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COMPUTATION OF THE ELECTROSTATIC FIELDS TO EVALUATE THE COMPRESSION OF ECCENTRIC INSULATION IN POWER CABLES

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حساب المجالات الالكتروستاتيكية لتقيم عملية الانضغاط الالكتروستاتيكى في عازل الكابل الغير محورى

الخلاصة :ـ

هذا العمل يبحث طريقة حساب المجالات الالكتروستاتيكية لتقيم عملية الانضغاط الالكتروستاتيكى فى عازل الكابل الغير محورى. استعمل لهذا الغرض احدى طرق التحليلات المعروفة بطريقة الانقلاب او الانعكاس للحدود المنحنية ، اى الانتقال بالتحليل الحسابى من مستوى معين الى مستوى اخر او العكس. قدم فى هذا البحث بيان تاثير الضغط الالكتروستاتيكى على جهد الانهيار الكانيكى الحراري المصاحب لعملية الانضغاط خلال برنامج عملية دورة التحميل المعروفة. وقد تمت مناقشة تحليل واستخلاص العلاقة بين جهد الانهيار الميكانيكي الكهربى الناتج من عملية الانضغاط الالكتروستاتيكى للكابل الغير محورى الى نظيره المحورى .

ABSTRACT

This paper investigates the computational electrostatic fields necessary to evalute the electrostatic compression of eccentric insulation in power cables. An analysis of the electrostatic fields using the transformation of curved boundaries via the inversion transformation is used to compute the compression of eccentric insulation. The effect of electrostatic pressure on thermomechanical breakdown of eccentric dielectric of power cables during the load cycle program is presented. The relation between the compressive electro-mechanical breakdown due to the electric field strength for eccentric insulation and coaxil cable is discussed and analysed.

1. INTRODUCTION

Some investigations involve the calculation of the compression of coaxial insulation of power cables during the load cycle program [1-3]. All cables break-down at one stage or another during the load cycle program; usually during the cool-down period. Relatively large differences in the coefficients of thermal expansion between the polyethylene insulation and the conductor, force the insulation to undergo plastic deformation within every load cycle [2]. This deformation has been brougt about by mechanical stresses in the insulation . In addition to the above mentioned process, there is technological inexactitudes, which may lead to eccentric placement of a cable conductor within surrounding dielectric. From this point of view, it is useful to study the common effect of technological inexactitudes during the load cycle program of power cables [2,4].

In this paper, our effort is devoted, as a first step, to compute the electrostatic forces required to determine the compression percent in case of eccentric insulation through the loaded cable. The study includes the transformation of curved boundires and their inversion-transformation to investigate the effect of an eccéntric insulation of single core cables as a model of calculation on thermo-mechanical breakdown during the load cycle program.

2. BASIC CONCEPT OF LOAD CYCLE PROGRAM

Fig. 1. demonstrates the load cycle program for any loaded eccentric cable, based on the previous study of coaxial cables [3]. The sequence of events in one load cycle leads to simulataneous application of axial tension and hoop stress to the dielecrtic cable during the cool-down phase. Generally, an eccentric cavity will form between the conductor and the insulation material , phase (b) of Fig. 1, while an eccentric cavity will form between the insulation and the metallic sheath, when the cable reaches the cold state , phaae (e).

3. ANALYSIS OF ECCENTRIC ELECTROSTATIC FORCES

The electrostatic force F_e is normally the gradient of the electrostatic stored energy W_E [2], viz ;

$$F_e = - \text{grad } W_E$$
$$= - (d/dX)(1/2\ C\ V^2) \qquad \ldots\ldots\ldots\ldots\ldots\ldots \qquad (1)$$

where

F_e is the electrostatic force
W_E is the electrostatic energy
C is the capacitance of cable dielectric
V is the voltage applied across the dielectric of the cable.

The solution of equation (1) is in determining the capacitance of eccentric cable insulation. For eccentric cable, let the non-concentric boundaries of Fig. 2. (a) be placed in z-plane with radii R_1, R_2. By using the special form of the bilinear transformation,inversion [6], it is found that, the field between the two charged of curved boundaries may be used to determine the breakdown voltage of cable insulation. The solution of this eccentric field is transformed into a concentric circles in the t-plane with radii of r_1, r_2 as shown in Fig. 2. (b).

where

$$d = \frac{R_2^2 - R_1^2 + e^2}{2e} + \sqrt{\left(\frac{R_2^2 - R_1^2 + e^2}{2e}\right)^2 - R_2^2} \qquad \ldots(2)$$

$$r_1 = \frac{R}{d^2 - R_1^2} = \frac{R_2^2 - R_1^2 - e^2}{2eR_1} - \frac{1}{2eR_1}\sqrt{(R_2^2 - e^2 - R_1^2)^2 - 4R_1^2 e^2} \qquad \ldots(3)$$

$$r_2 = \frac{R_2}{(d-e)^2 - R_2^2} = \frac{R_2^2 - R_1^2 + e^2}{2eR_2} - \frac{1}{2eR_2}\sqrt{(R_2^2 + e^2 - R_1^2)^2 - 4R_2^2 e^2} \qquad \ldots(4)$$

Now, the capacitance per unit length is found from the arrangement of t- plane as follows;

$$C = \frac{2\pi\epsilon}{\ln r_2/r_1} \quad \text{F/m} \qquad \ldots\ldots\ldots\ldots\ldots (5)$$

By substituting the two values of radii r_1 & r_2 of equations (3) and (4) into equation (5), then;

$$C = \frac{2\pi\epsilon}{\ln((K_1/R_2)\,/(K_2/R_1))} = (2\pi\epsilon\,/\,K) \qquad \ldots\ldots\ldots\ldots(6)$$

where,

$$K_1 = R_2^2 - R_1^2 + e^2 - \sqrt{(R_2^2 + e^2 - R_1^2) - 4R_2^2\,e^2}$$

$$K_2 = R_2^2 - R_1^2 - e^2 - \sqrt{(R_2^2 - e^2 - R_1^2) - 4R_1^2\,e^2}$$

$$K = \ln\,((K_1\,/R_2)/(K_2\,/R_1)),$$

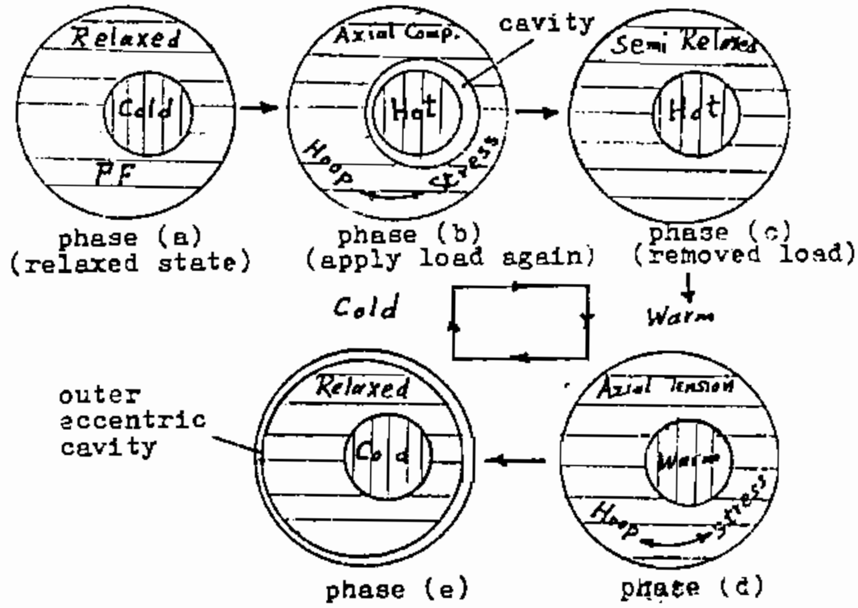


Fig. 1. Load cycle program for any eccentric insulation of cable.

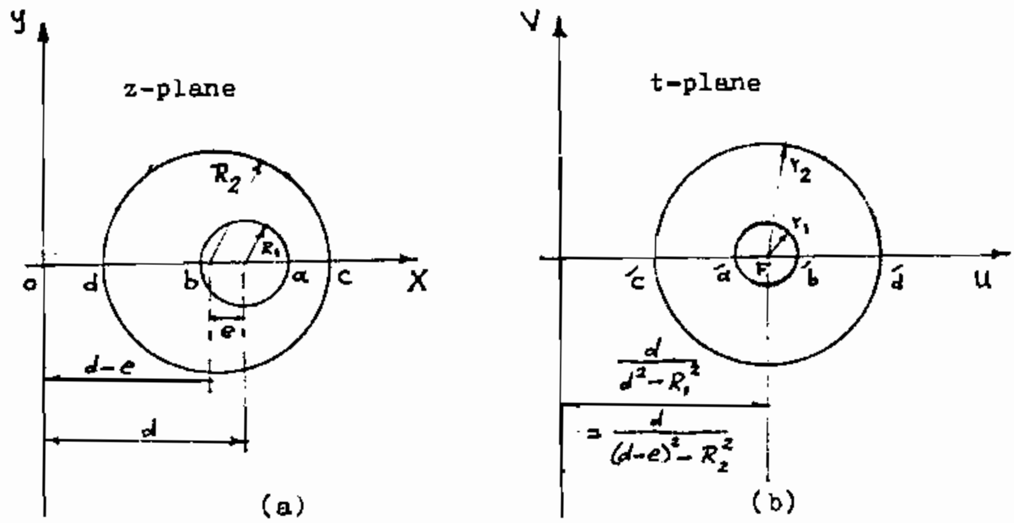


Fig. 2. Eccentric cable insulation as non-concentric boundaries in (a) of z-plane, and its transformati of inversion in (b) of t-plane.

and

$$r_2 = (K_1 / 2eR_2)$$

$$r_1 = (K_2 / 2eR_1)$$

Thus, the capacitive gradients at the two elecrodes of eccentric cable are given by :

$$dC/dR_2 = (d/dR_2)(2\pi\epsilon/K) = (2\pi\epsilon)(d/dR_2)(K)^{-1}$$

$$= -(2\pi\epsilon)(K)^{-2}(K_{22}) \qquad \dots\dots\dots\dots\dots\dots (7)$$

where

$$K_{22} = ((1/K_1)(K_1') - (1/K_2)(K_2') - (1/R_2)) ,$$

$$K_1' = (d/dR_2)(K_1)$$

$$= 2R_2 - \frac{2(R_2^2 + e^2 - R_1^2).\ 2R_2 - 8R_2e^2}{2\sqrt{(R_2^2 + e^2 - R_1^2)^2 - 4R_2^2e^2}} ,$$

$$K_2' = (d/dR_2)(K_2)$$

$$= 2R_2 - \frac{2(R_2^2 - e^2 - R_1^2).\ 2R_2}{2\sqrt{(R_2^2 - e^2 - R_1^2)^2 - 4R_2^2e^2}}$$

Similarly,

$$dC/dR_1 = (2\pi\epsilon)(d/dR_1)(K^{-1})$$

$$= -(2\pi\epsilon)(K^{-2})(K_{11}) \qquad \dots\dots\dots\dots\dots\dots (8)$$

where,

$$K_1'' = -2R_1 - \frac{2(R_2^2 + e^2 - R_1^2).(-2R_1)}{2\sqrt{(R_2^2 + e^2 - R_1^2)^2 - 4R_2^2e^2}} ,$$

$$K_2'' = -2R_1 - \frac{2(R_2^2 - e^2 - R_1^2)(-2R_1) - 8R_1e^2}{2\sqrt{(R_2^2 - e^2 - R_1^2)^2 - 4R_1^2e^2}}$$

Using equations (7) and (8), by substituting in equation (1), and dividing by the circumference in t-plane, the internal and external electrostatic pressures per unit area at constant voltage are seen to be;

$$P_i = \frac{-(1/2)(V^2\, 2\pi\epsilon)(-K^{-2}K_{11})}{2\pi r_1} = \frac{\epsilon V^2}{2(K_2/eR_1)} K^{-2}K_{11} \quad \dots (9)$$

$$P_{ex} = \frac{\epsilon V^2}{2(K_1 / eR_2)} K^{-2} K_{22} \qquad \text{......................} (10)$$

The cylinders in the z-plane, Fig 2. (a), have equipotential boundaries at different potentials and so, in the t-plane, Fig. 2. (b), the concentric cylindrical boundaries must be equipotential lines with the same difference in potential between them. Therefore, the potential of the field between two concentric cylindrical media in t-plane (Fig. 2. (b)), centered at point (F,0), separated by the same eccentric medium of relative permittivity and carrying a charge of q units per unit length is given by :

$$\psi + j\phi = (q/2\pi\epsilon) \ln (t - F)$$

By considring two points, one on each of these cylinders :

$t_1 = F + r_1$, and $t_2 = F + r_2$,

with the same flux function (ϕ). The potential difference between them may be expressed as:

$$\psi_1 - \psi_2 = (q/2\pi\epsilon) \ln (r_2/r_1) \qquad \text{................} (11)$$

where,

$\psi_1 - \psi_2$ is the potential difference between the concentric cylinders.

The potential gradient at any point in the medium between the two cylinders is based on equation of (11) and ref. [5], and is given by:

$$[E] = [dw/dz] = [dw/dz] . [dt/dz],$$

where,

$$dw/dz = (q/2\pi\epsilon)(1/t-F) = ((\psi_1 - \psi_2)/(\ln r_2/r_1))(1/t-F),$$

But the inversion of transformation is given by t=1/z , then:

$dt/dz = - 1/ z^2$. Thus;

$$[E] = [(\psi_1 - \psi_2)/(\ln r_2/r_1)(1/t-z)(1/z^2)$$

$$= [(V/(\ln r_2/r_1)(1/z(1-Fz))]$$

$$= [(V/K)(1/z(1-Fz))] \qquad \text{...................} (12)$$

The maximum value of potential gradient is important in the consideration of the breakdown voltage between the non-concentric boundaries (eccentric cable) of z-plane (Fig. 2. (a). This value is obtained at the point on the shortest line between the cylinders at the inner surface of boundary (point a). This point is $z = d + R_1$ at point a in z-plane to which corresponds the point $t = F - r_1$ at point a in t- plane, see Fig. 2. Thus;

$$[E\ max]a = [(V/K)(1/(d+R_1)(1-((1/d+R_1)-r_1)(d+R_1))] \qquad (13)$$

$$[E\ max]a = [(V/K)(1/r_1\ (d+R_1)^2] \qquad (14)$$

By substituting equation (14) at point a in z-plane, in Eq. (9), the internal electrostatic is given by;

$$P_i = \frac{\epsilon}{2(K_2/eR_1)} \cdot K^{-2} K_{11} [\ E^2 max_a \cdot K \cdot r_1 \cdot (d+R_1)^2] = C_1 \cdot \epsilon \cdot E^2 max_a \quad g/cm \qquad (15)$$

where

$$C_1 = (10^2 X10^9 /2X36\pi).(10^5/9.807) \cdot \frac{K_{11}\ r_1(d+R_1)^2 \cdot eR_1}{K_2 \cdot K}$$

Similarly, to obtain E min at point C of Fig. 2. (a), let $z = d + R_2 - e$, $t = F - r_2$ by inversion transformation [6], we get;

$$[E\ min]c = [(V/K)(1/r_2(d+R_2-e)^2] \qquad (16)$$

and the external electrostatic pressure at point C is given by ;

$$P_{ex} = \frac{\epsilon}{2(K_1/eR_2)} \cdot K^{-2} \cdot K_{22}\ [E^2 min_c \cdot K \cdot r_2(d+R_2-e)^2] = C_2 \cdot \epsilon \cdot E^2 min_c \qquad (17)$$

where

$$C_2 = (10^2/10^9 /2x36\pi).(10^5/9.807) \cdot \frac{K\ \cdot r_2\ (d+R\ -e).eR_2}{K_1 \cdot K}$$

Stark and Garton [1] show the stress strain relationship of polyethylene, which is given by;

$$Stress = Y\ ln\ X_o/X \qquad (18)$$

where

Y is taken as a constant modulus of elasticity,
X_o is the original length of dielectric
X is the compressed length

The relative compressed distance for each internal electric field at a , and each external electric field at c, refering to equation (18) are given as follows;

$$\Delta X/X_o = 1 - \exp\left(-C_1 \epsilon/2Y\right) E^2 max_a \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (19)$$

$$\Delta X/X_o = 1 - \exp\left(-C_2 \epsilon/2Y\right) E^2 min_c \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (20)$$

From equations (19) and (20), the relative compressed distance, based on the total electrostatic force between the medium from point a to c, is given by;

$$\Delta X/X_o = 1 - \exp\left(-\epsilon/2Y\right)\left[C_1 E^2 max_a + C_2 E^2 min_c\right] \quad \ldots\ldots\ldots (21)$$

3. 1. Examples :

(1) Consider the following data, R_1 = 4 cm , R_2 = 2 cm , V = 10 kV, ϵ = 2.3, we find that, the eccentric electric field at point a by substituting into equation (14) is equal to the value 779.7 kV/cm. The value of relative compressed distance $\Delta X/X_o$ at point a is given, about 16% . Thus, ΔX_1 = 1.6 mm.

By applying the same technique at point b at anoter side of the circle of Fig. 2. (a), we find that , the eccentric electric field at point b equal to the value 96.45 kV/cm. Also the relativ compressed distance $\Delta X/ X_o$ at point b is about 0.27% ; i. e. ΔX_2 = 0.027 mm.

This means that, the electrostatic force creates an eccentric air gap around the conductor as shown in Fig. 3.

(2) Phase (b) of Fig. 1, is taken as example to drive an equivalent electromechanical breakdown criterion for eccentric cable dielectric. The criterion can be used to calculate the critical voltage at which the dielectric is compressed to (X - X) of its original thickness X at the medium of shortest distance ac.

By substituting equations (14), (16) into equation (21), we find

$$\Delta X/X_o = 1 - \exp\left(-M V^2\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (22)$$

From equation (22) the critical voltage is given by

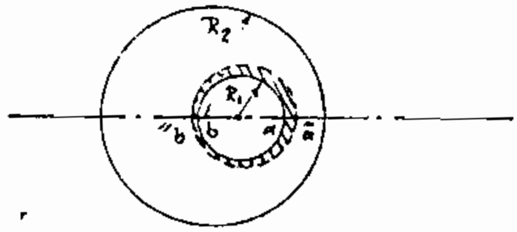
$$V = \sqrt{(1/M)\ \ln\ (X_o ac/X_o ac - \Delta X)} \quad \ldots\ldots\ldots\ldots\ldots\ldots (23)$$

where M is a variable function of different variables K ,K_1, K_2, C_1, C_2, and r_2 .

where r_2 is obtained from the inversion as follows;

$$r_2 = r_1 + ((1/d+R_1) - (1/d+R_2 - e))$$

From the relation (23), the critical voltage can be obtained as a



$\Delta X_1 = a \; a'' = 1.6$ mm

$\Delta X_2 = b \; b'' = 0.027$ mm

Diameter of internal cavity around the conductor

$= 2R_1 + \Delta X_1 + \Delta X_2$

$= 40 + 1.6 + 0.027 = 41.627$ mm ,

radius of eccentric cavity = 20.8 mm

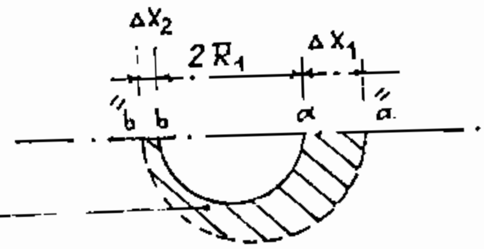


Fig. 3. Computation of eccentric cavity around the conductor due tu the ecceutric electric force.

function of conductor radius r_1 , thickness of insulation layer X_o , Modulus of elesticity Y , relative permitivity ϵ_r , the compressed thickness ΔX , and the value of displacement e; viz:

$$V = f\ (K\ ,\ K_1\ ,\ K_2,\ C_1,\ C_2\ r_2\ ,\ \ldots\ )\ \sqrt{\ln\ (X_o\ ac/X_o ac-\ \ X)} \qquad (24)$$

The largest stable value of voltage is obtained by the partial differentiation of equation (24) as follows:

$$\frac{\partial V}{\partial K} \cdot \frac{\partial K}{\partial K_1} \cdot \frac{\partial K_1}{\partial K_2} \cdots\cdots\cdots \frac{\partial r_2}{\partial \Delta X} = 0 \quad \cdots\cdots\cdots \qquad (25)$$

Solving the last equation by a graphical method [2] , the value of $\Delta X/X_o$ could be obtained. For the given example, it was found that, the electromechanical breakdown of eccentric insulation cable should happened when $\Delta X/X_o$ is 0.23. This value is about 50% of the required value in case of coaxial cable [3].

4. CONCLUSIONS

This paper presents an analysis to evaluate the compressed distance of eccentric insulation cables due to electrostatic forces. These forces create an eccentric air gap around the conductor which causes a complicated electrostatic field around it. A formula for the calculations of the compressed distance is obtained. It is found thst, the electromechanical breakdown of eccentric insulation cable should have happened when the relative compressed distance reaches to 50% of the required value in case of coaxil cable.

5. REFERENCES

[1] Stark, K. H., Garton, C. G.,"Electric strength of irradiated polythene", Nature, Vol. 176, pp. 1225-1226, 1955.

[2] Graneau, P.,"Under ground power transmission", JOHN WILEY & SONS, A Wiley-Interscience Publication, 1979.

[3] Gouda, O., El-Dessouky, S. S.,"Effect of electrostatic force on the thermo-mechanical breakdown of cable dielectric", Proceed. Internat. AMSE Confr. "Modelling & Simulation, Sorrento, Itely, Sept. Vol. 2-3, pp. 61-70, 1986.

[4] Fathi, M. H. Youssef, Taher, D. Eish, and El-Dessouky, S. S., "Influence of stranded eccentrcity on the electric parameters and forces in power cables", Proceed. Internat. AMSE Confr. "Modelling & Simulation", Cairo, Egypt, March 2-4, Vol. 2B, pp. 115-124, 1987.

[5] Binns, K. J., and Lawrenson, P. J.,"Analysis and computation of electric and magnetic field problems",Pergamon Press,1963.

A NEW EXPERIMENTAL TECHNIQUE TO MEASURE THE ELECTROSTATIC FORCE IN THE CABLE DIELECTRIC

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اسلوب تجريبي جديد لقياس القوة الالكتروستاتيكية فى عازل الكابل

الخلاصة :ـ

باسلوب تجريبي مقترح توجد امكانية لقياس القوه الالكتروستاتيكية فى عازل الكابل عندما يتعرض لدورات التحميل • لهذا الغرض تم تصميم نموذج اعد للتجارب لقياس الضغط الالكتروستاتيكى مباشره فى الفجوات التى تنشا نتيجة عمليات دورات التحميل سواء كانت بين الموصل و عازل الكابل او بين عازل الكابل الخارجى و غلاف الكابل الخارجى • وقد تمت مناقشة نتائج التجارب المعملية للقياسات الماخوذه بين الضغط الالكتروستاتيكى مع الزمن وكذلك مع الاجهاد الكهربى •

ABSTRACT

The proposed technique gives the possibility to messure the electrostatic force in the cable dielectric when the load cycle program is applied. For this reason, a new experimental model is designed to measure directly the electrostatic pressure in the cavities between the conductor and the insulation material or between the outer surface of the dielectric and the sheath of the cable. The experimental results of the electrostatic pressure with the time as well as with the electric stress are presented and discussed.

1. INTRODUCTION

All cables breakdown are usually at one stage or another during the series of load cycles. The load cycles creat cavities between conductors and the cable dielectric or between the metallic sheath and the outer surface of cable dielectric. These cavities were stored electrostatic energy. The change in the energy leads to electrostatic force and electrostatic pressure affect on the walls of coaxial cable insulation [1-4]. It is well known that, to calculate the electrostatic force , the gradient of the stored electrostatic energy must be found :

$$F = - \operatorname{grad} E$$

$$= - (d/dr)(1/2\ C\ V^2) \quad \text{.........} \quad (1)$$

where F is the electrostatic force.
E is the stored energy.
C is the capacitance of cable dielectric,
V is the applied voltage.

The negative sign indicates compression of the dielectric between cable conductor and the metallic sheath.

The analysis of the electrostatic force by applied the load cycle program of different phases from (a) to (e), Fig. 1, gives the internal and the external electrostatic pressure respectively as follows [3]:-

$$P_i = - (\epsilon_o \epsilon_r / 2) E_i^2 \quad \text{...........} \quad (2)$$

$$P_o = - (\epsilon_o \epsilon_r / 2) E_o^2 \quad \text{...........} \quad (3)$$

where

E_i , E_o are the internal and the external electric stress on the cable dielectrics.

From equations (2), (3), it is noticed that, the electrostatic pressure depends on the electric strength and the dielectric constant. It is not a function of the dielectric thickness.

Experimental work by J. D. Cross [5] indicates that, with 50 µm-thick polyethylen films, an electrostatic pressure of 25.9 kg/cm under voltage stresses of order 5 MV/cm.

Until now the electrostatic force on the insulation of a solid dielectric high voltage cable is not measured. This paper contains a proposed experimental technique to measure directly the electrostatic pressure in the cavity between the conductor and the dielectric cable with time at different values of electric stresses.

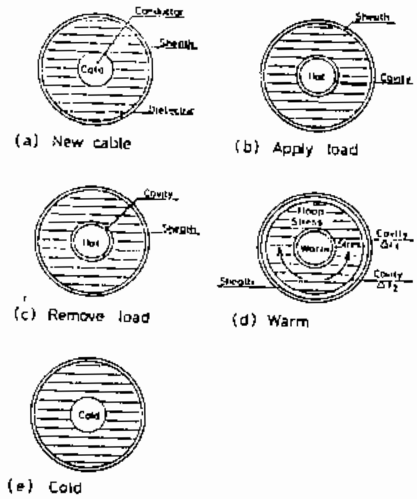

Fig. 1. Load cycle program for any cable.

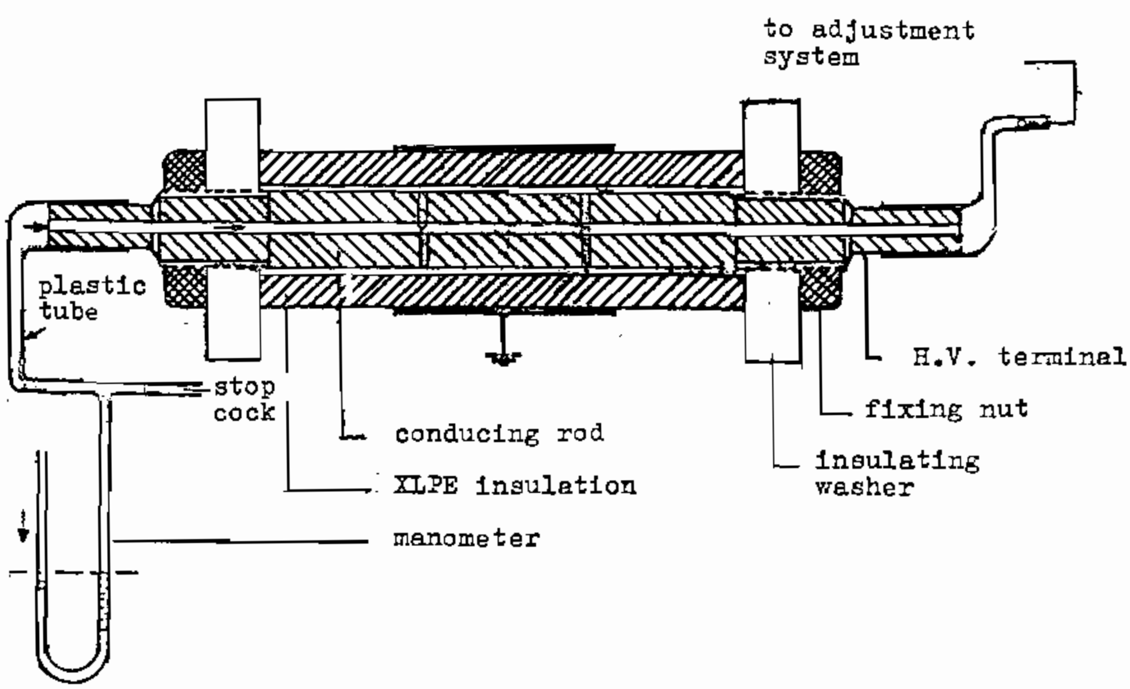

Fig. 2. Test arrangement.

2. EXPERIMENTAL WORK

2. 1. Test Technique

The test technique is carried out on a model of medium h. v. cable of XLPE-12/20 kV and 3x150 mm^2 cross sectional area of aluminum conductor. The model is prepared to simulate the condition of load cycle program of the cable when there is a cavity due to the compression of dielectric between the cable conductor and the inner insulation surface. The aim of this test is to measure the value of the electrostatic pressure between the cable conductor and the inner insulation surface under normal operation conditions.

The sample under test is taken from one single phase of the XLPE-12/20 kV cable with length of 9 cm. The aluminum conductor was extracted from its position, leaving it empty. A special brass conductor rod is inserter instead of the aluminum conductor with a clearance of 1 mm between it and the inner surface of insulation. The rod conductor consists of a brass rod of 17 cm length with 14 mm diameter. The rod was reduced to 8 mm diameter, and screwed from both sides to a distance of 2 cm. The rod was drilled along its axis with 3 mm diameter from both sides to a distance of 7 cm from each sides, and drilled prependicular to axis from both sides with 1 mm hole diameter till the hole reaches to the axis only as illustrated in Fig. 2. It is seen from the figure that, the rod conductor was inserted in the XLPE insulation with an air gap clearance of 1 mm between the rod conductor and the inner surface of insulation. The rod was tighted to insulation by the aid of a nut and insulation washer.

2. 2. Test Arrangement

The high voltage supply used in the experimental work is a single phase transformer, 60 kV, 80 kVA rating. The testing transformer is just complying with the IEC. The high voltage terminal is connected to the conductor, and the earthed electrode was connected to the external surface of the XLPE insulation as shown in Fig. 2.

One terminal of the hollow rod was connected to pressure adjustment system via a stop cock, the other terminal was connected to a manometer for pressure measurement.

2. 3. Test Procedure

The pressure inside the test sample is adjusted with the aid of adjustement system. The high voltage is then applied and the manometer reading is observed. It is noticed that, the pressure is changed with time. The electrostatic pressure inside the cavity between the cable conductor and the insulation surface affected the outer surface of the diele and this leads to increase in cavity thickness. This in turn produces the manometer readings. The arrows indicate to the flow of pressure, Fig. 2. At each specified voltage the pressure is recorded with time.

3. RESULTS AND DISCUSSION

The electrostatic pressure was measured under different voltage stresses, 60 kV/cm, 120 kV/cm, and 150 kV/cm. The test resluts of Fig. 3. give the relation between the electrostatic pressure in torr versus time in hours. It is noticed that, the relation is non linear, and the electrostatic pressure increases rapidely with the time of testing. This is because, the increasing in the electrostatic pressure increases the air gap thickness between the conductor and the insulation surface. This means more electrostatic stored energy and in turn increasing the electrostatic pressure. The testing was carried out to obtain the relation between electrostatic pressure and the electric stress at different times, (1/2 hour, 1 hour, 2 hours), as illustrated in Fig. 4.

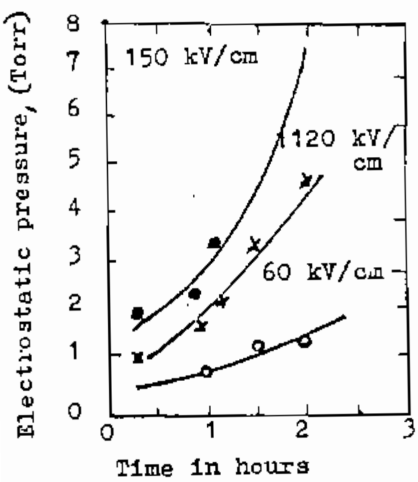

Fig. 3. Relation between the electrostatic pressure and the time of testing.

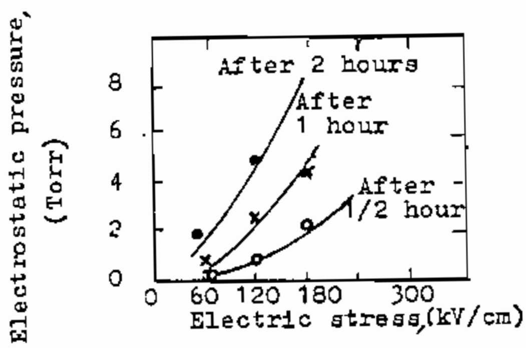

Fig. 4. Relation between the electrostatic pressure and the electric stress at different time.

The authors expect if the testing time increased to some days, the testing sample will expose to mechanical breakdown of insulation. Fig. 5. shows this phenomenon process until a mechanical breakdown of the insulation occurs.

One major difficulty of any mechanical breakdown model is to find mathematical description for the mechanical properties of the cable insulation. The stress-strain relationship of low density dielectric is suggested in Ref. [6] as follows;

$$\text{Stress} = Y \ln (X_o/X) \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

where

Y is the modulus of elasticity
X_o is the original length of the dielectric
X is the compressed length

By equating equation (4) to (2), we get

$$\Delta X/X_o = \exp(-\epsilon_o \epsilon_r/2Y)\ E_i^2\ ;$$

$$\Delta X/X_o = 1 - \exp(-\epsilon_o \epsilon_r/2Y)\ E_i^2 \quad \ldots\ldots\ldots \quad (5)$$

where

ΔX is the compressed distance of X_o

In case of phase (b), when the cavity is created between the cable conductor and the dielectric, the compressed distance ΔX can be calculated by equation (5). Another relation could be obtained in phase (e) by equating equations (4), and (3) ;

$$\Delta X/X_o = 1 - \exp((-\epsilon_o \epsilon_r/2Y)\ E_o^2 \quad \ldots\ldots\ldots\ldots \quad (6)$$

The relation between the electric field strength and the compressed distance relative to the original length $\Delta X/X_o$ is given in Fig. 6. Thereby the Young's modulus of elasticity is found to be 600 kg/cm.

In future, the same technique could be used to measure the electrostatic pressure between the outer surface of the dielectric and the sheath of the cable. Therefore, in phases (c) and (d) of Fig. 1, where the cavity around the conductor is going to remove and that between the outer surface of dielectric and metallic sheath is going to be created, the resultant electrostatic pressure is given by;

$$P_t = (\epsilon_o \epsilon_r/2)\ (E_o^2 + E_i^2) \quad \ldots\ldots\ldots\ldots \quad (7)$$

In this case, to determine the critical voltage producing the mechanical breakdown through the compressed distance between the inner surfsce and the outer surface of cable dielectric one must use the equation (7) with the above experimental results of the electrostatic pressure.

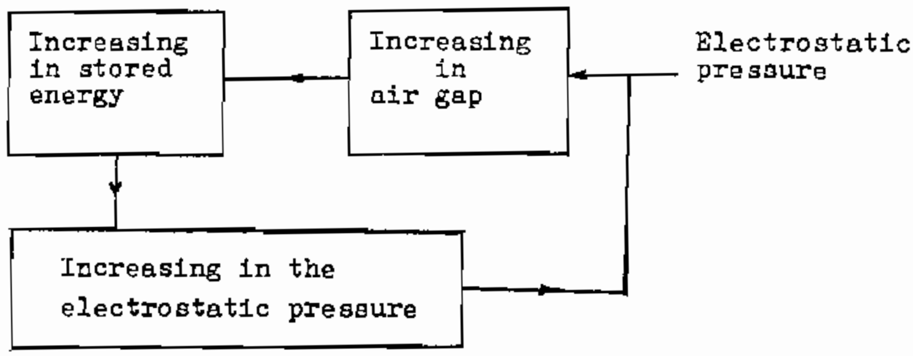

Fig. 5. Circulating of phenomenon process until mechanical breakdown of the insulation occurs.

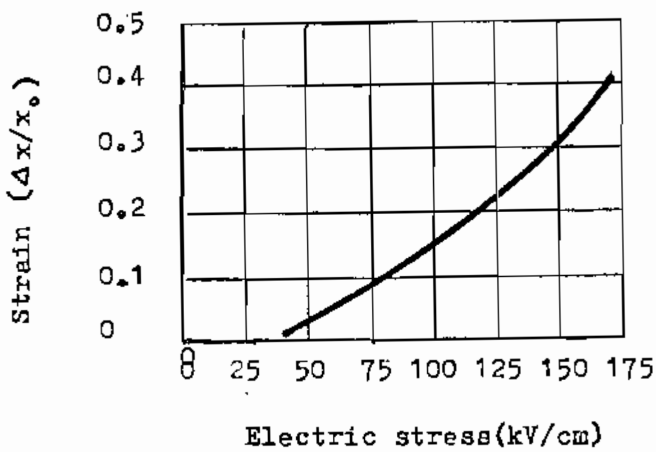

Fig. 6. Relation between ($\Delta x/x_o$) and the electric stress.

5. CONCLUSIONS

An innovative method is suggested to measure the electrostatic pressure in cavities between the insulation layer and the cable conductor. The results of electrostatic pressure with the time at different electric stress is non linear. The electrostatic pressure increases rapidely with the time of testing.

The results indicate phenomenon of circulating process of increase in air gap, increase in stored energy and in turn increasing the electrostatic pressure. The same technique could be used to measure the electrostatic pressure between the outer surface of the dielectric and the sheath of the cable.

5. References

[1] Stark, K. H., Garton C. G, "Electric strength of irradiated polythene", Nsture, Vol. 176, pp. 1225-1226, 1955.

[2] Graneau, P.,"Under ground power transmission", JOHN WILEY & SONS, A Wiley-Interscience Publication, 1979.

[3] Gouda, O., El-Dessouky, S. S.,"Effect of electrostatic force on the thermo-mechanical breakdown of cable dielectric", Proceed. Internat. AMSE Confr. "Modelling & Simulation, Sorrento, Itely, Sept. Vol. 2-3, pp. 61-70, 1986.

[4] Gouda, o., El-Dessouky, S. S.,"Effect of electrostatic force on the dielectric of the three phase under-ground cable", Proceed. Internat. AMSE Confr. "Modelling & Simulation", Cairo, Egypt, March 2-4, Vol. 28, pp. 115-124 , 1987.

[5] Cross, J. D., Chatterton, P. A., "The microstructure of condenced H O films when exposed to fields and breakdown in vacuum", J. Phys. D, Vol. 5, pp.2064-2067, 1972.

[6] Renfrew: Polythene, Interscience, 1960.