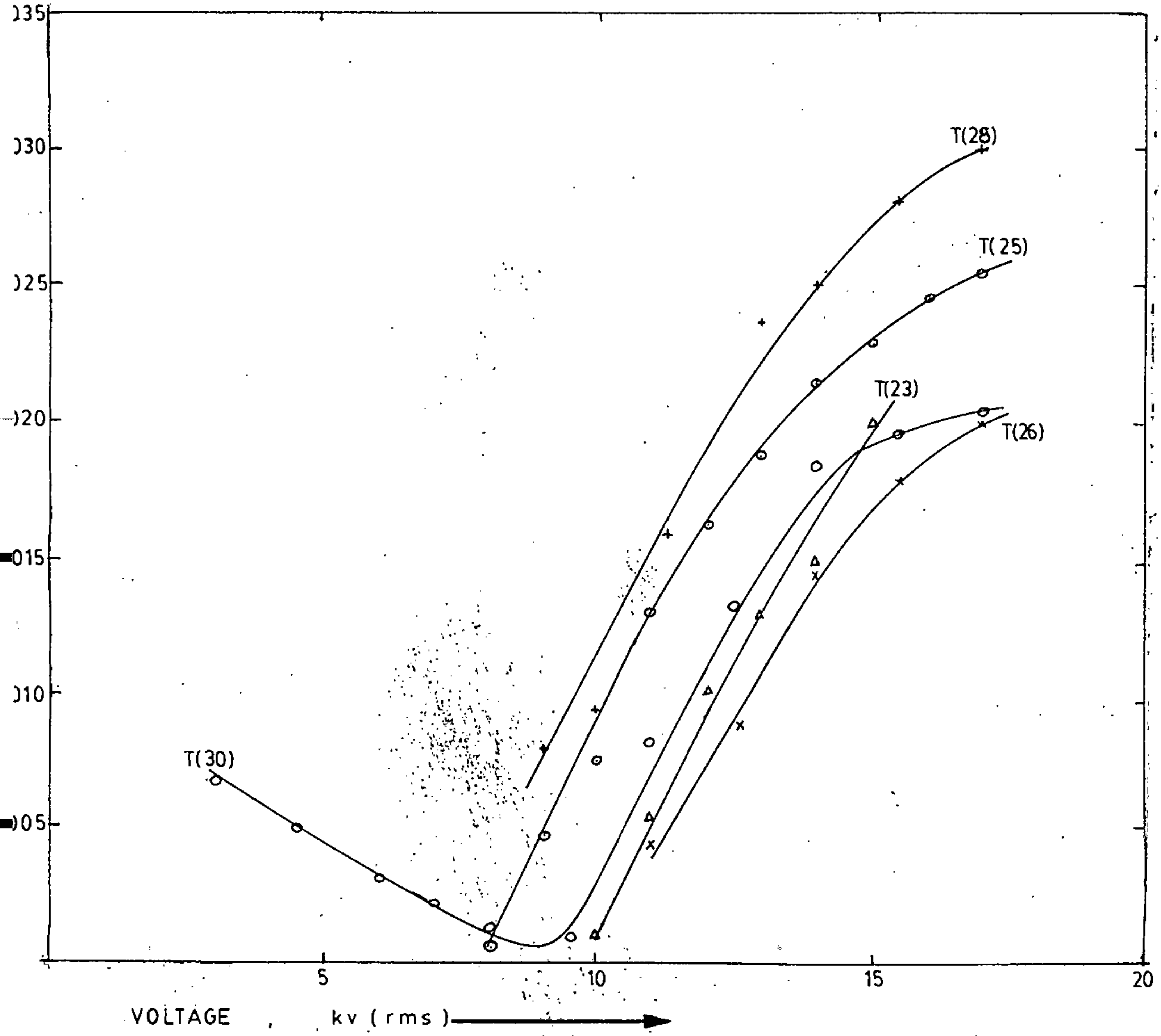


FIG. 4.5..a. VARIATION OF DISSIPATION FACTOR WITH VOLTAGE FOR INSULATION BETWEEN CORE I AND II, FOR DIFFERING CONDITIONS.

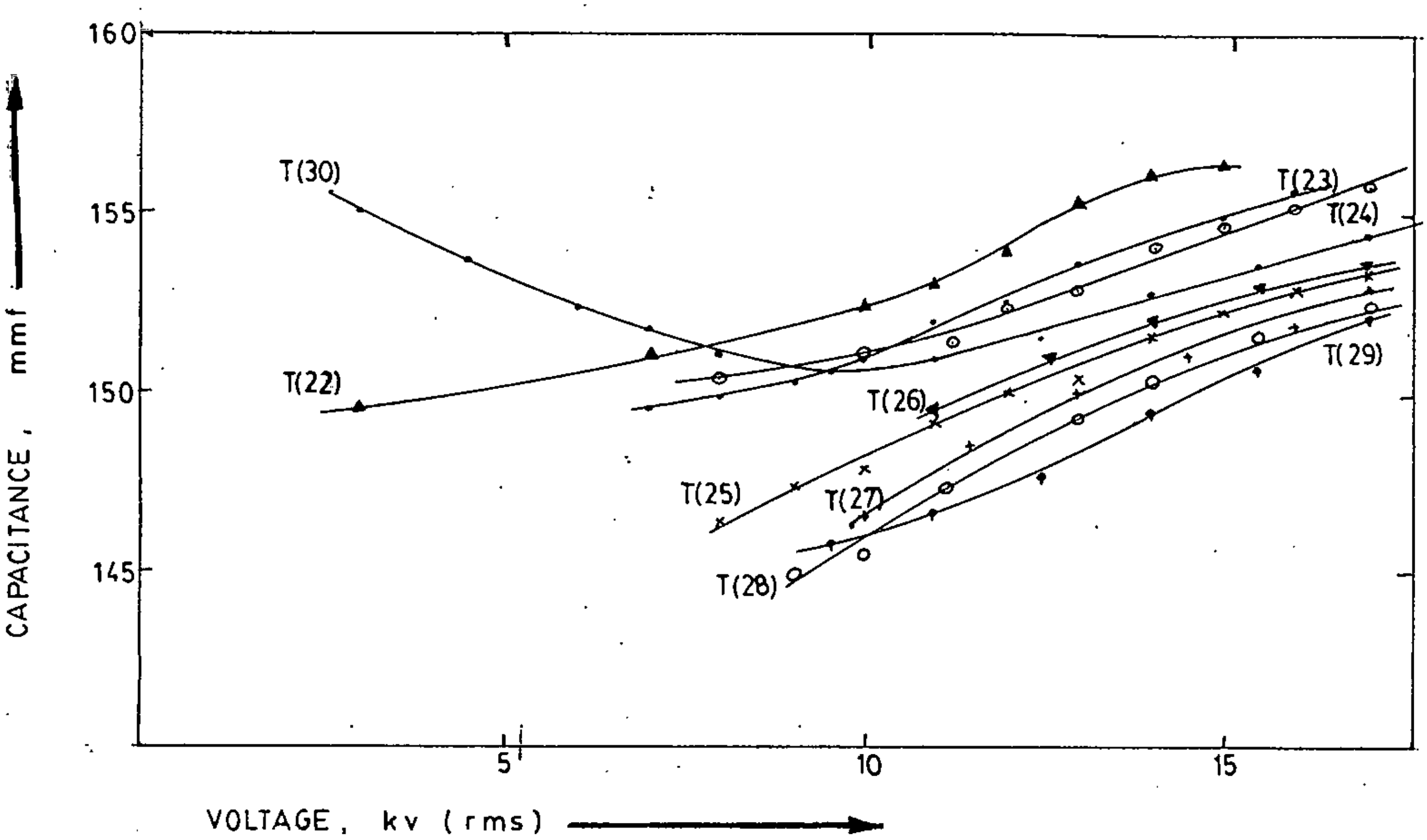


FIG. 4.5.b. THE VARIATION OF CAPACITANCE WITH VOLTAGE OF THE INSULATION BETWEEN CORE I AND II, UNDER DIFFERING CONDITION

DATA FOR THE INSULATION BETWEEN
CORE II AND III, TAKEN UNDER
DIFFERENT CONDITIONS.

TABLE-~~k~~ 31. [T(31)]

DATA TAKEN AFTER STRESSING THE INSULATION BETWEEN CORE II AND SHEATH AT 41 KV FOR 3 HRS.

APPLIED VOLTAGE, KV.	R_3, Ohms.	Tan δ = C_4, m F.	SPECIMEN CAPACITANCE, mmF.
8	2099.1	.0013	151.82
10.0	2089.4	.0028	152.58
11.0	2078.4	.0073	153.39
12.0	2073	.0110	153.79
13.0	2065	.0136	154.38
14.0	2054	.0163	155.21
15.0	2043	.0175	156.05
16.0	2035	.0198	156.66
17.0	2026	.0211	157.35

TABLE-32. [T(32)]

DATA TAKEN IMMEDIATELY AFTER APPLYING 35 KV FOR 2½ HRS BETWEEN CORE I AND SHEATH.

APPLIED VOLTAGE, KV.	R_3, Ohms.	Tan δ = C_4, m F.	SPECIMEN CAPACITANCE, mmF.
8.0	2145.8	.0008	148.38
9.5	2135.3	.0023	149.29
11.0	2123.1	.0051	150.16
12.5	2112.	0.0085	150.95
14.0	2100.0	0.0133	151.81
15.5	2085.0	.0187	152.90
17.0	2074.0	.0210	153.71

TABLE-33. [T(33)]

DATA OBTAINED IMMEDIATELY AFTER APPLYING 41 KV (RMS) BETWEEN CORE I AND SHEATH FOR 3 HRS.

APPLIED VOLTAGES, KV.	R_3, Ohms.	Tan δ = C_4, m F.	SPECIMEN CAPACITANCE, mmf.
9.00	2187.5	.0007	145.74
11.0	2163.1	.0017	147.38
13.00	2141	.0060	148.90
14.5	2126	.0100	149.85
16.0	2100	.0130	151.81
17.0	2090	.0140	152.94

TABLE-34. [T(34)]

MEASUREMENTS DONE IMMEDIATELY AFTER STRESSING THE INSULATION BETWEEN CORE II & SHEATH AT 45 KV FOR 2 HRS.

APPLIED VOLTAGE, KV.	R_3, Ohms.	Tan δ = C_4, m.F.	SPECIMEN CAPACITANCE, mmF.
8	2200	.0034	144.91
9	2187	.0065	145.77
10	2169	.0113	146.98
11	2161	.015	147.52
12	2141	.020	148.90
13	2134	.022	149.39
14.0	2115	.0253	150.73
15.5	2100	.0277	151.81
17.0	2084	.0295	152.98

TABLE-35. [T(35)]

READINGS OBTAINED 20 HRS. AFTER STRESSING THE INSULATION BETWEEN CORE II AND SHEATH AT 45 KV FOR 2 HOURS.

APPLIED VOLTAGE, KV.	R_3, Ohms.	Tan δ = C_4, m.F.	SPECIMEN CAPACITANCE, mmF.
10	2189	.0016	145.64
11	2182	.0023	146.10
12.5	2163	.015	147.39
14.0	2144	.0183	148.69
15.5	2128	.023	149.81
17.0	2095	.0250	152.17

TABLE-36. [T(36)]

DATA TAKEN FIVE DAYS AFTER THE BREAKDOWN OF THE INSULATION BETWEEN CORE II AND SHEATH.

APPLIED VOLTAGE, KV.	R_3, Ohms.	Tan δ = C_4, m.F.	SPECIMEN CAPACITANCE, mmF.
3.0	2049	.0079	155.59
5.0	2082.5	.0041	153.09
6.5	2103.9	.0024	151.53
8.0	2118.1	.0009	150.51
9.5	2123.1	.0008	150.16
11.0	2120	.0074	150.38
12.5	2109	.012	151.16
14.0	2104	.0155	151.52
15.0	2094	.0175	152.24
17.00	2072	.0193	153.85

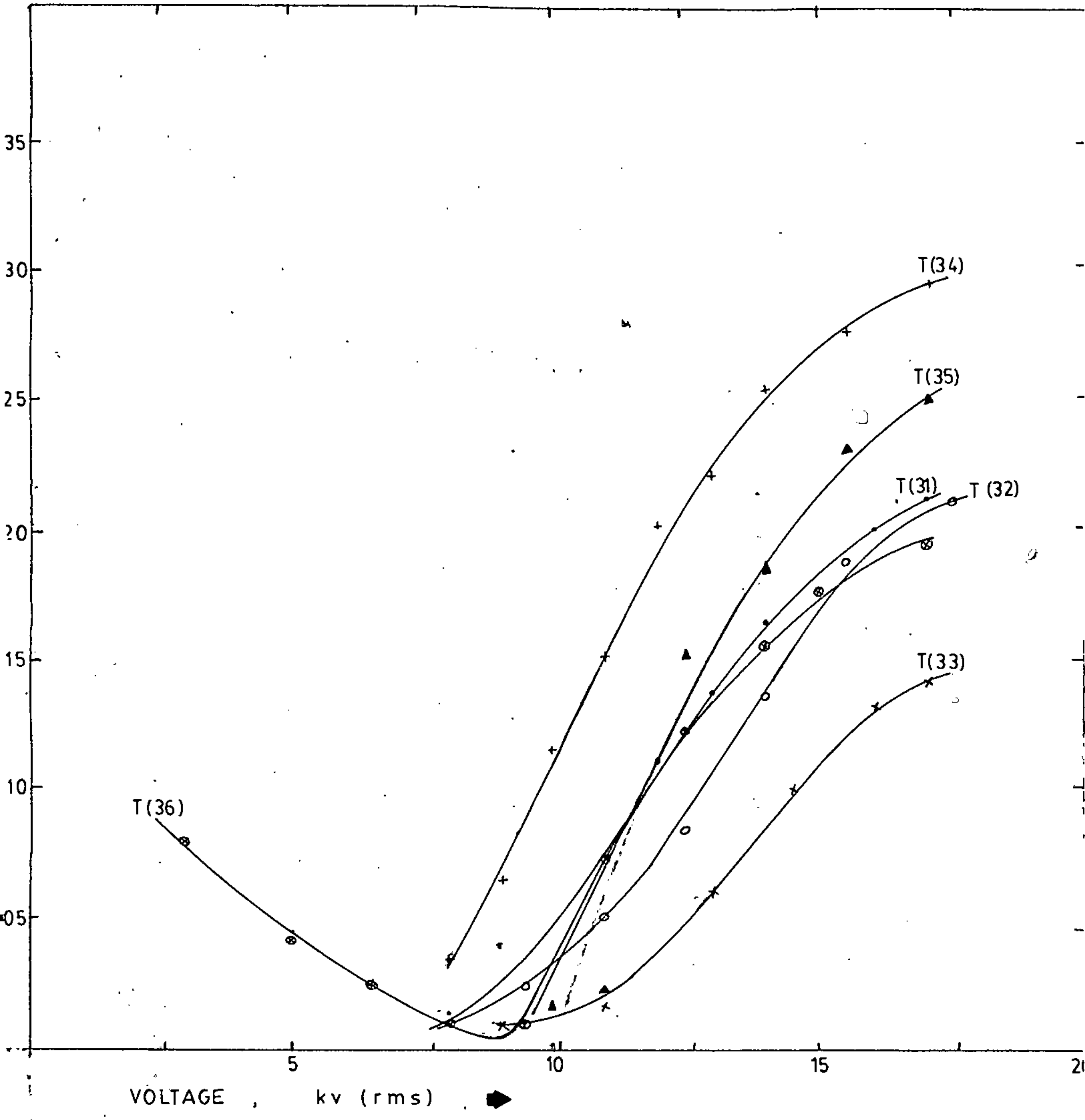


FIG. 4.6.a. VARIATION OF THE DISSIPATION FACTOR WITH VOLTAGE FOR THE INSULATIO BETWEEN CORES II AND III , FOR DIFFERING CONDITION.

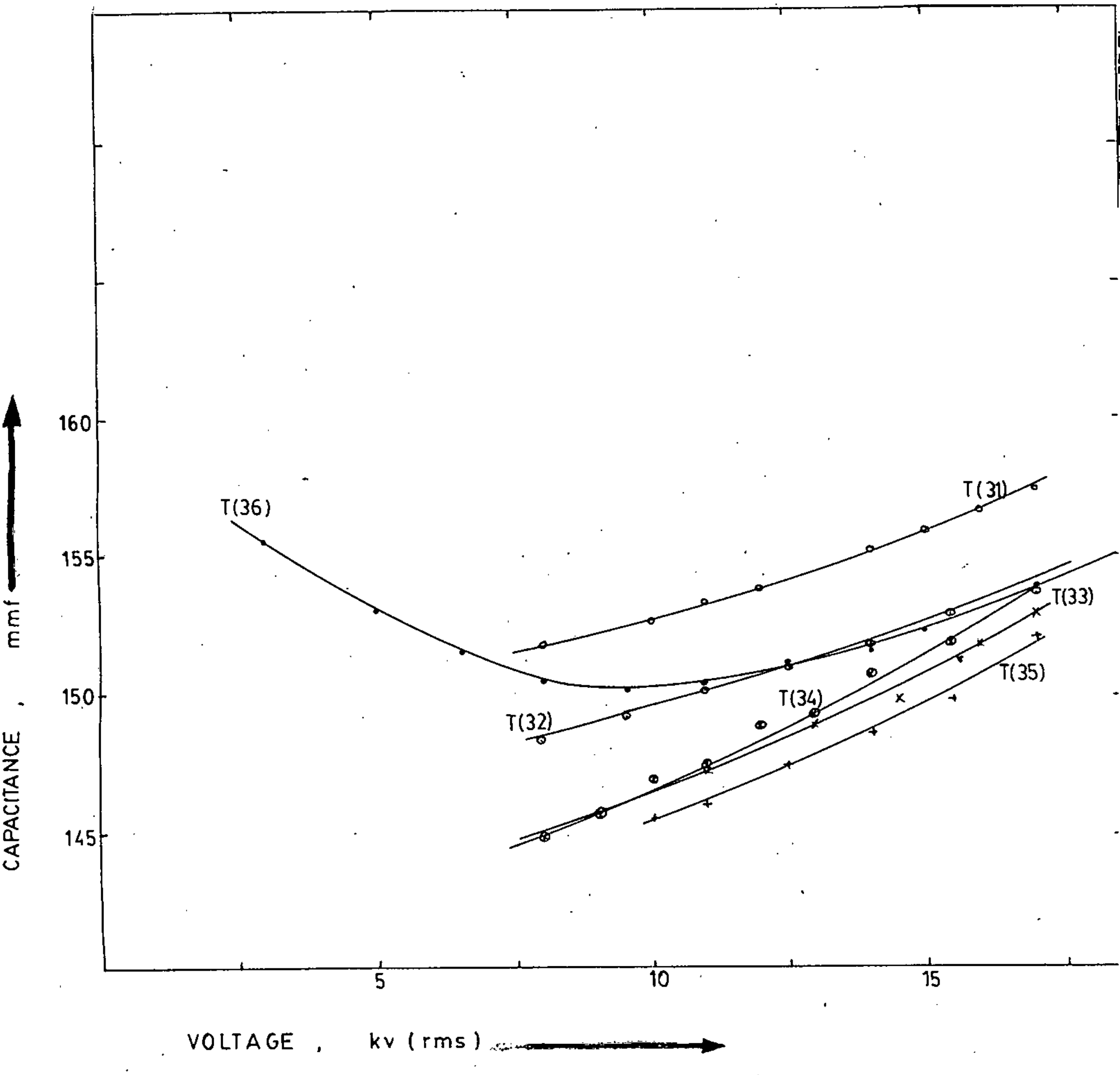


FIG.4.6.b. THE VARIATION OF CAPACITANCE WITH VOLTAGE FOR THE INSULATION BETWEEN CORE II AND III UNDER DIFFERING CONDITION.

DATA FOR INSULATION BETWEEN CORE I AND III, TAKEN UNDER DIFFERENT CONDITIONS.

TABLE-37. [T(37)]

READING TAKEN AFTER THE INSULATION BETWEEN CORE I AND SHEATH HAS BEEN STRESSED AT 50 KV FOR A FEW MINUTES.

APPLIED VOLTAGE, KV.	R_3, Ohms.	Tan δ = C_4, m.F	SPECIMEN CAPACITANCES mmF.
3.0	1960	.0002	162.65
5.0	1986	.0016	160.52
7.0	2003	.0013	159.21
11.0	2180	.011	144.91
13.0	2040	.022	146.24
14.0	1990	.031	159.48
15.0	1981	.034	160.93

TABLE-38. [T(38)]

READING TAKEN 45 HRS. AFTER STRESSING THE INSULATION BETWEEN CORE I AND SHEATH AT 50 KV FOR A FEW MINUTES.

APPLIED VOLTAGE, KV.	R_3, Ohms.	Tan δ = C_4, m.F.	SPECIMEN CAPACITANCE, mmF.
3.0	2178		146.57
5.0	2156.0		147.87
7.0	2130.0		149.67
9.0	2117.0		150.59
10.0	2114.5		150.77
11.0	2100	.0051	151.81
12.0	2090	.0096	152.54
13.0	2074	.013	153.71
14.0	2066	.017	154.31
15.0	2056	.020	155.06

TABLE-39. [T(39)]

READINGS TAKEN IMMEDIATELY AFTER APPLYING 45 KV FOR 1/2 HR. BETWEEN CORE I AND SHEATH.

APPLIED VOLTAGE, KV.	R_3, Ohms.	TAN δ = C_4, m.F.	SPECIMEN CAPACITANCE, mmF.
3.0	2140		148.97
5.0	2129		149.74
7.0	2109	.0026	151.16
9.0	2095.3	.0046	152.15
10	2094	.0047	152.24
11	2076	.0108	152.56
12	2064	.0144	155.46
13	2051	.0180	155.44
14	2042.0	.0210	156.12
15	20 2.5	.0225	156.85
16	2025	.0250	157.43

TABLE-40. [T(40)]

DATA TAKEN IMMEDIATELY AFTER APPLYING 35 KV FOR 2½ HRS BETWEEN CORE I AND SHEATH.

APPLIED VOLTAGE, KV.	R_3, Ohms.	Tan δ = C_4, m. F.	SPECIMEN CAPACITANCE, mmF.
8.5	2148	.0028	148.42
10.0	2124	.0071	150.09
11.50	2113	.0130	150.88
13.0	2096	.0180	152.10
14.5	2083	.0213	153.05
16.0	2077	.0236	153.86
17.00	2062	.0255	154.61

TABLE-41. [T(41)]

DATA TAKEN 45 HRS. AFTER STRESSING CORE I AND SHEATH INSULATION AT 35 (KV) FOR 2½ HOURS.

APPLIED VOLTAGE, KV.	R_3, Ohms.	Tan δ = C_4, m.F.	SPECIMEN CAPACITANCE, mmF.
10.5	2124	0004	150.09
12.0	2109	005	151.16
13.5	2091	0071	152.46
15.0	2072	0089	153.86
16.00	2061	0120	154.68

TABLE-42. ~~[T(40)]~~ [T(42)]

DATA TAKEN IMMEDIATELY AFTER APPLYING 41 KV FOR FOR 3 HRS. BETWEEN CORE I AND SHEATH.

APPLIED VOLTAGE, KV.	R_3, Ohms.	Tan δ = C_4, m.F.	SPECIMEN CAPACITANCE, mmF.
9	2149.5	.0070	148.31
10.	2133	.0113	~~148~~ 149.46
11.5	2106	.0185	151.38
13.0	2093	.0225	152.32
14.5	2073	.0245	153.79
16.0	2055	.0265	1555.13
17.0	2046	.0278	155.82

TABLE-43: [T(43)]

DATA TAKEN FIVE DAYS AFTER THE BREAKDOWN OF THE INSULATION BETWEEN CORE II AND SHEATH.

APPLIED VOLTAGE KV.	R_3, Ohms.	Tan δ = C_4, m.F.	SPECIMEN CAPACITANCE, mmF.
3.0	2018	.0110	157.98
5.0	2041	.0082	156. 0
6.5	2060	.0063	154.76
8.0	2073	.0053	153.79
9.5	2078	.0050	153.42
11.0	2070	.0109	154.01
12.5	2062	.0150	154.61
14.0	2051	.020	155.44
15.5	2044	.023	155.97
17.0	2032	.025	156.89

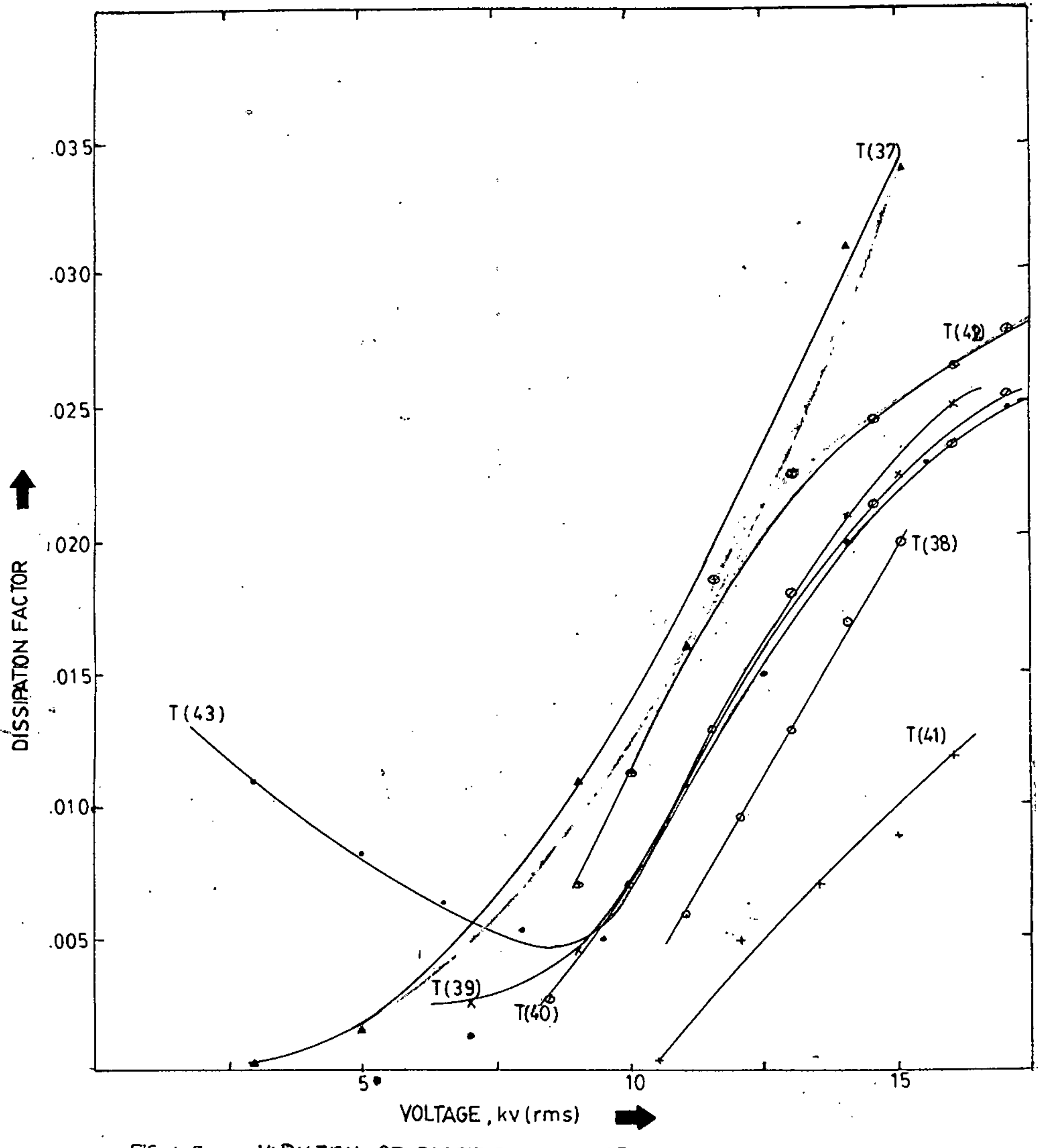


FIG. 4.7.a. VARIATION OF DISSIPATION FACTOR WITH VOLTAGE FOR THE INSULATION BETWEEN CORES I AND III

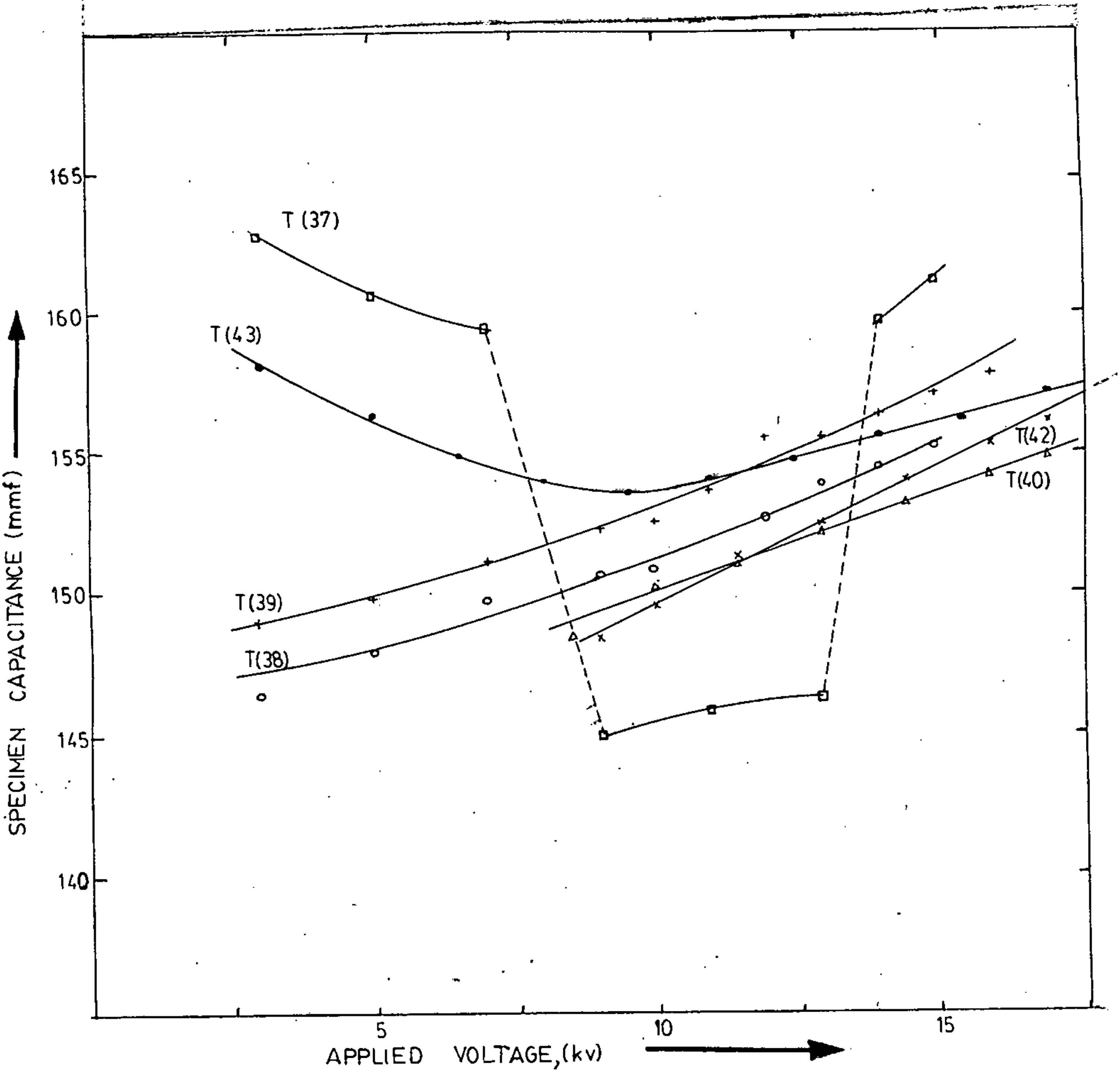


FIG.4.7b.THE VARIATION OF CAPACITANCE WITH VOLTAGE FOR THE INSULATION BETWEEN CORES I AND III FOR DIFFERENT CONDITIONS.

4.4 DISCUSSION ON THE B DATA OBTAINED IN CORE TO SHEATH MEASUREMENTS:

4.4.1 -DISSIPATION FACTOR BEHAVIOUR BEFORE BREAKDOWN:

The data was taken for the behaviour of the insulations after different stressings. These stressings were at times in excess of 4 to 4½ times the working voltage, and applied for different durations. Ultimately, the insulation broke down after some periods of stressing.

This repeated stressing for long durations in excess of the working voltage will cause ionization and will result in the degradation of the dielectric; newer products will form. These will possess qualities different from the earlier original dielectric. This is discussed in details in Appendix 'C'.

It has been observed that before any stressing, the ionization curve shows a practically constant value of dissipation factor with increase in voltage upto a certain value. After this, the increase in the dissipation factor is observed. The ionization point (the voltage at which the dissipation factor begins to increase with voltage) in the two cases (core I-Sheath and Core II-Sheath) is somwhat different. However, the rate of increase ofloss tangent with voltage is about the same in both the cases. For the data obtained on one core (core-II -Sheath), it is seen that, at higher voltages, there is a trend in the loss tangent to slightly decrease the rate of change with voltage. Evidently, at still higher voltages—— - provided the insulation does not breakdown——there will be a maximum in the loss tangent and then the loss tangent will decrease with voltage. This is characteristic of polar materials, which possess a peak in their dissipation factor, and paper is a polar material, although the impregnant may not be fully so (The structure of paper and its effects on losses is discussed indetails in Appendix-D)

With different stressings, on different occasions for different intervals, it has been observed, that there is a gradual deterioration of the dielectric. The stressings (in excess of the working voltage) produce discharges, which adversely affect the oil-impregnated paper insulation. Those discharges could be seen to form near the ionization point, and have been observed on the oscilloscope. Evidently, with increase in stress, the discharges will multiply in number, and also their amplitudes will increase.(For a discussion on discharges, refer to Appendix-'C'). It is observed that the rate of increase of dissipation factor decreases somewhat at higher voltages after each stressings; it is observed that the dissipation factor (loss tangent) increases in value, which indicates that the conductivity of the dielectric is increasing,—a sign of deterioration oftheinsulation.

4.4.2 BEHAVIOUR AFTER BREAKDOWN:

The data obtained five days after breakdown is very different from the earlier datas.In this case, it is seen that the curves are 'V' curves. The dissipation factor (loss tangent) starts from a high value, at lower voltages, and begins to decrease as the voltage is increased, and then it increases as the voltage is raised still higher. This may possibly be due to the formation of newer materials, having behaviours and response which are different. It could also possibly be due to space-charge effects. We also find that although the dissipation factor begins to decrease, it does not come down to very low values.

4.4.3: CAPACITANCE BEHAVIOUR BEFORE BREAKDOWN :

For the behaviour of specimen capacitance with voltage, under different conditions, first data was taken before any sort of stressing. It has been observed, that for both sets of data (Core I-Sheath and Core-II-Sheath), the variation of capaciatance with voltage is smooth, and its increase with voltage is not rapid. This increase is capacitance with voltage, is due to discharging voids, which short-circuit the voids. It has also been observed that the overall capacitance of one core to sheath (I-S) is greater than that of the other one (II-S). However, the rate of increase is found to be similar.

For data obtained, on intermediate dates, after different stressings, it was observed, that the rate of increase of capacitance with stress has increased. Moreover, in one case (I-S), it was observed that the overall capacitance of the insulation has decreased below the value obtained before any sort of stressing. In the other case (II-S), it has been observed that the value of the capcitance of the dielectric has increased in value, and has become greater than that before any stressing.

4.4.4 : AFTER BREAKDOWN :

After the breakdown of the insulation, it was observed that the natureof of cpacitance curve has changed. In one case (I-S) it is observed that the value of the capacitance has decreased condiderably. It is also seen that at first, the capacitance slightly increases with voltage (upto a certain value), takes a peak value, and than begins to decrease as the stress is increased. Moreover, the rate of decrease is very rapid. Then, there is a tendency in the behaviour to increase with voltage;

but the rate of increase is very gradual. This is probably due to the formation of newer materials, whose behaviour with stressing is different. The value of the capacitance in the other case (II-S) has increased very much after breakdown. Moreover, the shape of the curve is nearly the same as the one in the previous case.

For an intermediate set of datas in both cases (Core-I Sheath and Core II -Sheath) it is observed that the data for both the loss-tangent and the capacitance does not confirm with the manner in which the other datas behave. In the case of didsipation factor behaviour, there is slight dip in both the cases, which in indicative of the fact that sapce-charge effects are predominant in this region. Moreover, in both the cases, it is found that the value of the dissipation factor at low values is quite high. Moreover, the value of the dissipation, at a particular stress, is also higher than in cases obtained later.

As for the case of the capacitance behaviour, it is observed in one case (I-S) that the behaviour is not systemmatic. At first, the increase in the capacitance is slow, and then, at a certain stress, it increase abruptly to a higher value, from where it begins to increase slowly. This could possibly be due the fact, that a greater number of discharges have occurred, and have short-circuited the voids, thus resulting to an increase in the capacitance.

4.4.5: CONCLUSION:-

For the case of capacitance behaviour, it is observed that for an intermediate set of data, it capacitance is much greater than in other cases obtained before the breakdown. The capacitance curve show a condition when the capacitance increases but slightly with voltage, and then it begins to increase at a greater rate. Then also, there are some irregularities present in the variation. Moreover, it is observed that the variation is analogous to that of the loss tangent, becuase where there is a dip in the ionization curve, there is a slight dip in the data points obtained, the same sort of irregularities are present in both the cases. The curves that are presented in the graph are not made to pass through all points. By letting the curves pass through all the points the undulations could be observed. One cannot rule out the effect of extraneous capacitive coupling, which could affect the data. Care had always been taken to ensure that the screening isproperly done. May be, it could be so, by accident sometime, the screening had not been properly done.

It remains to be mentioned that not each core to sheath insulation had been stressed for the same voltage and duration. Also it the number of stressings were different. Finally, under stress for some hours, breakdown of one core to sheath insulation occurred.

Due to increased stressing the insulation below the sheath has borne much of the deterioration, because in each stressing it had to be present. Since the number of stressing, their magnitude and duration were different, it is assumed that the deterioration in the different core to sheath pores(due to discharges) have been different. This results in the formation of carbon particles and other products.

The electro-chemical effects of ionization and the discharging voids is that they gradually deteriorate the oil by oxidizing it. Moreover, as a result of oxidation and other (1) chemical changes, newer chemical materials are known to form. Electrical discharges in the gas space in the environment of the liquid dielectric cause a more or less permanent increase in the conductivity of the dielectric.

4.5: DISCUSSION ON DATA FOR CORE TO CORE EXPERIMENTS:

4.5.1 : DISSIPATION FACTOR BEHAVIOUR BEFORE BREAKDOWN:

From the data, for different core to core measurements, it is found the rate of increase of loss tangent (dissipation factor), after the ionization point, increases after each stressing of the insulation. In one case, it is observed that the value of dissipation factor is greater than that obtained later because in this case, a maximum of 50 KV(RMS) had be applied for a few minutes across Core I and sheath insulation. The curve for I-S data of the same date is also a bit different. Moreover, in the ionization curve for this data, we find a small dip at lower voltages before the ionization point. This indicates that space-charge effects are taking place at those values of stressing. At higher voltages, it is observed that the rate of increase of dissipation factor decreases with increase in voltage. This is also the case with other set of readings. If the voltage is further increased, one would observe that after passing through a peak value, the dissipation factor will decrease with an increase in voltage. This is the case with polar dielectric, which possess a peak in their dissipation factor. This peak value is a function of temperature, frequency

4.5.2 : AFTER BREAKDOWN :-

The behaviour of the dissipation factor with voltage after breakdown is different from the curves obtained earlier and before breakdown. The pattern is however similar to that obtained in the case of core to sheath measurements. It is observed, that 'V' curves are obtained : first, at low values of stressings, the dissipation factor begins to decrease as the voltage is increased. It goes through a minimum value and then rises as the voltage is increased further. The portion of the 'V' curve which shows an increase of dissipation factor with voltage is however similar to the other ionization curves. Moreover, the rate of increase is also similar.

The curves for the three core to core measurements are similar, except that for core I - III data, the value of the minimum in the ionization curve, after breakdown, is greater than that in the other two cases. This could possibly be due to the fact that both cores I and II had been repeatedly stressed by applying voltages, in excess of four to four and a half-times the working voltages, across the respective cores and shath. Moreover, since the core II to sheath insulation was affected by breakdown, it is evident that greater damage has been occurred to the core II insulation, as compared to that of core I, since this core did not breakdown.

4.5.3 : CAPACITANCE BEHAVIOUR BEFORE BREAKDOWN:

The variation of the capacitance of the specimen with voltage, shows a gradual decrease in its value with increase in voltage after each stressing. However, the general trend— increase of capacitance with increase in voltage—is present.

There is exception present in the case of core I - III measurements. For the data obtained on 11.10.76, the behaviour is not in confirmity with other datas. This sis also observed with the data obtained on 11.10.76 for the core-I-S measurements. One could presume that the oil-impregnated paper insulation of Core-I is somewhat "different" from those around other cores.

4.5.4 : AFTER BREAKDOWN:

For the curves obtained from data taken after the breakdown, it is observed that the capacitance also decreases in value with increase in stress upto some values of stressings, then it begins to increase as the stress is increased. The portion showing the increase in capacitance with voltage lies in the region between the values obtained for other cases. The curve obtained in the case of core I-III measurement is a bit different from the other two curves--(for core I-II and II-III data) Here, initially, there is present a peak in the curve. This is also found for the core I-S capacitance curve obtained after breakdown. The decrease in the capacitance with increase in voltage, for the initial portion of the curve, is also more rapid as compared to the other two cases. Moreover, the value of capacitance is greater than that for the other two cases. It may be mentioned, that the pattern of the capacitance reverse voltage curve for the Core I-S measurements obtained after breakdown, was also different from that obtained for II-S measurements under similar conditions.

4.6 : CONCLUSION:-

The effect of discharges that take place in the gas pockets in oil-impregnated paper insulation manifests in a gradual change in the composition of the dielectric materials[1]. As a result of the discharges, newer materials are fomned due to electro-chemical effects. Electrical dissharges in the gas space within a dielectric liquid cause a permanent damage to the dielectric—and results in an increase in its conductivity. The increased electrical conductivity of deteriorated oils may in some cases result from the formation of substances that are electrolytically dissociable, usually it results from the formation of colloidal ions[1]. A feature common to such colloids is a constituent that by itself is insuluble in theoil. Examples of such materials are'soluble' sludge, asphalt, cuprons soaps or oxides, and condensation products that result from electrical discharge reactrons involving oxygen, nitrogen as well as hydrocarbons. It has been[1] observed that the conductivity markedly increases when hydrocarbons are subjected to electrical discharge in the absence of air, oxygen usually accelerates the process.

Balsbangh[24] and Co-workers[25] have investigates between the amount of oxygen absorbed and the conductivity, the dielectric constant and color. Balsbangh[26] has also observed that for both oil and oil-impregnated paper, subjected to oxidation in the presence of x copper catalysts, the conductivity in the early stages of oxidation increased more when the supply of oxygen was limited than when it was un-limited. The effect of copper salts in causing high power-factor in seriously deteriorated oil-filled cable has been pointed out by Hirshfeld, M Meyer, and Wyatt[27]. Evans and Davenport[28] discovered evidence for the presence of strong acids as well as weak ones in oxidised insulating oils.

Piper and Co-workers[29] have investigated into the effect of lead soaps and copper soaps at different temperatures. They have reported that these soaps caused high power factors at temperatures appreciably above those at which their solutions became visibly heterogeneous upon cooling.

CHAPTER-5.

EXPERIMENTS ON LIQUID DIELECTRIC SAMPLES:

5.1 : THE OIL SAMPLE:-

To study the behaviour of liquid dielectrics, commercially available transformer oil was taken. This oil sample was used before in transformer. To prepare the specimen—so that no visible foreign particles could be present—the following procedure had been used :

The oil sample, taken from the stock kept in a drum, was heated upto 120°C so that dissolved gases and moisture could escape from the oil. This was done because, breakdown occurred (many times) in many samples. The breakdown voltage was about 120 volts/mils, and even less on many occasions. After breakdown it would be observed that carbon particles would depoist on the electrodes; at places on the electrodes between which discharge would take place (probably), larger dark spots could be observed.

5.2: CLEANING OF THE SPECIMEN HOLDER :-

It has to be mentioned here that utmost care was needed to clean the specimen holder otherwise impurities would present difficulties in taking data. To this effect, carbon tetrachloride was utilised as a cleqning agent. It is a very useful organic soluent. Standard quality of the solvent was used. The following procedure was utilized to clean the specimen holder(8): First, some CCl_4 was poured into the specimen holder, then covered and shaken so that the soluent could reach all the places. The cover was then removed and both the electrodes were scrubbed with a piece of clean cloth, and the specimen holder closed again and shaken. The CCl_4 was poured out (thrown away). Then a further quantity of CCl_4 was poured into the specimen holder, and the specimen holder thoroughly rinsed. Finally, some more of the soluent was poured in, and final rinsing was done, the soluent was poured out. The specimen holder was then heated, with the lid on, upto 120°C for sometime. This process has been found to be quite effective in cleansing the specimen holder free from soluble and suspended impurities which could be present in the specimen holder[8].

Before taking the liquid sample for experiments, the specimen holder was rinsed with some of the liquid to be tested, and (the liquid) thrown out. The hot sample (at 120°C) was then poured into to specimen holder in sufficient quantity (about 75 CC). The specimen holder was covered, and the liquid allowdd to cool upto the termperature at which readings were to be taken.

5.3.1:MAINTAINING CONSTANT ELEVATED TEMPERATURE:

Since different readings had to be taken at different elevated temperatures, it was necessary to keep the termperature constant. For this purpose, the specimen holder had to kept on a hot brick (which had to be heated for a pretty long time). The temperature would come down in a single set of readings. Then the brick was again heated to obtain the required temperature. This process is quite cumbersome. Another process is given below (as present in the bridge manual)[8] :

5.3.2 : ANOTHER METHOD:

Place the assembled specimen Holder (containing the specimen) in an air temperature both on a surface which is insulated for 3000 to 4000 (and remove handle 3). Then place a thermometer in the well in the specimen holder.

Raise the termperature of the test specimen (by means of the temperature bath)upto a value of 100 to 105^{o}C as indicated by the thermometer. Then allow the temperature of the specimen to drop to the value at which the measurement is to be made.

DATA OBTAINED ON LIQUID DIELECTRIC
(TRANSFORMER OIL) SAMPLES AT
DIFFERENT TEMPERATURES.

TABLE-44 [T(44)]

DATA OBTAINING ON TRANSFORMER OIL SAMPLE (SAMPLE-I) AT ROOM TEMPERATURE (21°C).

APPLIED VOLTAGE, KV.	R_3, Ohms.	Tan δ $=C_4$, mF	Temp. T°C	SPECIMEN CAPACITANCE, mmF
2.73	1899		21°C	167.88
4.09	1881			169.48
5.45	1870			170.48
6.84	1865.1			170.93
8.18	1902.3			167.59
9.55	1899.2	.0012		167.86
10.91	1897.5	.0024		168.01
12.27	1896.5	.0035		168.10
13.63	1894.7	.0046		168.26
15.00	1893.6	.0059		168.36
16.35	1892.9	.00736		168.42

TABLE-45. [T(45)]

DATA OBTAINED ON THE ABOVE SAMPLE AFTER DISCHARGE, AND AT ROOM TEMPERATURE.(21°C)

APPLIED VOLTAGE, KV.	R_3, Ohms.	Tan δ = C_4, mF.	SPECIMEN CAPACITANCE, mmF.
9.55	1866.4	.0017	170.81
10.91	1864	.0029	171.03
12.27	1862	.0046	171.21
13.63	1860	.0059	171.40
15.00	1857.5	.0075	171.63
16.35	1854.0	.0094	171.95

TABLE-46. [T(46)]

DATA OBTAINED ON SAMPLE I 24 HRS. LATER, AND ROOM TEMPERATURE.(22°C).

APPLIED VOLTAGE, KV.	R_3, Ohms.	Tan δ = C_4, mF.	SPECIMEN CAPACITANCE, mmF.
3.48	1903		167.52
4.99	1877		169.85
5.45	1878		170.21
6.82	1870		170.48
7.57	1869		170.48
8.25	1868.4	.0001	170.63
8.86	1867.2	.00075	170.74
9.55	1866.3	.00147	170.82
10.36	1865.1	.00213	170.93
11.32	1863.3	.00287	171.09
12.27	1861.1	.00352	171.30
13.35	1859.7	.00498	171.43
14.83	1858.1	.00613	171.57

TABLE-47. [T(47)]

DATA OBTAINED ON A FRESH SAMPLES(SAMPLE 2) OF TRANSFORMER OIL AT 85°C.

APPLIED VOLTAGE, KV.	R_3, Ohms	Tan δ = C_4, m.F.	SPECIMEN CAPACITANCE, mmF
1.36	1957	.051	162.90
2.59	1920	.065	166.04
3.28	1910	.070	166.91
4.09	1892	.082	168.50
4.61	1888	.102	168.86
5.18	1873	.105	170.21
6.41	1871	.113	170.39
7.02	1860	.121	171.40
8.32	1859	.128	171.49
8.69	1864	.128	171.03

TABLE-48. [T(48)]

DATA OBTAINED ON SAMPLE-2 AT 73.5°C.

APPLIED VOLTAGE, KV.	R_3, Ohms.	Tan δ = C_4, m.F.	SPECIMEN CAPACITANCE, mmF.
1.36	1869	.0125	170.57
2.32	1831	.0218	174.11
3.41	1810	.0275	176.13
4.64	1795	.036	177.60
5.45	1790	.043	178.10
6.40	1783	.049	178.80
7.72	1781	.057	179.00
8.46	1775	.065	179.61
9.20	1766	.071	180.52
10.23	1774	.078	179.71
10.91	1770	.082	180.11

TABLE-49. [T(49)]

DATA OBTAINED ON SAMPLE 2 AT 69°C.

APPLIED VOLTAGE, KV.	R_3, Ohms	Tan δ = C_4, m.F.	SPECIMEN CAPACITANCE, mmF.
1.36	1866	.0004	170.85
3.41	1799	.0198	177.21
5.45	1780	.0276	179.10
7.06	1774	0.037	179.71
8.18	1764	.048	180.73
9.68	1761	.063	181.03
11.05	1753	.066	181.86
12.06	1750	.071	182.17

TABLE-50. [T(50)]

DATA OBTAINED ON A NEW SAMPLE (SAMPLE 3) OF TRANSFORMER OIL AT 77°C).

APPLIED VOLTAGE, KV.	R_3, Ohms.	Tan δ = C_4, m.f.	SPECIMEN CAPACITANCE, mmF.
1.45	1750	.071	182.17
2.21	1777	.060	179.40
3.15	1793	.059	177.80
4.78	1803	.064	176.82
6.14	1806	.071	176.52
6.84	1811	.076	176.04
6.93	1818	.079	175.36

TABLE-51. [T(51)]

DATA ON SAMPLE 3 AT 65°C, AND AFTER REMOVING IMPURITY PARTICLES FROM THE LOW-VOLTAGE ELECTRODE SURFACE BEFORE MEASUREMENTS.

APPLIED VOLTAGE KV	R_3, Ohms	Tan δ = C_4, m.F.	SPECIMEN CAPACITANCE mmF.
1.364	1908		167.09
1.95	1878	.0045	169.76
2.92	1858.3	.0089	171.55
4.09	1848	.00170	172.51
5.81	1833	.0211	173.92
6.14	1836	.026	174.11
7.00	1825	.028	174.68
7.55	1825	.030	174.68
8.32	1821	.033	175.67

TABLE-52. [T(52)]

DATA TAKEN ON SAMPLE 3 AT 46°C

APPLIED VOLTAGE KV	R_3,Ohms	Tan δ = C_4, m. F.	SPECIMEN CAPACITANCE m.m.F.
1.65	1908.1		167.08
2.50	1880		169.58
3.86	1862.5	.0001	171.17
4.92	1857.7	.0028	171.98
5.45	1850.3	.0040	172.30
6.14	1846.2	.0052	172.68
7.02	1842.5	.0066	173.03
7.86	1839.7	.0078	173.29
8.73	1836.3	.0099	173.61
9.27	1833	.0108	173.92

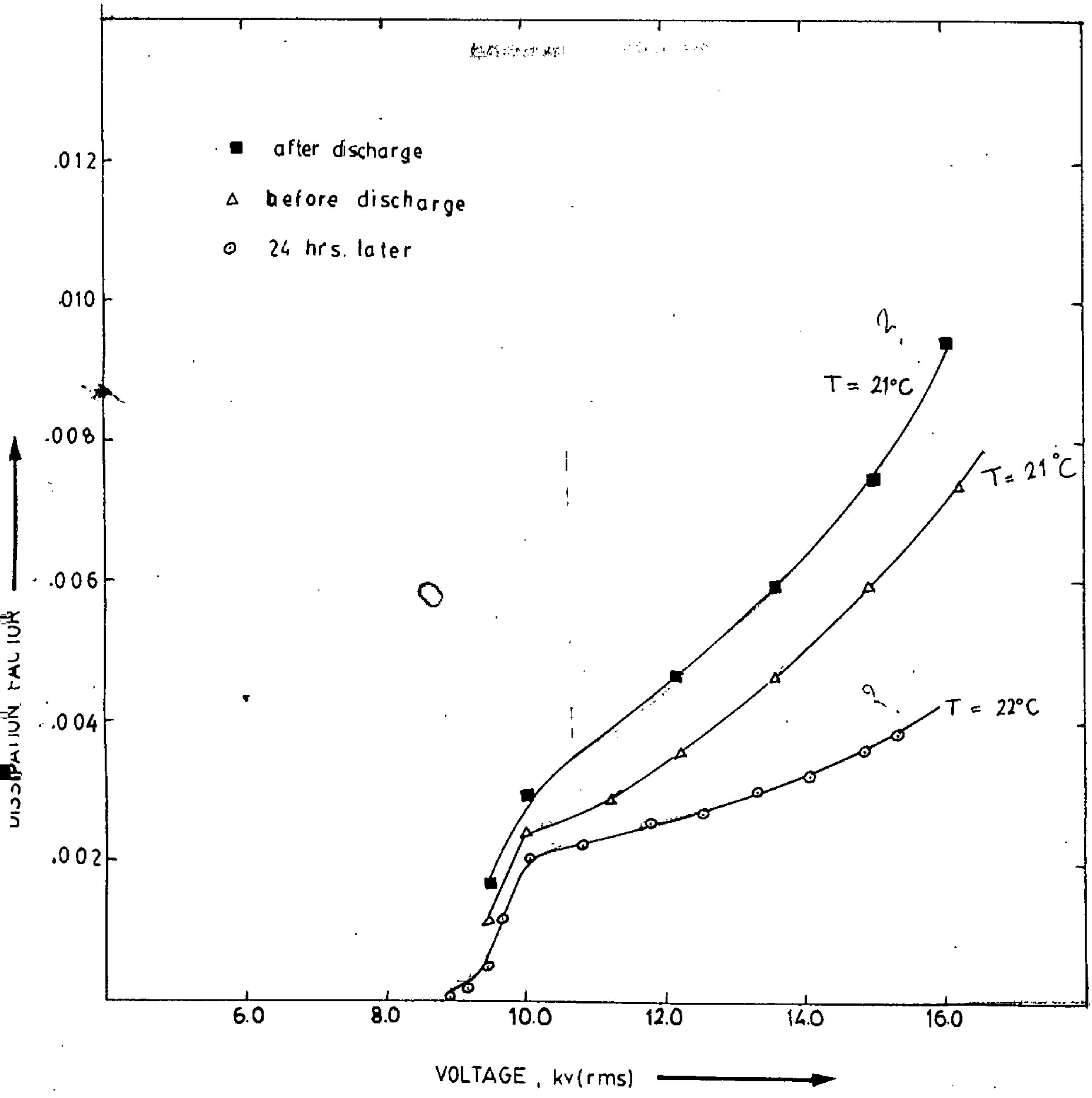


FIG. 5.1 VARIATION OF DISSIPATION FACTOR WITH VOLTAGE FOR SAMPLE 1 OF TRANSFORMER OIL AT ROOM TEMPERATURES

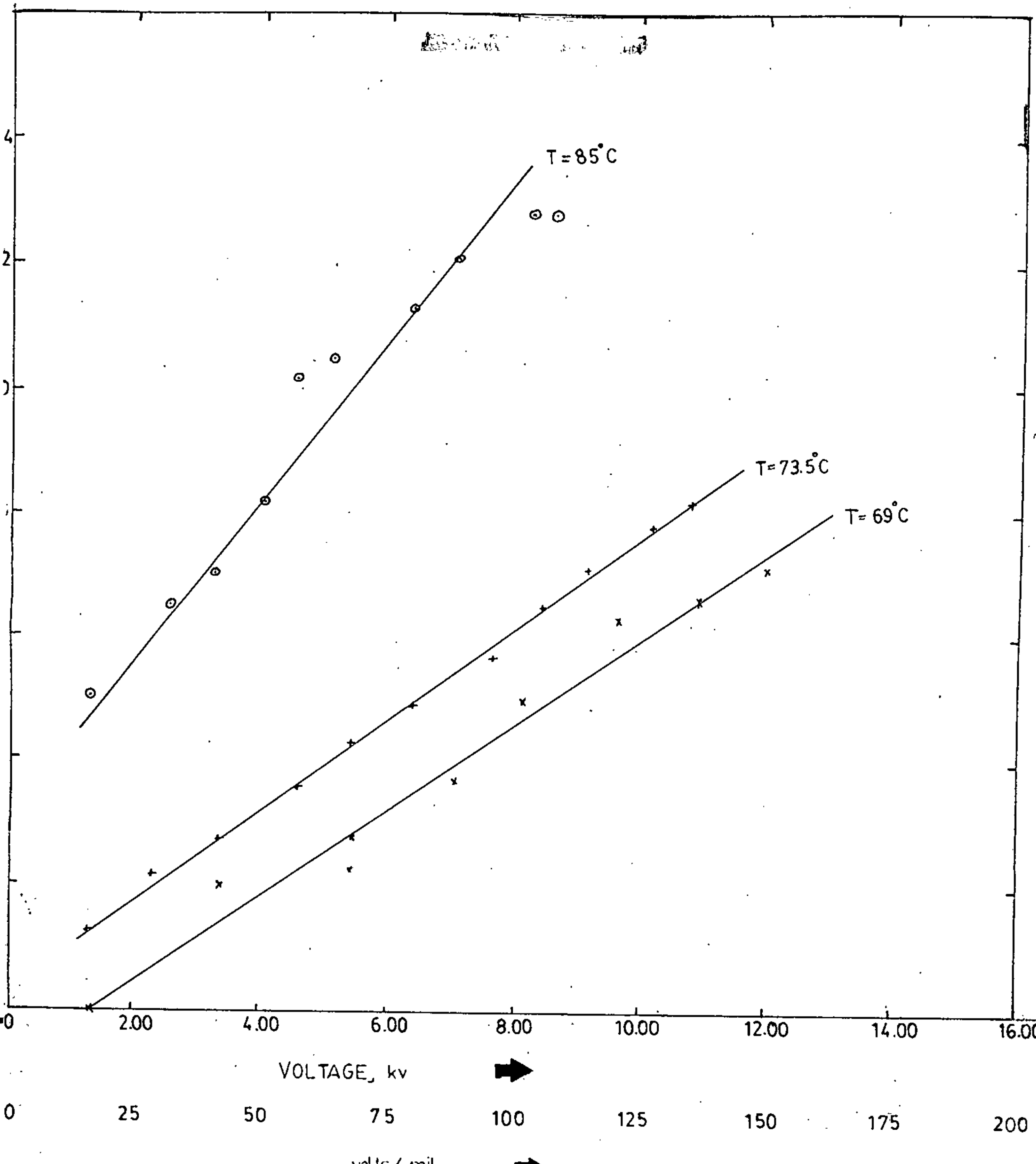


FIG. 5.2. VARIATION OF DISSIPATION FACTOR WITH VOLTAGE FOR SAMPLE 2 OF TRANSFORMER OIL AT DIFFERENT TEMPERATURES.

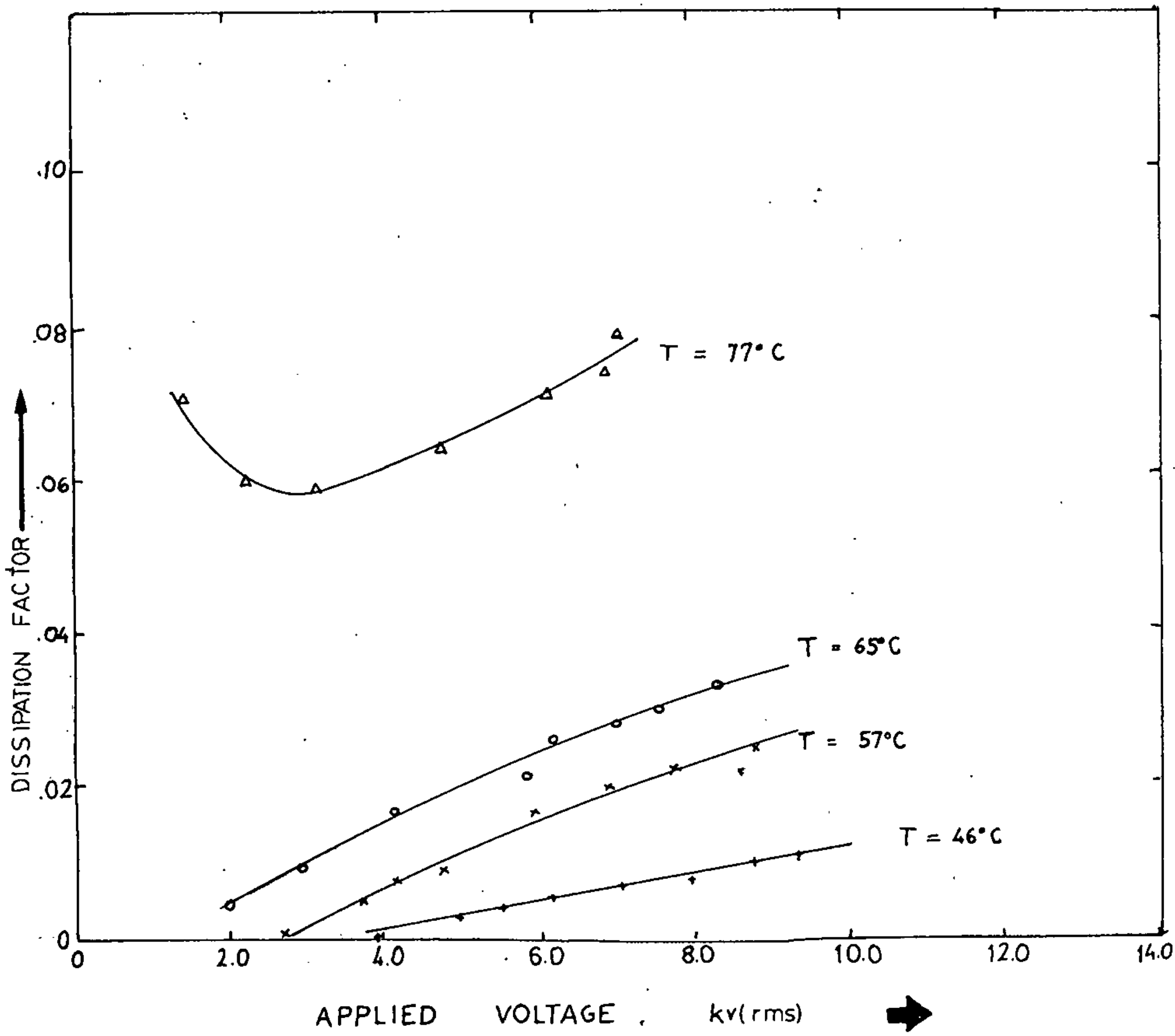


FIG. 5.3. VARIATION OF DISSIPATION FACTOR WITH VOLTAGE FOR SAMPLE 3 OF TRANSFORMER OIL AT DIFFERENT TEMPERATURES.

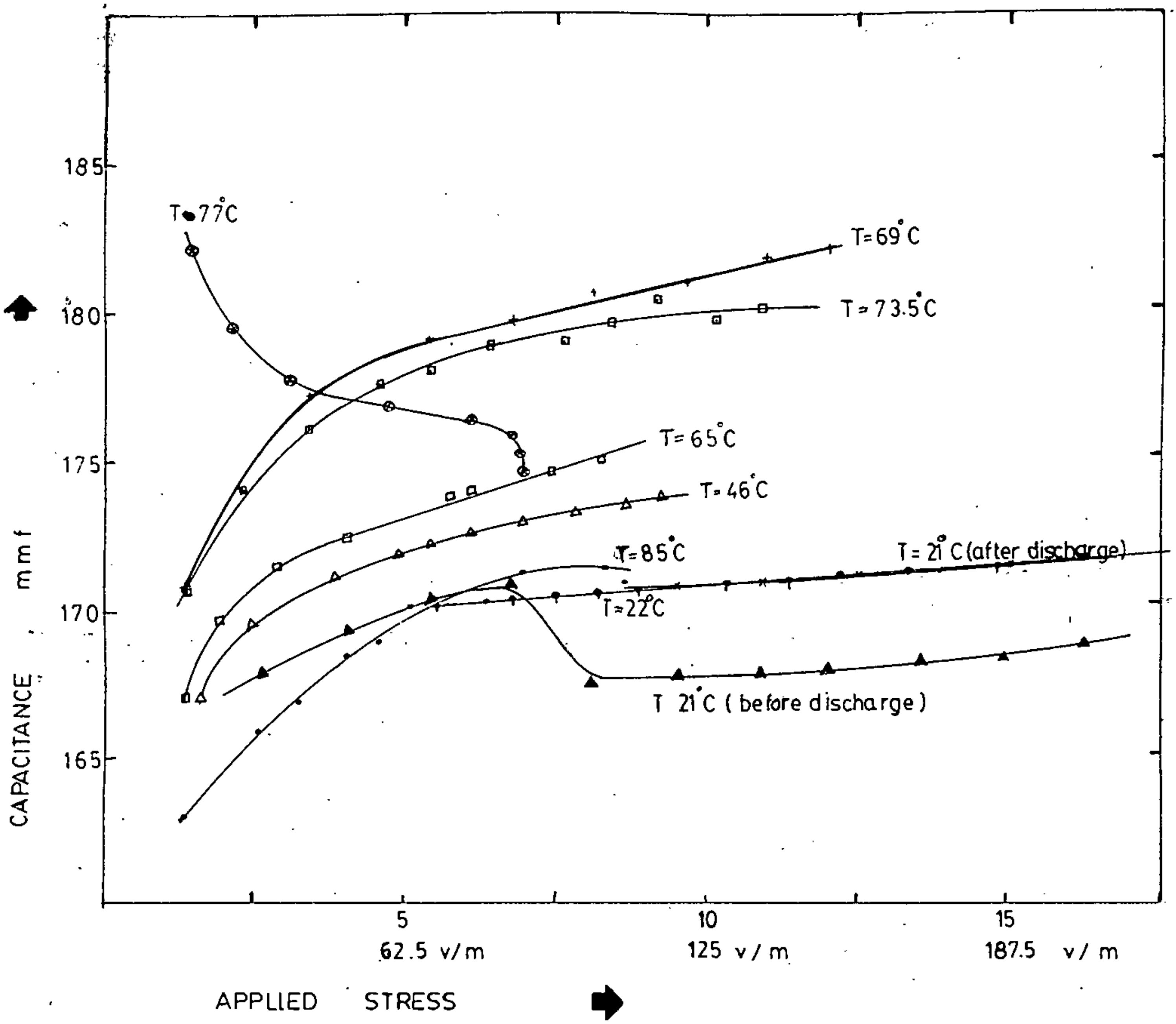


FIG. 5.4. VARIATION OF CAPACITANCE OF INSULATING OIL WITH VOLTAGE AT DIFFERENT TEMPERATURES.

5.4 : DISCUSSION ON THE RESULTS OBTAINED:

Transformer oil(commercially available that had already been used, but centrifuged) was taken to study its dissipation and capacitance behaviour under stress. Temperature was taken as a parameter. Data was taken at different elevated temperature, as is given in Tables 44-52. The data was taken on three different days. It has to be mentioned that the samples had to be changed becuase the discharges within the liquid led to the formation of impurities. The effect of discharges on liquid dielectrics is discussed in Appendix C.

5.4.1 : DISSIPATION FACTOR:-

It has been observed that no dissipation factor reading could be obtained at lower voltages, and at 21°C and 22°C. At about 8.0 KV, thedissipation factor could be read, after which it begins to increase with voltage. In one set of data, it was found that the dissipation factor increases markedly after the occurrance of discharges (the datas were taken on the same day). When the readings were taken on the same sample, the next day, it was found that the dissipation factor has decreased, below those obtained the previous day. However, the room temperature in this case was 1°C higher. The curves in the three cases are all similar. These curves are shown in Fig.

Another fresh smaple was taken, and after performing the functions mentioned in section 5.2, data was taken at three different temperature,--85°C, 73.5°C and 69°C. It was found that at 69°C and, 73.5°C, we get curves which are parallel, and the dissipation factor increases with voltage.Evidently, the one at higher temperature shows a greater dissipation factor. The dissipation factor for the temperature of 85°C are very much greater.

The points obtained are irregular, but can be approximated by a straight line curve.

The curves for another samples obtained from data taken at 46°C, 57°C, 65°C and 77°C show only a slight anomaly. The data obtined at 77°C gave a 'V' curve, while that at 46°C gave an increase of dissipation factor with voltage which is lower than that for 57°C and 65°C.

5.4.2: CAPACITANCE BEHAVIOUR:

The capacitance data obtained on the three samples, at different temperatures, shows a some what irregular behaviour. In the case of sample I, it is found that there is a gradual increase in capacitance. On one occassion (before discharge), it was found that the capacitance increases with voltage to some extent, after which it comes down to a lower value, and again increases but gradually. There is no irregular behaviour of capacitance in the data obtained for sample 2. The capacitance increase is curvilinear, and comparitively, the capacitances at higher temperatures, are lower. The data obtained on sample 3 indicate an irrgular capacitance behaviour.

In this case, it was found that at higher temperatures, the capacitances are higher. This is just the opposite of that for sample 2. In one case (at 77°C)it is found that the capacitance starting forom a highe value at low voltage, decreases as the applied stress is increased. In the other two sets of data for the same sample, it is found that the capacitance increases in the manner of that for sample 2, but the capacitance is lower at lower temperature; that is, the capacitance at 46°C is lower than that at 65°C.

5.5: CONCLUSION:-

From the data obtained, it has been found that the dissipation factor of the liquid dielectric is very low at low-valuesc of stress and lower temperatures and are not measureable upto certain stress. However, it begins to increase at higher voltages, and the increase is linear in general. Moreover, it was obtained that at higher temperature the dissipation factor, in general, possesses at higher value; also, the dissipation factor is obtainable at lower voltages. This is due to the fact that, at higher temperatures and higher stress, the impurities increase in mobility and also there is a dissociation of the impurity molecules and those of the dielectric liquid itself into ions, which contribute to the increase in the conductivity of the liquid. The conduction mechanism in liquid dielectrics is discussed in greater details in Appendix 'F').

As for the capacitance behaviour, no regular data could be obtained. For the three samples studied (these are taken from the same stock)the behaviour is somewhat different. But it has been observed that at higher temperatures, the capacitances are higher, in general. This results from the fact that at elevated temperatures that there is a sharp increase in permittivity. This is because the viscosity fall to a lower value. This contributes to the increase in capacitance.

Dielectric liquids behave very peculiarly becuase of the presence of impurities; impurities even in slight amounts very much affect the behaviour of liquid dielectrics. Different investigator have in general have obtained conflicting data, and their interpretation differ markedly.

CONCLUSION AND SUGGESTION FOR FURTHER WORK:

6.1 : CONCLUSION:-

To study dielectrics under differing conditions, the following dielectrics were taken : (i) Polyethylene high-frequency cable, (ii) 11-KV 3 core oil-impregnated paper cable, and (iii) transformer oil. These were studied under differing conditions and at high-voltages to observe the behaviour of their dissipation factor and capacitance. The data obtained during the investigations tally with the theoretical interpretations in nearly all cases. The cable behaviour after breakdown, though not represantative of the data taken prior to breakdown, indicates the formation, to a considerable extent, of newer materials. (This breakdown took place after many stressings at 4-4½ times the working voltage). These materials form as a result of ionic discharges; electro-chemical changes take place. Although, no chemical analysis was done, it is presumed that water in sufficient quantity is present during measurements (because on one occassion while studying transformer oil, similar 'V' curve was obtained. Later it was found that droplets of water were present in the specimen holder). Or it could be that newer materials contributing to space-charge polarization have formed (Ref. Appendix 'E')

6.2 : SUGGESTIONS FOR FUTURE WORK:

The formation of discharges and their behaviour can be further investigated by using the Schering Bridge, provided that certain other auxiliary apparatus, such as filter circuit and also amplifier for high-frequency, are added. It is hoped that further studies on dielectrics of different types- to suit our condition--would greatly help in the proper utilization.

Investigations can also be carried out to determine the behaviour of materials not generally used as dielectrics but which possess insulating properties.

It is suggested that the study of power loss-using an electrostatic wattmeter-together with the study of dissipation factor behaviour at different voltages (and differing conditions) would help much becuase under stress and during ionization newer materials are formed which possess different permittivities. This sort of study would throw light on the formation of newer materials.

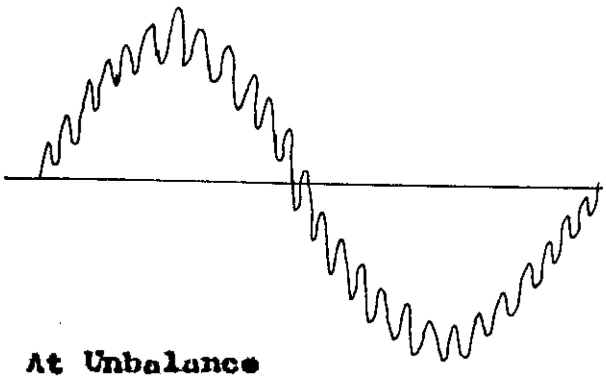
The usual practice had been to study the dissipation factor (or power factor) behaviour in order to determine the behaviour of dielectrics at high voltages. The study of capacitance behaviour will also be useful, as has been suggested by Dakins[17].

APPENDIX - A.

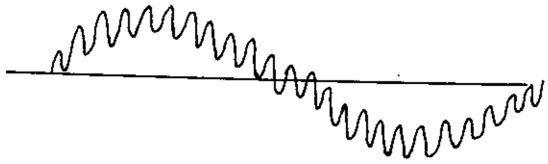
THE OBSERVATION OF DISCHARGES ON THE OSCILLOSCOPE.

We have used an oscilloscope as a null detector. The signal is fed from the amplifier—a power— frequency amplicr, provided along with the bridge. It may be mentioned that, instead of a vibration galvanometer or a d-c micro-ammeter, use has been made of the oscilloscope. The vibration galvanometer has not been used becuase its use becomes very cumbersome and difficulties arise as regards the effects of mechanical vibrations on them. Moreover, the auxiliary apparatus supplied to be used with the bibration galvanometer, were not in operating conditions. A d-c microwammeter had been also tried, but its use, near points where balance has to be changed from resistive branch to capacitance branch, becomes difficult to find the proper value of a particular setting, becomes a little difficult. Finally, we tried the vibration galvanometer, and it has been found that it is easy to use it as a null indicator.

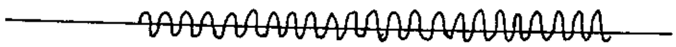
By using an oscilloscope, discharges were observed on the oscilloscope. These discharges increased in amplitude as the applied voltage was increased. It may be mentioned, that these discharges —having a frequency very much larger than the supply frequency,—could not have been observed with either a vibratioon galvanometer or a d.c. micro-ammeter. These discharges currents are superposed on the 50 cps frequency. As the amplifier and bridge had not be designed for their balance, they were even present when the bridge is balanced. At balance, these discharges are present, but instead of being superposed on the supply wave-shape, they are symmetrical about a straight line. Another oscilloscope (with better sensitivity had also been, but this does not affect the values of the data much) had also been used. The behaviour of the output, as seen on the oscilloscope, it unbalance, near balance and at balance are shown diagrammatically in the figures below. Moreover, it is observed that there is no appreciable change in the amplitude of those discharges.



At Unbalance



Near Balance



At Balance

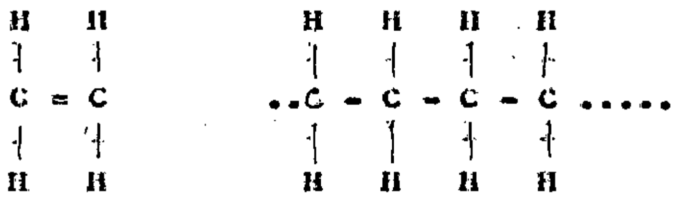
It may be mentioned that the formation of discharges in the specimen became observable on the oscilloscope at about 10 KV, as is noted for measurements taken on 1-9-76. In each cycle if two discharges take place, then for a 50 cps input, there are 100 discharges occuring per second.

APPENDIX - B.

STRUCTURE OF POLYETHYLENE : A BRIEF DESCRIPTION :

Polyethylene[1] has a cross-linked type of molecular structure. This resembles a three-dimensional fishnet. Instead of being long, thin and flexible, the molecules resemble an irregular three-diemensional fishnet, and the properties are very much dependent on the size and distribution of the meshlinks. When the meshes are very large, with very few crosslinks, the properties are like those of linear chained structure. An example is uncured rubber, with its high elongation and recovery. On the otherhand, very many crosslinks make the material hard and stiff, and probably brittle, as in the case of hard rubber or phenolformaldehyde resin.

The fishline type of molecule includes a wide variety of chemical structures. Polyethyelene is made by linking large number of ethyelene molecule in a chain. This is done by a process known as polymerization. Polyotheydene is the simplest vinyltype resin. It has excellent electrical properties. The dielectric loss angle is very low; since it is a non-polar material the dielectric losses are also low.



STRUCTURE OF POLYETHYLENE

PHYSICAL PROPERTIES:

The structure of polyetheylene is very simple and uniform. It is a compound of high molecular weight and is crystalline. It has been reported that it is 40 to 60 percent crystalline at room temperature. It decreases at higher temperatures and becomes zero at about 105°C. This crystablivity at room temperature makes the polyethylene inert to many of the solvents and chemicals which would be expected to attack hydrocarbones. The fact that it is a saturated hydrocarbon makes it resistant to chemical attack also.

ELECTRICAL PROPERTIES :-

A number of observed electrical properties are not entirely consistent with the structure shown. Becuase it has a symmetrical structure, it is non-polar. Thus we would expect no dipole moment, and hence there should be no loss, Commercial samples have a low, but not zeroloss, particularly after the plastic has been milled. It undergoes structural changes under the action of high voltages.(5)

CONCLUSION:-

When considering polyethylene as used in high-frequency cables, it must be borne in mind that a compounded material is being used. This is so because stabilizers are added to minimize the degradation due to heat, sunlight etc. Thus the values obtained and reported are on such a mixture.

Polyethylene has found wide uses in high-frequency applications such as radar cables and also for the insulation of communication and submarine cables. In its use for power cables two w weaknesses must be guarded against. Although polyethylene is ozone-proof, it is very susceptible to corona, possibly becuase the corona raises a portion of the polyethylene above its melting point, and dielectric failure ensures. A polyethylene cable, furthermore, will not withstand over-heating, by short-circuiting current of more than momentary duration.

APPENDIX-C

THE PRESENCE OF VOIDS, AND THEIR INFLUENCE ON THE DISSIPATION FACTOR AND CAPACITANCE OF AN INSULATING MEDIUM.

VOIDS AND THEIR PRESENCE IN SOLID INSULATING MEDIUM:

Voids and gas pockets are invariably present in solid and oil-impregnated paper insulations[15]. These voids are present in the cellulose structure and when oil is added to it as an impregnant, it is absorbed into the hollow cellulose fibres and their interstices, and also on the surface of the paper. This results in an almost homogeneous dielectric. The impregnant increases the dielectric strength because the gas voids are now filled with oil (the presence of voids reduces the dielectric strength). Voids still remain, and impose an upper limit upto which stress can be applied without breakdown. The presence of these voids are due to defeciencies in the manufacturing process or to the unavodable physical changes brought about during operation. Ionic discharges take place within the voids, however, small they may be. Above a certain critical stress intensity, these discharges cause severe local damage and destruction to the dielectric leading to breakdown.

THE FORMATION OF VOIDS AND THEIR MULTIPLICATION:

No discharges are present in oil-impregnated paper insulation at lower voltages. However, when the stress is raised above a certain value, a gas bubble forms in the dielectric. Discharges[16] take place within the voids. These discharges usually occur in small steps over a range of applied voltage during each half cycle of the applied a.c. voltage. The formation of these discharges are dependent on such factors as the high surface resitances of the insulation facing of voids, the existence of more or less active points of discharge initiation, the presence of surface charge concentration from previous discharges. Krasuchi[18] informs that the presence of moisture appears necessary for the formation of gas bubble. Some researchers[19] have shown that electrical discharges occur above a certain critical value of applied stress, E_i, even if the paper is so well impregnated that no voids are present initially. If the voltage be maintained at the discharge inception voltage level, the discharges increase rapidly in magnitude, sometimes to several times the initial value within the first few minutes, and life may be very limited. This discharge inception voltage is dependent on the hydrostatic pressure on the oil. However, it has been shown that the effects of density and the type of paper, and the viscosity and iodine number of the oil on the discharge inception voltage are relatively small.

The authors[18,19] have also shown that the gas initially generated in electrically stressed paper impregnated with a dielectric liquid is derived from the water retained by the cellulose (which is hygroscapic) through absorption forces,however well the paper is dried. Provided the gas bubbles are not present initially, the threshold value of stress for gassing at normal pressures is low only with impregnated materials containing an appreciable amount of absorbed moisture,and is increased by drying. If any water be present in the liquid form, it can be electrolysed readily into its constituents at power frequencies and suitable current densities. The oxygen so evolved may react with the oil, resulting in the deterioration of the oil-impregnated paper. Repeated stressing, above a certain voltage, will definitely result in electrical discharges in larger numbers and also elecrochemical reactions, which could lead to the destruction of the insulating properties of the oil-impregnated paper insulation.

When[18] electrical discharges take place within a gas bubble already present, they generate further gas through the decomposition ofthe oil, and the gas bubble increases in size. The rate of gas evolution is dependent on the nature of the oil, and the presence of additives.

THE RESULT OF DISCHARGES:

It has been reported[20] that ionic discharges result in carbonization, vapomrization. This carbonization short circuits the discharging void. It has also been observed that changes take place due to the cumulative effect of local chemical deterioration, vapourisation and resulting mechanical damage which may ultimately produce a condition where failure can occur, perhaps by an over-voltage.

EQUIVALENT CIRCUIT REPRESENTATION OF A SOLID INSULATION CONTAINING VOIDS:

A dielectric containing voids may be fairly represented as a combination of capacitances and resistances arranged as shown in figure (C.1) below[16]:

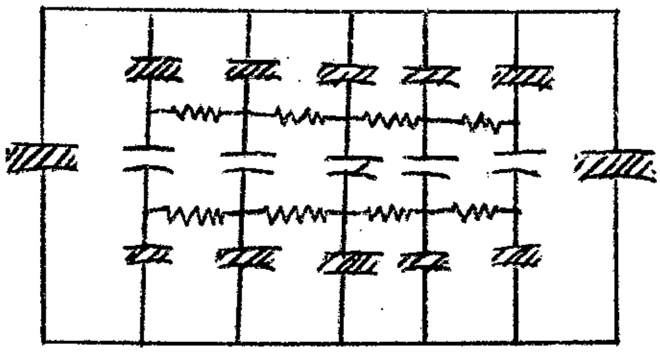


Fig: C.1 : Circuit Model of an Insulation consisting of Internal Voids.

Here the solid insulation is represented by shaded capacitors and the internal voids by unshaded capacitors. Each gas space is divided into numerous small capaciatances separated by resistors which correspond to the surface resistance of the insulation facing the gas space. Not all the gas voids discharge simultaneously. The discharge within the voids is dependent upon the stress developed within the voids, as a result of the application of voltage. Areas that have active points discharge first, and are followed by other areas as the voltage is raised higher and higher.

Burnier[16] has given a rather simple circuit analogy of the insulation under conditions of stress. He considers the gas spaces, in which discharges occur, as a capacitor shunted by a resistor. The value of this resistor- its resistance--varies with the applied voltage, being infinite at low-voltages and beginning to decrease as the voltage is raised above the corona starting voltage. The capacitor---gas space--is in series with a capacitor representing solid insulation whose loss angle is invariant with the voltage. From an analysis, it has been observed that a maximum in dissipation factor (tangent of the dielectric loss angle) will occur as the voltage is raised above the corona starting voltage.

THE EFFECT OF DISCHARGES ON THE DISSIPATION FACTOR:

The discharges taking place in the voids represent and irreversible absorption of power and contribute to the dielectric losses in the dielectric.

If there were no losses in the dielectric medium, then the angle between the voltage across it and the current through it would be in guardrature[30]. In an actual dielectric, this is not the case.

The difference in the angle is less than a right-angle. The difference between the quadrature angle and the angle actually present, is known as the dielectric loss angle. The tangent of this loss angle, δ, is called the dissipation factor. The dissipation factor is a very important parameter of an insulation.

Leaving out other factors, we shall consider the variation of dissipation factor with voltage. This is of considerable importance especially for the insulation of high-voltage cables, electric machines and other applications. The general tendency of this relationship, for a dielectric containing voids, is represented in figure (C.2.). The dissipation factor, tan δ, is almost constant upto a certain range of voltage V upto Vion, after which it begins to increase rapidly.

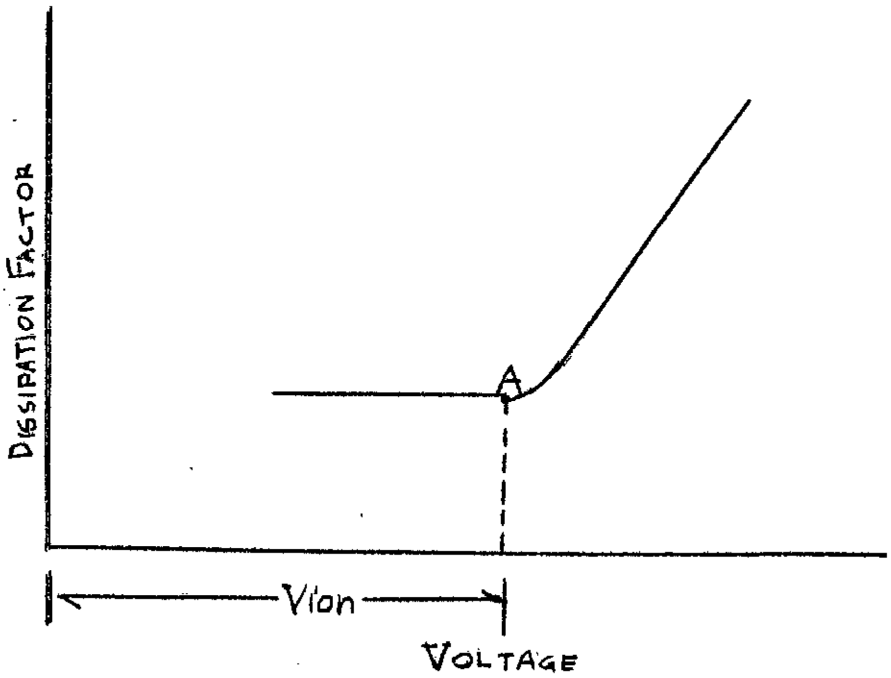


Fig : C.2. - The Ionization Curve of an Insulation having air or Gas Entrapped in it.

The curve showing the[19] relationship between dissipation factor and voltage is called the 'ionization curve'. Point A marks the threshould of ionization in the voids trapped inside the insulation. These voids increase in number as the applied stress is increased. This ionization is associated with a considerable absorption of energy which causes a sharp rise in the dissipation factor. It may be mentioned that the higher the ionization point, and the flatter the ionization curve beyond point A, the better is the quality of the insulation.

THE POWER LOSS IN DIELECTRICS:[21]

The dielectric power loss P (in watts) for an insulating medium is given by

$$P = V^2 2\pi f C \tan\delta$$

where V = applied voltage in volts

f = frequency of the applied voltage in cps.

C = capacitance of the insulation in farads.

The specific dielectric loss per unit volume of dielectric, is given by

$$P = E^2 f \frac{\varepsilon \tan\delta}{1.8 \times 10^{12}}, \text{ Watts/cm}^3$$

where P represents the specific dielectric loss per unit volume of the dielectric in W/cm^3

E = electric field intensity at the given point of the insulation in V/cm,

ε = permittivity of the dielectric.

THE EFFECT OF DISCHARGING VOIDS ON THE CAPACITANCE OF A DIELECTRIC:

The overall capacitance of a dielectric in which voids are present(or come into being as ax result of stressing or otherwise) is a combination of the capacitance of the solid insulation as well as the capacitance of the voids, which may contain air or any other gas. The representation of such a dielectric by a circuit model has been earlier in figure.

When a void discharges(16), it instantaneously short-circuits in the void a small area of the gas space, or the whole void. This results in the increase of the capacitance of the dielectric medium; becuase these gas spaces are in series with the solid dielectric. Since the number of discharges increase as the applied stress is increased, it is evident that the capacitance of the dielectric will also increase.

EQUIVALENT CIRCUIT REPRESENTATION OF A DISCHARGING VOID:

White head(22) has represented a discharging void, as shown in figure (C.3), by an equivalent circuit model. An internal discharge involves the partial or complete discharge of the capacitance of a void in a very short time compared to charge the capacitance by the variation of the applied voltage, except at high frequencies. In the figure C_c represents the gas-filled void in a solid dielectric, where C_b is the solid dielectric in series

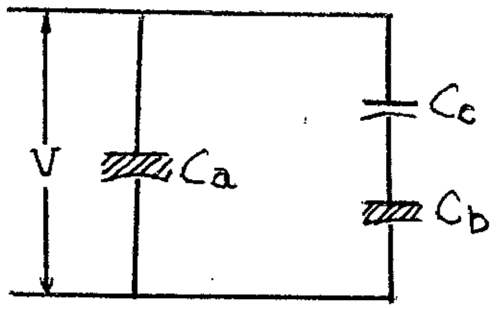


Fig: C.3 : Equivalent Circuit of a Discharging Void.

with it and Ca is the remaining dielectic. If now the gas in the void breaks down the voltage across C_c will fall by ΔV in a time not more than 10^{-7} sec when the discharge is extinguished. The energy dissipated is approximately

$$C_c \ \Delta V \ (V - 1/_2 \ \Delta V),$$

where V is the discharge voltage.

This happens provided Ca and Cc are much greater than Cb.

THE EFFECTS OF IONIC DISCHARGES IN THE VOIDS ON THE LIFE OF THE INSULATION:

Ionization or [1] corona is detrimental to the dielectric. They shorten the life of the insulation. The effects of corona may manifest in a change in the chemical composition of the dielectric,resulting in thedeterioration of the same. This is a volume effect and affects the whole insulation. The effects of these discharges can be observed by measuring the change in the dissipation factor. Evidently, the rate of ionization increases as the applied stress is increased.

APPENDIX-D.

THE FACTORS CONTRIBUTING TO THE LOSSES IN OIL-IMPREGNATED INSULATING SYSTEMS:

GENERAL DISCUSSION :

The dielectric loss behaviour in oil-impregnated paper insulation are influenced both by the geometry and the space-charge, which is trapped in the solid-liquied interface.(23) The losses are also affected by the behaviour of each component forming the interface. Three types of loss mechanism are generally found in insulating liquids. These are : i) ionic conduction, ii) dipole orientation and iii) space-charge polarization. Oils containing aromatic, napthanic, paraffinic constituents exhibit all the three types of loss. Ionic conductivity primarily determine the losses in cables at power frequencies and at about room temperatures. This ionic conduction increases with the increase in temperature, applied field strength, the polar contents of the oils, and also the oxidation products which form in the insulating liquid.

THE NATURE OF PAPER AND HOW IT AFFECTS IONIC CONDUCTION LOSSES:

The mechanism of loss in kraft paper assumes a very complex form due to the fact that the chemical and physical structure of the kraft paper affects the loss mechanism in oil impregnated paper insulation, system. The cellulose molecules of the paper fibres consists of a series of glucose repeating units arranged ar shown in the figure below :

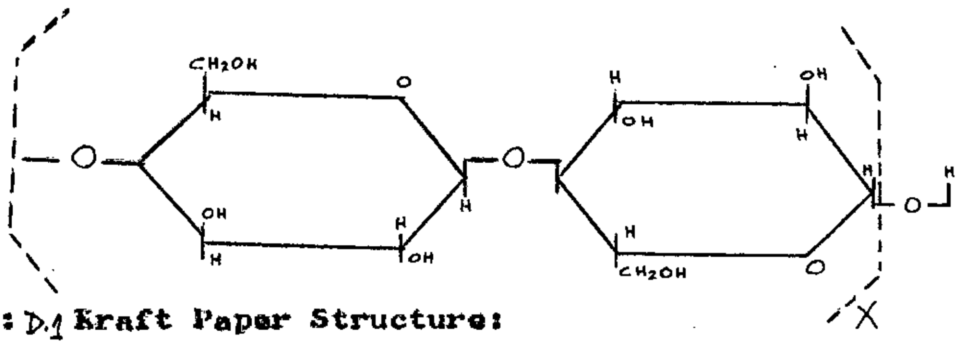


Fig: D.1 Kraft Paper Structure:

The repeating units are each of the order of 10Å, having an approximate width of 9 Å, and a thickness of 5Å. The polymolecular nature of the paper filmes prevent an exact determination of the molecular weight and chain-length, but estimates mange from 10^5 for the former and 10^3 A° for the latter. Then there are the carboxyl group which have not been shown in the figure obouve. They occur at the rate of about on per hundred glucose units. Their presence causes the cellulose to behave as a weak acid, having an ionization constant of 2×10^{-14}. Thus, if one views ionic conduction as a rate process, the carboxyl groups may, to some extent, effect the ionic losses within the paper at power frequencies. The smallest pore within a single cellulose fiber varies in length from 10 to 100Å. The cellulose fibers form a complex interwoven channel system within the paper, and hence enough space is there for long-range ion excursions within oil-impregnated paper, with, of course, the size of the ions being smaller than the pore size.

THE PRESENCE OF WATER DUE TO ABSORPTION:

There is some water present in the paper, even after the best methods of drying have been used, for a long durations. These water molecules are retained through absorption forces, by hydrogen bonds that exist between the H_2O dipoles, and the hydroxyl groups of the cellulose molecules. These will contribute to the ionic conductivity if dissociated. It is generally seen that even with the best drying, 0.5-1.0 % of the bound water is retained by the paper fibers.

SPACE CHARGE EFFECTS:

The space-charge effect can be macroscopically described by Wagner equations, if the properties of the insulating medium forming the interface are known.

The Wagner equations is :

$$\tan\delta = w\tau K/(1 + w^2\tau^2 + K)$$

where τ and K are the relaxation time and the absorption factors respectively, and are given by

$$= (E_2' + E_1')/(\sigma_2 + \sigma_1)$$

$$\text{and } K = \frac{(E_1'\sigma_2 - E_2'\sigma_1)^2}{E_1 E_2 \ (\sigma_1 + \sigma_2)^2}$$

Here σ_1, σ_2 and E_1', E_2' are the conductivities and the real permitivities of thetwo contiguous layers.

Thus, it is seen that $\tan\delta$ is an explicit function ofthe frequency, w, and an implicit function of the temperature and the field strength, becuase these determine the values of σ and E'.

From the above equation for K, it is seen that K is of finite value, so long as

$(E_1'\sigma_2 - E_2'\sigma_1) \neq 0$, when an interfacial space-charge loss results. It magnitude, at power frequencies, depends markedly on the value of $\tau = 1/_2\pi f$. At this value, the peak in $\tan\delta$ occurs. The value of $\tan\delta$ can thus rise or fall with frequency, temperature, and the field strength. It has been shown that the application of Wagner's analysis, in practice, is rendered impossible becuase numberous interfaces, having dielectric parameters whose values cannot be established and defined with certainty, are present.

There are some other mechanisms that describe the space-charge effects, but none of these can fully determine overall dielectric response of the complex solid-liquid insulating system. These mechanisms are known as (i) Garton and (ii) Boning effects.

The figure given below, depects a typical space-charge effect obtained with a practically dried cable model, impregnated with a low-viscosity pipe-filling oil.

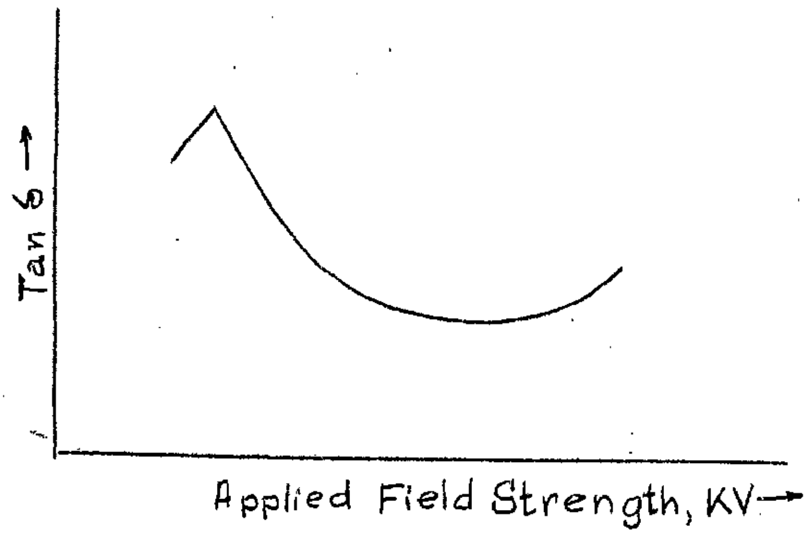


FIG. D.2. Space-Charge Effect.

DIPOLE ORIENTATION:

The third effect that contributes to the overall losses in the oil-impregnated paper insulation system is the effect of dipole orientation. This results from the alignment of induced and permament dipoles in the form of bridges and chains. An electron can travel with relative ease along these chains, and thus contributes to the conduction current. Since the diameters of the dipoles are small, an alignment of permament dipoles in the usual type of cable insulating oils is not possible over moderate field-strengths. However, induced dipoles, the majority of which consists of paper fibres suspended in the oil within the pores of the paper, the pores of the paper, are sufficiently large to form bridge. According to Kok, the condition for induced dipole alignment is

$$E_1' \left[\frac{E_2' - E_1'}{E_2' + 2E_1'}\right] r^3 E^2 = 1/_2 KT.$$

where E_1' and E_2' are thereal permittivities of the impregnated and the induced dipole, and E is the value of the applied field, K is the Boltzmann constant and T is the temperature in degress absolute.

CONCLUSION:

In the above discussion, a member of loss mechanisms have been described in brief. These loss mechanisms account for the losses, that take place in oil-impregnated-paper insulation. The factors contributing to the losses, have been shown to be depended on the mobility of the oil, the field strength, the temperature. Since a large number of factors are involved, a quantitative approach to the problem is difficult. Hence, the treatment of the problem should be along phenomenological times.

APPENDIX-E:

"CALCULATION OF ERRORS IN PERMITTIVITY AND POWER FACTOR FOR FLAT ELECTRODE SYSTEMS".

The Calculations given belowshow the differences, between the ture (true) and measured values of the dielectric constant and dissipation factor. Although, no flat electrodes were used, this section is given to facilitate further measurements and calculations.

PERMITTIVITY MEASUREMENTS:

Let C = equivalent series capacitance in μμf of the contact effect per cm^2 of area.

r = equivalent series resistance per cm^2 of area.

E = overall series permittivity of the specimen and contact.

t = thickness of the specimen in cm^2.

The overall capacitance per cm^2

$$= \frac{E}{4 \times 0.91} \mu\mu f = 0.0885 \frac{E}{t} \mu\mu f.$$

and the capacitance, C_s, of the specimen itself per cm^2 is obtained from,

$$\frac{t}{0.0885 E} - \frac{1}{C} = \frac{1}{C_s}$$

$$\text{ie., } C_s = \frac{0.0885 E_C}{tC - 0.0885E} \mu\mu f.$$

$$\frac{\text{Observed Permittivity}}{\text{Permittivity of the Dielectric}} = \frac{0.0885 E}{t} \frac{x(tC-0.0885E)}{0.0885EC}$$

$$= \left[1 - \frac{0.0885}{tC}\right]$$ from which the error introduced into the permittivity measurement is easily obtained.

POWER FACTOR MEASUREMENTS:

With regards to the power factor measurements, the tangents of the phase angles are considered.

Let ϕ_m be the angleof current lead for the material alone.

Let ϕ_T be the overall angle of current lead for the specimen and contact.

Then the series equivalent resistance (R) of the specimen and contact is

$$\frac{10^{12}}{w \times 0.0885\frac{E}{t}\tan\phi_T}$$

, where $w = 2\ \ x$ frequency.

Then the equivalent series resistance of the material alone is $(R - r)$

Hence,

$$\frac{\tan\phi_T}{\tan\phi_M} = \frac{\frac{W \times 0.0885\ EC}{(tC - 0.0885E)}(R - r)}{w \times 0.0885\frac{E}{t}R}$$

$$= \frac{(1 - r/_R)}{(1 - \frac{0.0885\ E}{Ct})} =$$

From this equation the error in power factor can be found out.

APPENDIX-F

CONDUCTION IN LIQUID DIELECTRICS :

INTRODUCTION:

The conductivity of pure liquid dielectrics is very low at low values of voltages. The conductivity can, however, be increased by increasing by the applied stress or by injecting conducting 'particles' into the liquid by some process.[31] Many workers have reported their investigations on the conduction phenomenon in weakly conducting liquids. It may be mentioned that they have used different techniques and mechanisms in their investigations. They have also reported that the conductance of liquid dielectrics increases due to the presence of impurities, including dissolved air, and also upon the material of the cell electrodes.

LOW-FIELD CONDUCTION:-

In hihgly purified insulating liquids, such as hexane, it has been observed[31] that, at low field strengths($<$ 10KV cm^{-1}), the resideual conduction current is due to trace amounts of impurity ions, and that the lower limit of current is ultimately determined by the ionization of the liquid molecules themselves by external cosmic radiation

HIGH FIELD CONDUCTION:

At high fields ($>$0.1 MV cm^{-1}) the[31] conduction process is known to involve emission of electrons from the cathode by either (1) cold emission, sometimes called field emission , in which the electrons tunnel through the surface potential barrier, or (2) by field enhanced thermoionic emission, usually refered to as Schottky emission. The latter process is a consequence of the lowering of the work function barrier by the applied field. This results in the emission of appreciable thermoionic currents even at room temperature.

In addition to[31] the above mentioned electrode processes, the dissociation of the liquid molecules, at high stresses, will in itself generate charge carriers. This effect results from the fact that the equilibrium constant of an undissociated molecule and its ions will increase with increasing field.

THE CONDUCTION IN IMPURE LIQUID

Since experiments here were performed on ordinary transformer oil, which contains impurities in many forms—such as dissolved gases, suspended particles, other dissolved impurities —, discussion on conduction phenomenon on such liquid dielectrics is presented here.

THE CONDUCTION MECHANISMS:

The conductivity of a liquid dielectric can be divided into two roups[22]: (1) the intrinsic conductivity and (2) the so-called impurity conductivity. The first is due to the liquid molecules themselves which dissociate into charged carriers at sufficiently high fields and which is dependent upon the applied stress. This intrinsic conductivity of liquid dielectrics is not equal to zero, no matter how thoroughly they are purified; there is always found to exist a certain residual conductivity. The intrinsic conductivity is ionic in nature, and results from the transport, by the electric field, of ions formed by partial dissociation of the basic molecules comprising the liquid. The degree of dissociation depends upon the molecules structure; neutral molecules are less capable of dissociation then polar ones. Hence, as a rule, dielectrics with a low dielectric constant exhibit poorer electrical conductivity than those having a greater dielectric constant. A non-polar (neutral) transformer oil has a residual conductivity of the order of 1×10^{-18} ohm^{-1} cm^{-1}.

IMPURITY CONDUCTIVITY

The impurity conductivity—as the name itself suggests—is due to the presence of the impurities in liquid dielctrics. Evidently, the nature of these impurities, their behavior in electric fields, contribute differently to the impurity conductivity. Thus, those impurities that are dissociable easily will contribute more than those which are not dissociable easily. Non-polar ones will contribute less than polar ones. Readily dissociable contaminants greatly increase the conductivity in polar dielectrics liquids because their degree of dissociation in such liquids is more than in non-polar ones.

MOLAR-IONIC CONDUCTIVITY:

Emulsified water, solid particles, and other contaminants give rise to still another form of additional electrical conductivity under the action of an applied electric stress, droplets of emulsified water and suspended solid particles will become electrically charged; they can therefore act as current carriers. Such conductivity may be termed molar ionic. In general, colloidal particles(as well as larger suspended particles)become positively changed by the electric field of their dielctric constant is greater than that of the liquid they are suspended in. If the liquid dielectric has a higher dielectric constant, the particles become negatively charged. This molar-ionic conductivity will rise with increase of temperature, due to decreased viscosity.

Depending on the ionic concentrate the electrical conductivity σ of a liquid may be expressed by the equation (22)

$$\sigma = N_o q f \; (K_+ \quad + K_-)$$

where N_o = number of ion pairs / cm^3

q = charge per ion

K_+ = mobility of the positive ions

K_- = mobility of the negative ions.

Mobilities of the positive and negative ions are not equal owing to the difference in their masses.

Ionic conductivity increases sharply with increase in temperature. This is due to greater dissociation and higher ion mobility with increase in temperature. If it is assumed that the mobility is the same for both types of charged carriers, the temperature dependance of ionic conductivity can be given by (21)

$$= A_e - \frac{a}{T} \quad ohm^{-1} \; cm^{-1}$$

$$A = \frac{N q^2 \; l^2 f}{6 \; KT}$$

where N = total number of ions/cm^3

l = distance between the particles in the liquid

f = frequency of natural vilirations of particles.

K = Boltzmann constant

T = absolute temperature.

a = $W/_K$.

W = activation energy.

The activation energy is the amount of energy necessary for separation of an ion from a neighbouring molecule to which it becomes attached during its movement in the electric field. As a first approximation, the quantity A may be considered independent of the termperature, especially in relation to the quantity $e^{-a/T}$.

SOME FACTORS RESPONSIBLE FOR INCREASED CONDUCTIVITY

Reaction between the liquid dielectric and oxygen also contributes to an increase in the conductivity. Investigations carried out by Balsbangh and his co-workers[27] point to the fact that for both oil and oil-impregnated paper subjected to oxidition in the presence of a copper catalyst either that conductivity in the early stages of oxidation increased more when the supply of oxygen was limited than when unlimited. Davenport and Évans[29] have shown that both weak and strong acids are present in oxidised insulating oils. Also, organic acids occur naturally in transformer oil, which is a mixture of non-polar hydrocarbons.

ELECTRICAL DISCHARGES IN LIQUID DIELECTRICS, AND THEIR EFFECT ON CONDUCTIVITY:

Electrical discharges in dielectric liquids result in electro-chemical reactions. Important to their behaviour is the formation of gaseons ions, gases, and condensation products. Even for simple hydrocabrons[29], like benzene (C_6H_6), it has been shown that a great variety of gaseons ions are formed. The volume of thegas evolved depends upon the structure, volatility, and viscosity of the oil, and the partial pressure of the gas in contact with it. In general, paraffinic hydrocarbons evolve the greatest amount of gas and aromatics the least, as judged by the overall results of the various investigators.

Electrical discharges usually produce more polymerized or condensed hydrocarbons than gas, as has been reported for decalin.[1]

Electrical discharge, in the gas space in the environment of liquid dielectrics generally cause a more or less permanent increase in the conductivity of the dielectric liquid.[32]

Although the[1] conductivity increases very much when hydrocarbons are subjected to elect.discharges in the absence of air, oxygen usually accelerates the process. It has been also shown that nitrogen or carbon dioxide also increases the conductivity markedly.

APPENDIX - G.

BRIDGE NETWORKS GENERALLY USED FOR THE MEASUREMENTS OF DISSIPATION FACTOR AND CAPACITANCE OF DIELECTRICS.

INTRODUCTION:

A brief description is given here of some bridge methods that have been used for the study of dielectrics, particularly to find their capacitance and dissipation factor (the tangent of the dielectric loss angle). B. Hague's book[2], "Alternating Current Bridge Methods", describes several devices for such measurements. A few important methods are included below:

1.1 WEIN-DE SAUTY'S BRIDGE: De sauty's[2] simple bridge, with resistance ratio arms, as improved by Wein is shown in figure 1.1. Balance can be secured by varying the resistance B and the variable resistance S, it being in series with the standard air capacitor, C_s, r_s. at balance,

$$\text{(a)} \tan\delta = (W C_x r_x)$$

$$= \tan\delta_s + wC_s$$

$$\text{and (b)} \quad C_x = BC_s/A.$$

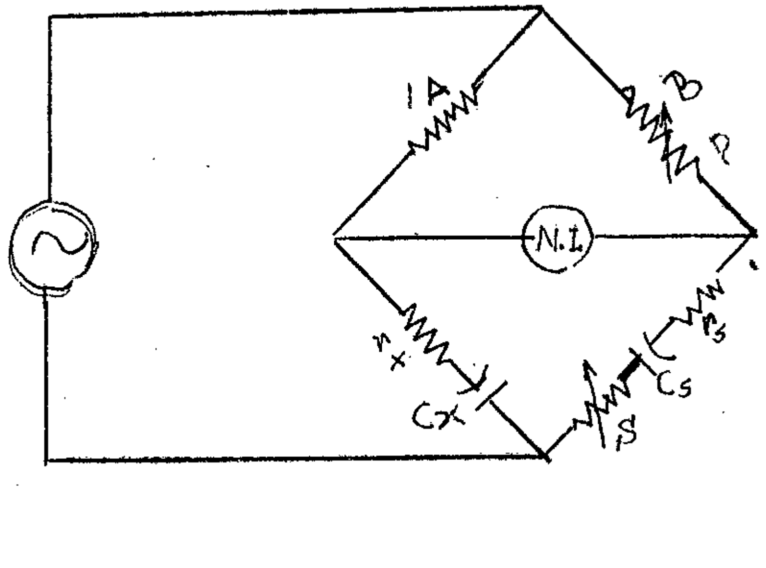


Fig-A.1. WEIN-DE SAUTY'S BRIDGE.

Maximum sensitivity is secured when A = B. These may be identical resistance coils, final balance being secured by alternately vary C_s and S.

1.2 ATKINSON'S BRIDGE:

Atkinson[5] has mofified the Wein Bridge by using an auxiliary transformer on one side. This enables the unknowns of the capacitor, a length of high-voltage cable, to be determined in terms of the ratio arms, R_1 and R_2 (Fig. A.2), a low-voltage standard air-capacitor C_s of fixed value and provided with a variable resistance r_s, and the ratio arms T of auxiliary transformer to main transformer. By using a substitution method and an air capacitor of known capacitance C_o, the transformer ratio term drops out of the expression

$$C_x = C_a \frac{R_1 R_2'}{R_2 R_1'}$$

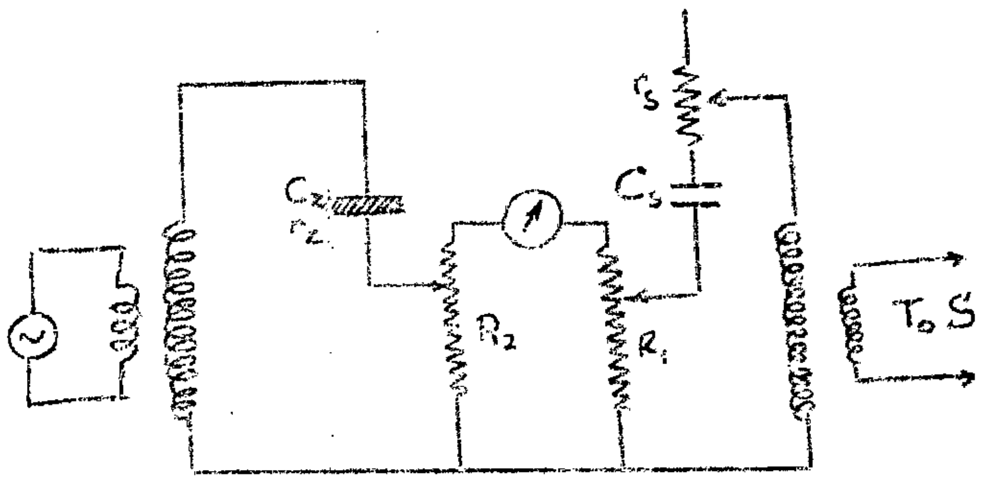


Fig-A.2.

Atkinsons' Modificationof the Wein Bridge For Measuring Dielectric Loss in Cables.

It R_2 is changed only in steps, so that R_2'/R_2 is any integer m, then

$$C_x = m\, C_a\, R_1 / R_1'$$

Finally, $\tan \delta_x = w\, r_x C_x = wC_s \left[(r_s - r_s') + (R_1 - R_1')(1-T) \right]$.

The bridge can be made direct-reading as to capacitance, and Atkinson has introduced a method for making the value of r_s read per cent power factor directly.

1.3 DAWES AND HOOVER'S BRIDGE:

Dawes and Hoover(6) have added a mutual inductor to the basic De sauty's bridge. Their bridge is shown in fig 1.3.

Neglecting self-inductance M, we get

$$C_x = C_s R_1 / R_2$$

$$\text{and } \tan \delta_x = wC_x R_x = w\, M/R_1.$$

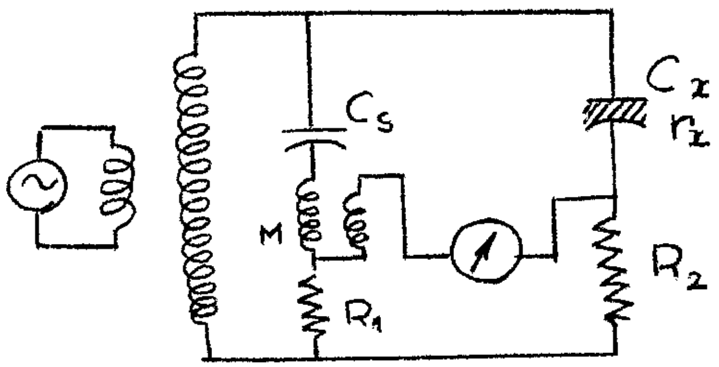


Fig-A.3. Dawes and Hoover's Bridge.

1.4 TRANSFORMER BRIDGE:

A Transformer Bridge has been designed by Doyle and Saltor [7]. In this method, the principle of capacitance-train method(used to determine the ratio of instrument protential transformers), is reversed a transformer with known transformation ratio is used to compare the capacitance under test, (C_x, r_x), with a standard capacitor C_r. By making a second balance with a loss-loss air capacitor C_s, the ratio of the transformer is eliminated, and $C_x = C_s\, C_r' \,/\, C_r''$.

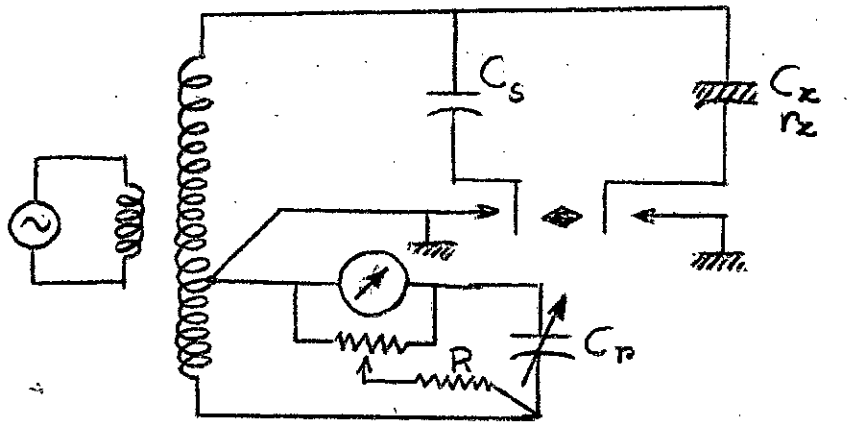


Fig-A.4 : Transformer Bridge.

The application of the Aryton shunt to the shunting resistance R, across C_r, permits the determination of tan , and the computation of the loss tangent or dissipation factor

$$\tan \delta = w\, C_x\, r_x = \frac{1}{W\, C_r\, RS}.$$

is the multiplying power of the Aryton Shunt.

This method has a considerable advantage because the guard plate of the test piece, and also all guards and shilds, can be connected directly to earth.

The above equations (for the different types of bridges mentioned) are approximate, and are correct within 0.1% for capacitors with power factors below about 5.0%.

SCHERING BRIDGE:

A detailed description of this bridge has been given in the Chapter-2, r, because it was used in the experiments.

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