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Measurement of Strength of Vacuum Di-electric medium, [Cryogenic Insulant] in Vacuum Interrupter

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Abstract— OuThe paper is targetd to develop the system is to provide the path, for suspended particals in vacuum interruptor , which will constitute a leakage current through the vacuum insulent medium. As these suspended particals become the charge carriers; this current may or may not be a continuous or constant current. Therefore this current is not treated as the conventional current, but it is measured in terms of nano or micro coulombs, being a partial discharge through the medium. This partial discharge is inversely proportional to the 'strength' of the vacuum. The paper has defined the term 'strength' of the vacuum medium.' as "It is the Quantum of charge carriers present in vacuum medium."

Index Terms— B- Magnetic flux density,. ϕ- Flux, σ_r - Real surface charge density ,σ_p . Polarized surface charge density, E_r . Electric field intensity of real charge ,E_p . Electric field intensity of Polarized charge ,ϵ_o. Permittivity of vacuum

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1. INTRODUCTION-

The word cryo means extreme low, and gen means freezing. the term cryogenic means the matter dealing with extreme low freezing temperatures. The insulating materials show their performance as an ideal insulator when working with such cryogenic temperatures are treated as cryogenic insulants .This concept is on the parallel track of super conductors, but instead of conductivity, super insulating properties are given precedence. The cryogenic insulant means the insulating material, which shows practically ideal performance, when the particular degradation characteristics are known, under stressed size, stressing time, voltage shapes, voltage stresses, contaminants, voids etc.

However, such insulant must withstand any particular stressing voltage. Estimation of the amount of degradation needs the reliable extrapolation from small-scale experimental data, but there should not be any degradation in **Resistivity and Permitivity**.

Strength measurement of the vacuum, a cryogenic insulant dielectric medium includes **two** engineering parameters. One is it should indicate the Electrical parameter as **availability of free charge carriers** (air partials in this case); and second is mechanical engineering parameter, i.e. **degree of vacuum.**

As the paper talks about the "strength of vacuum dielectric medium using vacuum interrupter."

If the degree of vacuum approaches to the absolute vacuum, then 'it is possible for a vacuum circuit breaker to achieve the state of breaking at natural zero point exactly.'

This is solely depends on the ability of measuring system to measure the availability of free air particles as charge carriers in the VI chamber.

Strength measurement of a vacuum dielectric medium in a vacuum interrupter is a critical thing, because the **strength of vacuum dielectric medium in VI, depends on the impedance offered by the vacuum medium.** This impedance mainly depends upon the availability of the free charge carriers in the medium. In the Vacuum Dielectric medium, **the role of charge carriers is played by, the free residual air partials** in the vacuum. This is because, **it is practically impossible to create absolute vacuum in side the VI.**

As these charge carriers are also responsible for the thermal conduction through the medium, for thermal insulation calculations also the strength measurement is equally important in view of the mechanical engineering. Similarly the negative Pressure based Processes in chemical or Pharma industries are also keeping interest in correctness of degree of High vacuum measurement, found financing these researches.

The 'strength' of the vacuum medium. does not mean the B.D.V. of the medium for defined gap. It is to be defined as the term 'strength' of the vacuum medium.' as It is the Quantum of charge carriers present in vacuum medium.

The Selection of the vacuum – interrupter is purposely done because, as any other insulant mediums, like solid, liquid, Or Gaseous, we cannot take a sample quantity of vacuum for testing. Therefore a VI bottle is considered as a sample of vacuum.

I am interested in the methods **presently adopted to measure the strength of vacuum, and** about the new method suggested by my self. It uses the **inter action** of static electrical field and rotating magnetic field on the **charge carriers** present in the high vacuum medium.

I have discussed and gone through the various methods adopted by the different manufacturers and users for the measurement of strength of vacuum. The list of the same is as follows: -

1.Use of Gaga ohmmeter.
2.Using Magnetron principle to measure leakage current.
3.Use of logarithmic amplifier to measure leakage current.
4.Using vertically electrostatic field and in cross static magnetic field.
5.Calibration with mechanical evacuation system vacuum gauge.

Unfortunately, the studies on these issues are carried out in the view of Mechanical engineering only. Although this Cryogenic insulants have equal importance in **Mechanical** engineering aspect as a **Super Thermal insulation** as that of Electrical engineering aspect, but scope of the paper kept, limited to Electrical engineering aspect only.

The tests Related to Electrical Engineering Insulation Parame-

ters are considered only for the study purpose. The Mechanical Engineering Parameters are found by calibrating the electrical engineering parameters in terms of their Mechanical Engineering counterparts.

As per the mechanical engineering requirements, those people have taken interest in measurement of DEGREE of vacuum only as per their requirement norms. The present methods are sound, not sufficient to sweep the cornered or under trajectory charge carriers, while measuring the strength of vacuum in side the Vacuum interrupter.

The importance of Vacuum as an **electrical insulation** is only studied by some of the scientists working with mis sile or aerospace vehicle technologies or Vacuum circuit Breaker Manufacturers. But the problem with VCB manufacturers is limited to their guarantee period. This is because the factory made VI s cannot keep their internal pressure (**vacuum**) throughout their lifetime. As the claimed life of VI is in the range of 10 to 20 years, and Customer wants to be sure that the pressure in the vacuum interrupter won't increase significantly during this period. Thus it is a need of VCB manufacturers that there should be a technique, which could enable to detect the residual pressure in VI at any moment of time.

2. REQUIREMENTS FOR TESTING

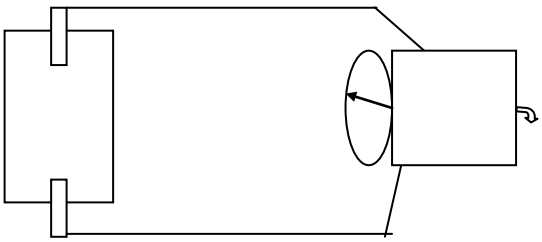
The most fundamental requirement of testing is an **AVAILIBILITY of test sample**.

For other Cryogenic insulants, which are either in **fluid** or **solid** form, it is easy to make the **sample** available for trial or testing purpose; and keep that sample at cryogenic conditions and then we can carry out all types of required testings. All above said methods are not able to measure the strength of vacuum up to required accuracy. Therefore the efforts are needed to measure the strength up to the electrical engineering expectations approaching to an ideal insulator. This is the motive behind this topic selection. But it is just to be impossible to collect some sample of the **high vacuum** medium.Therefore a **vacuum interrupter** is used and treated as a sample bottle of the vacuum medium available for testing purpose.

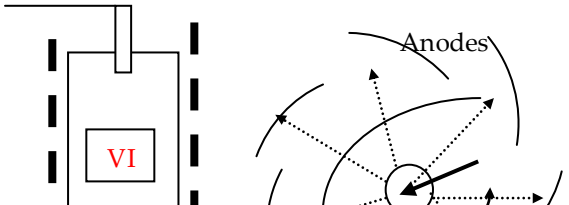
3.OLD TECHNIQUES:

a)Use of Gaga ohmmeter

This is the most basic and commonly used method for measuring the resistively of any insulator, similler to that of mega ohm meter. Only thing is the development of **Gegaohm** meter, on the basis of **Galvanometer** principle. In this method the VI is connected across the Gegaohm meter and the resistance is measured on the display.



b) **Using Magnetron principle to measure leakage current**. :

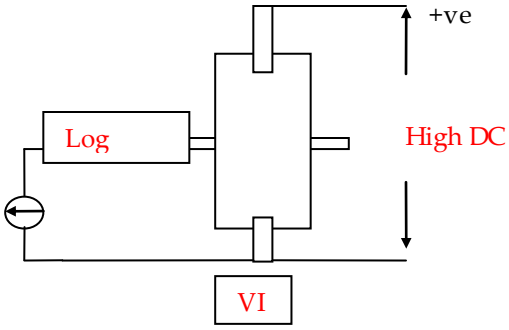


Cathod

In this type of vacuum strength measurement method, the shielding electrodes are specially designed and during testing, they are fed one at a time by a pulsating dc positive train to make them +ve one after another to achieve **Magnetron effect** , for the emitted electron from centrally located Kathod [in this case the VI contact]. This will develop **helical path** for the electron (free air particles in this case).and the electrons are oriented in a required trajectory.

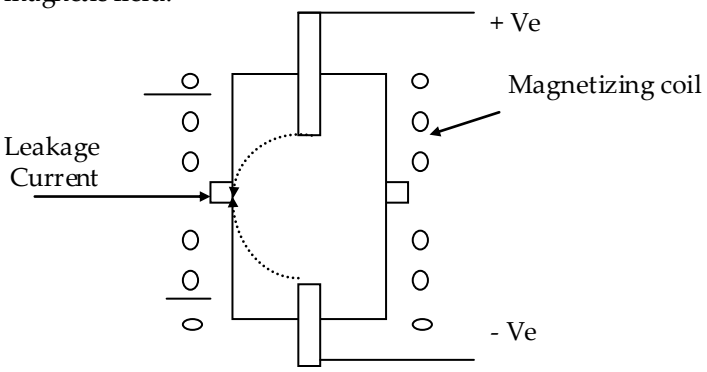
These are collected by shield and discharged through a decided path.Then by measuring this discharge current ,the strength is calculated of a vacuum medium.

c) Use of logarithmic amplifier to measure leakage current.



In this method, the high DC voltage[1.2 RATED] is applied across the open contacts of VI and the shielding electrode is kept at ground potential as a Reference voltage and the leakage current is measured by using Logarithmic amplifiers since the current is in neno- amperes.

d) Using vertically electrostatic field and in parallel static magnetic field.



In this system, the open contacts of VI bottle are subjected to high Voltage DC supply to establish the capacitance between two contacts.

The magnetic solenoid coil terminals are connected to the high DC current supply to develop heavy magnetic flux.

Their **joint action** on free air particles, make them to get **pola-**

rized to words shielding electrode kept at reference potential, by measuring the current through it and calibrating the same, the strength of the field is determined**.**

The fundamental principle used behind this method is based on the Faraday's Law, saying that '**whenever a current carrying conductor is placed in the magnetic field a force gets exerted on it**.' In this

case, the charged particles and their free movement in a medium can be treated as instantaneous current and there is a development of MAGNETIC DRAG according to the effect of '**Lorentz Force'** which gets developed on a charged particle when a charged particle moves in a region where both the magnetic and electric field are present. The **equation** of this motion for the **charge** is given by the relation,

$$m\,(dv/dt) = QE + Q\,(v \times B)$$

4. Concept Development:

Now, at this stage it was an attempt to design the scheme according to my new concept,That is the use of rotating magnetic field for giving the discharge flow orientation to suspended air or gas particles in the evacuated interrupter bottle. For this purpose, it is needed to convert these suspended particles in to charged ones. As the air particle is electrically neutral, so it is achieved by applying an electric [D.C.] potential across the vacuum medium and making these particles as **'electric dipoles'**.

Then by developing the rotating magnetic field inside the medium the orientation can be given. The direction of discharge flow orientation depends on direction of the rotating magnetic field and the polarities of the DC potential applied across. As well as the value of DC voltage and field strength of the rotating field.

Being a familiarity with induction motor stator function, the use of induction motor stator design is done for development of rotating magnetic field. The speed of the field can be precisely varied by varying the supply frequency or the pole changing method, by pole changing, we can vary the speed in even multiples. The variable frequency source availability in range (power frq.to RF) at 3-ph.ac voltages is not easily possible, hence it is suggested to use multipole three-phase induction motor design for this purpose.

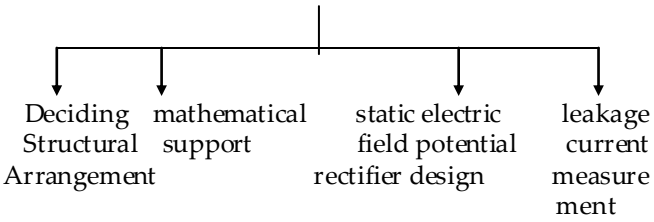
The DC potential is developed by using a ripple free three-phase rectifier unit. The requirement and use of mechanical fixtures to have a separation in VI contacts is not considered as a design part.

The significant development in measurement of vacuum is done, in around **1995,** after **approximately two decades,** by Indian Ex-BARC scientists, Dr.P.K.Naik along with the Manager of Crompton Greaves ltd Mr.M.M.Katre, and these intellectuals developed an instrument based on **INVERTED**

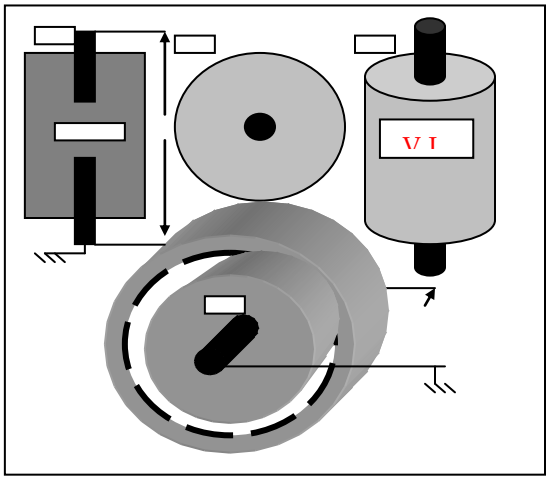
MAGNETRON Principle for their own industrial exclusive use only.

All above said attempts are the out come of the urge shown by these scientists and their different ideas. Every body claims about the maximum accurate and precise measurements by his method, but because of their own national/company interests, nobody gives the details about the method developed by him. Therefore a comparative study of all these methods could not been carried out. Only preliminary conceptual method details could be collected.

5.Development Of The System:



5.1] <u>Deciding Structural Arrangement</u>: - The structural arrangement is proposed as shown in the figure below.



[fig-3.1]

The scheme consists of the rotating magnetic field similar to that of the field developed in case of the 3hree phase induction motor. Therefore a 3-phase induction motor stator is used for this purpose. The stator winding is designed accordingly. As the field strength is depending on the current flowing through it, and the speed is a function of 1.supply frequency and/or 2.no.of poles developed by the stator winding. Then the VI is to be placed in the stator at the place where normally the rotor is used to be placed. Therefore the developed rotating magnetic field acts on the suspended air particles [charge carriers] inside the VI ceramic body, which is sealed and so isolated from external atmospherical conditions. The suspended air particles are already under the influence of static dc electric field so they are converted in to electrical dipoles. these dipoles when come under the influence of the magnetic field, starts moving in an helical path. It is targated to provide them the path, which will constitute a leakage current through the vacuum insulent medium. as the dipoles are the charge carriers; this current may or may not be a continuous or constant current. therefore this current is not treated as the conventional current, but it is measured in terms of nano or micro coulombs. being a partial discharge through the medium. this partial discharge is inversely proportional to the 'strength' of the vacuum.

To get the desired precise results from the scheme, it is necessary to have an uniform air gap through out the periphery of the VI and the stator winding. This is achieved by the VI holding fixture.
The core of the stator winding is selected of the high silicon material. This is because of that the frequency range required to control the speed of the magnetic field, can vary from few Hz to radio- frequency range in MHz.The main reason of avoiding this high frequency 3-phase supply is, its nonavailibility. Therefore It is chosen the method of multipolar induction motor. Though it has a disadvantage of change in speed in steps of multiple of two.
The Vacuum Interrupter is required to be placed in the rotating magnetic field, developed by similar method as that of a three phase induction motor . the VI should be placed as that of a rotor with all around air gap.
Then the static electric field has to be developed by supplying high DC voltage to the open electrodes of the VI .
Then the developed rotating helical force will be able to sweep the cornered and off track suspended air particles. This was not possible with the other methods discussed above.

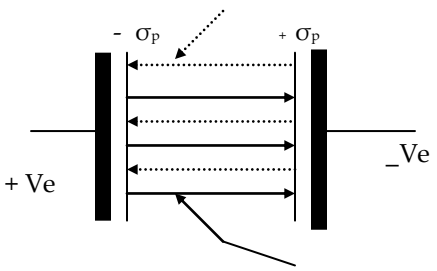
6.Mathematical Support: -

As Discussed above the suspended air particles are kept in a static electric field, and the rotating magnetic field. Therefore the particle is subject to two forces one is due to static electric field and another is due to magnetic field.

Their effects can be determined according to following theories.
Polarization of suspended particles:-

When an electric field is applied between two electrodes having a dielectric medium between them then, there are two kinds of electric charges to be considered. (i) Bound charges in the dielectric, which are produced due to polarization in the dielectric and are called polarized charges or polarized electric Dipoles. These charges are bound to the atoms or molecules. (ii) Real charges, which are present on the electrodes.
If, E_r = electric intensity produced without dielectric then;

$E_r = \sigma_r / \epsilon_o$ when dielectric K (S.I.C.= specific inductive capacity, some times called as relative permeability) fills the space between the two electrodes ; then surface density of two sides of dielectric becomes $+ \sigma_p$ and $- \sigma_p$. These will produce their own intensity $E_p = + \sigma_p / \epsilon_o$ and $E_p = - \sigma_p / \epsilon_o$ respectively, but in apposite direction to the initial one. Hence the intensity of the field gets reduced. This results in reduction in PD between electrodes. Hence increase in the capacity in arrangement to take up more charge.



Original

The resultant intensity E and the induced charge, On the surface of the dielectric may be found as below.;

$E = E_r - E_p . = \sigma_r / \epsilon_o - \sigma_p / \epsilon_o = \sigma_r / \epsilon_o K.$ -------(I)

Therefore, $\sigma_p = \sigma_r (K-1 / K)$ and, $q_p = q_r [(K-1) / K]$

And $q_p = q_r [1 - (1 / K)]$ ---------- (II)

So, $q_p < q_r$, therefore $q_{p/A} = q_r$---------- (III)

Thus Induced surface charge per unit area i.e. $[q_{p/A}]$ is called electric polarization and is denoted by P .
Therefore $q_r /A = (q_r / \epsilon_o AK) \epsilon_o + P$, or

$q_r /A = \epsilon_o E_r + P = D$

This gives us, $D = \epsilon_o E + P$ ----------(IV)
Since in ISOTROPIC media (Media having same physical properties in all directions) like Vacuum ,$P \alpha \epsilon_o E$ or $\chi = P / \epsilon_o E$. This χ = [Polarization / Applied field] and called as Dielectric Susceptibility , a dimension less ratio and is analogous to Magnetic Susceptibility .
Hence we can write $D = \sigma_r = \epsilon_o EK$ --------(V)

From equation (IV), we can state $\epsilon_o KE = \epsilon_o E + P$

or $P = \epsilon_o E (K-1)$ ---------- (VI)

For the vacuum medium $K = 1 + \chi$

It must be noted that E is local field within the dielectric i.e. Vector sum of external field applied and that due to atomic or molecular DIPOLES formed because of polarization.
The above discussions can make a generalized statement that the equation (V) is a generalized equation, which states that, electric induction in an isotropic medium like vacuum equals the product of dielectric constant and electric intensity.

D- is also called as the density of the lines of induction. In vacuum , K =1.and so the value of

$D = \epsilon_o E = \sigma$ ..... (VII)

We can conclude that,
1. D is concern with free charges only and the lines of D begin and ends up with free charges.

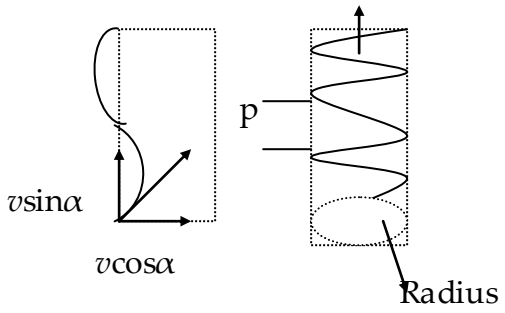
2. P is linked with the polarization of charges only. and the lines of P start and ends up with polarized charges only.

3. E is connected with all charges, which are either Real charges or polarized ones.

4. The unit of E becomes Newton / coulomb, while P & D are measured in coulombs/ m^2.

Spiral Path

If a particle of charge q comes in a path of a magnetic field of flux density B with a relative velocity v, making an angle α with the direction of the field, the velocity of which may be resolved in to two components, i) $v\cos\alpha$ parallel to the field and ii) $v\sin\alpha$ perpendicular to the field.



The first component will not be affected by the field, but provides translatory motion. The component $v\sin\alpha$ perpendicular to B produces circulation about B, which is superimposed on the motion of translation, results in a spiral path or Helix about B.The radius of the spiral is given by,

$m(v\sin\alpha)^2 / r = B q v \sin\alpha$;

therefore $r = mv\sin\alpha / Bq$

The pitch of the spiral is the distance traveled with translatory velocity, $v\cos\alpha$;

in time T. where, T is the time period of revolution about B.

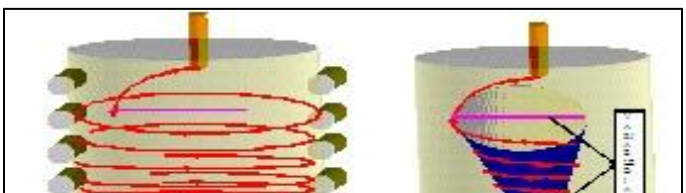
but $T = 2\pi r / v = 2\pi mv / B q$

Therefore pitch = $p = v\cos\alpha$. And $T = 2\pi mv \cos\alpha . / B q$.

When α is small, $\cos\alpha \approx 1$. The pitch is dependent of α.

Conclusion:

New concept sweeping of charges can be understood by referring the three-dimensional figure below.



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[1] Mr. John R. Lucek and he had a **US Patent No.3263162 dated 20.04.1962** for the apparatus and method for measuring the vacuum inside the vacuum circuit interrupter..

[2]. Mr. W.W.Watrous jr. et al .
after about six years. He has **US patent No.3575656 dated 30.08.1968** for Method and apparatus for measuring pressure in vacuum circuit interrupters.

[3]. Indian Ex-BARC scientists, Dr.P.K.Naik along with the Manager of Crompton Greaves ltd Mr.M.M.Katre, and these intellectuals developed an instrument based on **INVERTED MAGNETRON** Principle for their own industrial exclusive use only.

[4]. **Mr. J.Gerhold**, of Technische Universitat Grz, Institut fur Electrische Maschinen und Antriebestechnik, kopernikusgasse 24, A-8010 **Graz,** Austria. Wrote a paper in Elsevier Science Ltd. write-up on 27 April 1998, High Vacuum, cold gases and liquids, and solids are the principal insulating materials