STUDY OF VARIOUS VACUUM INTERRUPTERS' PRESSURE MEASUREMENT TESTING TECHNIQUES

Nikita A. Sonkamle[1], Prof. S. M. Kulkarni[2], Prof. A. P. Paranjape[3]
[1]Student ME (EPS), [2,3]Assistant professor, Department of Electrical Engineering,
PES College of Engineering, Nagsenvana Aurangabad.

Abstract
In this paper, the near investigation of various techniques to measure the VACUUM level inside the VACUUM Interrupter is completed. The prerequisite of estimation of VACUUM level is important to know the strength of the VACUUM interrupter. Regularly received strategies for the assurance of VACUUM level are required to be looked at for the exactness of the estimations, at makers' end and in addition at the field. The test setup at makers' place is not accessible at the site or field. Subsequently the more practicable and simple to work and also a convenient test framework is constantly ideal in the fields. This paper gives merits and de-merits of different test techniques, their standards of operation, and thought regarding the physical size.

Keywords: 760 mm of Hg = 1 Atmospheric pressure at sea level, = 1 Bar pressure. 1 millibar = 760/1000 = 0.76 mm of Hg. 1mm of Hg = 1Torr Vacuum.

I. INTRODUCTION

Among the different sorts of circuit breakers accessible in the market, in Vacuum Circuit Breaker the arc interruption takes place in vacuum medium inside the interrupter. The space inside the interrupter being high vacuum, next to no particles is accessible between the contacts. The Vacuum Circuit Breakers (VCBs) are especially favorable for use in the voltage extends 3 kV to 38 kV. The gas pressure should lower than $1.33*10^{-3}$Pa, normally around 10^{-4}Pa. Because of the quick recapturing of dielectric quality of vacuum inside the interrupter the re-striking does not happens.

The quality of a vacuum is indicated by amount of air matter remaining in the vacuum bottle, so that a high quality vacuum needs very negligible air matter left in it (Vacuum bottle). This negative pressure or vacuum is measured by referring following;

- Absolute vacuum. (760 torr).
- Temperature.
- Chemical composition of components of vacuum bottle.
- Mean free path (MFP) of residual gases, which indicates the average distance those molecules will travel between the two electrodes & make collisions with each other.

The VIs high interrupting capacity is based on the physical principle discovered by Louis Karl Heinrich Paschen (1865-1947).

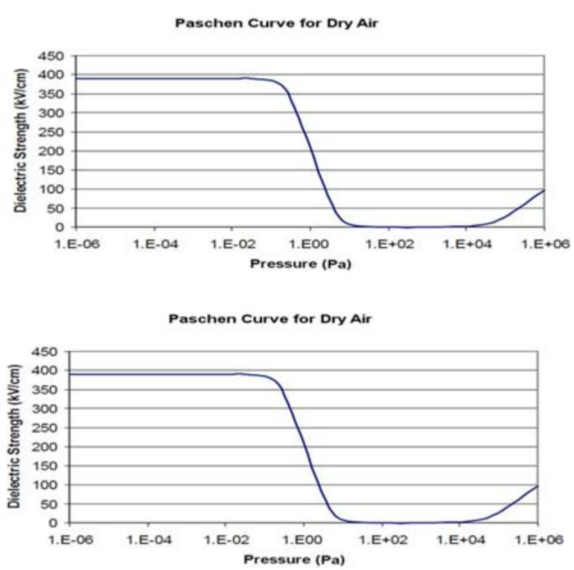

Fig. 1 Paschen curve

Paschen did original experimental research and discovered that the dielectric strength (*V*) of a gas is a function of the gas pressure (*P*), the distance between the two electrodes (*d*) and the type of gas.

$$v=\frac{apd}{\ln(pd)+b}$$

Where *a, b* are the constants derived for dry air. Electrical insulation in vacuum follows the "Paschen curve" shown above.

Normally for vacuum, we are interested in the left hand part of the curve. The curve shows that the dielectric level of air starts to increase dramatically as the pressure drops below approximately 10Pa ($10^{-1}mbar$). It continues to rise swiftly until pressure reaches approximately $10^{-1}\ Pa(10^{-3}mbar)$and then remains fairly steady at slightly less than 400kV/cm (approximately 1000kV/in).Any pressure better than $10^{-3}mbar$ has no effect on the dielectric level of the vacuum gap. As pressure begins to deteriorate, the breakdown voltage performance also deteriorates this means that any change in pressure which remains lower than $10^{-3}mbar$ will have no effect on the performance of the vacuum interrupter or switch.

This is termed as the "limiting value". The interrupting capacity in a VI will vary depending on

- Contact design.
- Contact separation.
- VACUUM level.

The contact design and separation are design features for any given VI. However from the previous discussions we can say that the interrupting ability will be very high and very sensitive to the pressure (vacuum) level inside the vacuum interrupter. This leads us to the detailed study of vacuum level present inside the vacuum interrupter and various methods to measure the vacuum level inside the VI.

According to *the theory of Townsend discharge*, which is very common in gas dielectrics, the development of current in a gap relies upon the movement of charged particles. In the absence of such particles, as in the case of perfect vacuum, there should not be any traces of conduction and the vacuum ought to be a perfect medium of insulation. The level 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 particles in the vacuum. This is because, it is practically impossible to create absolute vacuum inside the VI**.**

Level measurement of vacuum includes two parameters

- Availability of free charge carriers.
- Pressure of vacuum.

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

II. **VI FAILURE MODES**

Although vacuum interrupters are very long-lived, they have a useful service life just like any other equipment. The projected life of a VI, as determined by the factory leak-rate test, assumes a constant leakage rate throughout the life of the VI – an assumption that may not be valid for any given interrupter. There are several possible types of VI failure.

- The most common failure occurs when a VI reaches its wear limits due opening and closing of contacts.
- Another common failure is internal arc flash-over caused by metal vapor and sputtering material being deposited on the inside of the canister.
- A third type of failure is loss of vacuum due to mechanical failure of the bellows, pinch tube, or a manufacturing defect.
- Last is the loss of vacuum due to leak rate. The leak rate was checked at the factory and is determined generally to exceed 20 or even 30 years; however, the leak rate can be greatly increased by improper installation, failure of components, or damage during maintenance procedures.

Of course, life extension and failure prevention can both be dramatically improved by proper maintenance.

III. VARIOUS VACUUM LEVEL TESTING EQUIPMENTS

In light of the above talked about actualities different strategies are acquainted with know the measure of vacuum accessible inside the VI, which are considered relatively in the succeeding parts. These techniques are recorded underneath.

1.Use of Gaga ohm-meter.
2.Use of logarithmic amplifier.
3.Use of magnetron.
4.Inverse magnetron method.

A. Use of Gaga Ohmmeter

It is the most fundamental and basic technique. This technique has a premise of the fact that the quality of vacuum dielectric medium in VI relies on upon the impedance (resistance) offered by the vacuum medium and this principally relies on the accessibility of free charge carriers in the medium

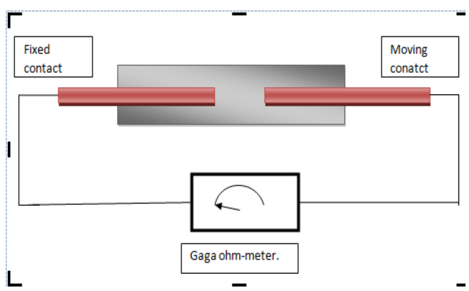

Fig. 2 Gaga Ohmmeter

Gaga ohm-meter is a high resistance measuring meter which can measure resistances in the range (10^6 ohm to 10^9 ohm). The VI is connected across the Gaga ohm-meter and the resistance esteem can be seen on the meter show. The level of vacuum present inside the VI bottle will be reliant on the measure of resistance measured by the ohm-meter.

B. Use of logarithmic amplifiers.

The idea driving this technique is to build up the capacitance between the two electrodes (contacts) and measuring the leakage current because of free charge carriers shown inside the VI. As the suspended particles are in little amount the leakage current because of these particles will likewise be in little sum, in the order of nano amperes. In this technique a high DC voltage is connected over the open contacts of VI and the fixed terminal is kept at ground potential as a kind of reference voltage the leakage current and its watt component utilizing its connection with tanδ (dielectric dissipation factor) then using logarithmic scale the adjustment is conveyed to the quantifiable incentive on the meter.

C. Magnetron method

This method is a modified form of the penning gauge method for the vacuum level measurement, which works on the penning discharge principle. Magnetron also uses the Penning discharge principle to determine the level of vacuum inside a vacuum interrupter. This gauge consists of a pair of plates (electrodes) mounted within the vacuum envelope between which a static electric field is generated. The electric plates are immersed in a magnetic field aligned substantially at right angles to the static field. Through the application of the static and magnetic fields of the proper field strength, any stray electrons within the confined space will not travel directly to the Vacuum pressure measurement by magnetron method.

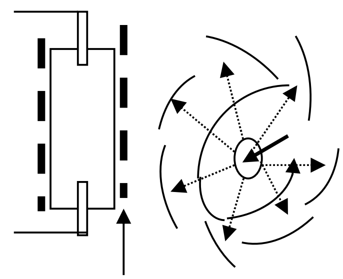

Fig. 3 Cross Field in Magnetron

Positively biased plate (anode), but will travel in cycloidal or elliptical paths within the confined space. At low pressures, for example at pressures of the order of 10^{-4}torr and below, relatively few gas molecules are present in the vacuum space, therefore the tortuous route taken by the electrons greatly enhances the number of collisions with the remaining molecules, so as to enhance the probability of an ionizing collision. The current produced in a magnetron type gauge is proportional to an exponential of pressure. Thus, by measuring current the pressure of the vacuum level can be directly obtained.

D. Single Inverse Magnetron Discharge (SIM)

In the single inverse magnetron mode the interrupter contacts are closed, the interrupter is placed in a solenoid which provides an axial field, and a high dc voltage is applied between the contacts and the center shield, setting up a radial electric field, fig. below.

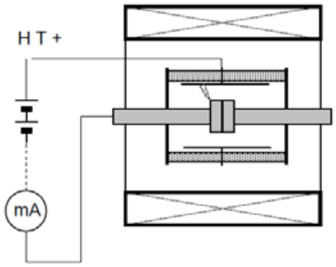

Fig. 4 Vacuum Interrupter in Magnetron Coil Connected For Single Inverse Magnetron Mode.

Without the magnetic field no current would flow, due to the very low gas pressure, but the magnetic field causes electrons and ions to travel in circular paths, greatly increasing the number of ionizing collisions occurring, and in theory giving ability to measure pressures down to 10^{-10} mbar. When the fields are switched on there is a discharge resulting in a small pulse of current: gas in the interrupter is ionized and transported to the electrodes providing the electric field. This pulse is recorded and as the pulse height is proportional to the amount of gas in the vacuum space, this gives a measurement of pressure (Figure 5).

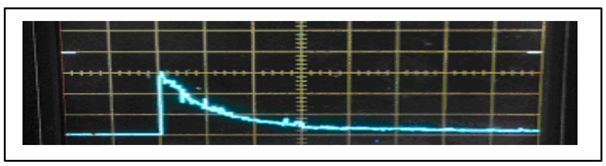

Fig. 5 Typical current pulse for single inverse magnetron discharge.

E. Double Inverse Magnetron Discharge (DIM)

If the center shield cannot be electrically connected from outside, then the double magnetron mode must be used. For this the contacts are opened and the voltage is connected across the two contacts: the center shield is of floating potential and charges capacitively. A radial electric field becomes established between one contact and the center shield, and a second radial electric field becomes established between the center shield and the second contact. Thus the current path consists of two discharges in series fig 3.

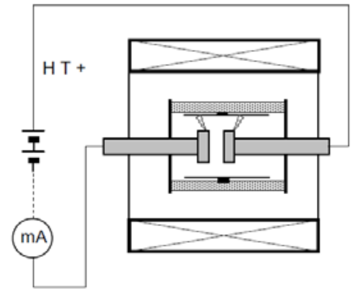

Fig. No. 6 Vacuum interrupter in Magnetron coil connected for Double Inverse Magnetron mode.

Of course an interrupter whose Centre shield is accessible from outside can be tested by both the single and the double magnetron method.

F. Vacuum pressure testing Equipment

The solenoid used 40 kg of copper wire on a former 180mm long and with a central hole of diameter 250mm (Fig. 7). This allowed the largest interrupters we are aware of to be tested. The coil is of optimized geometry and is powered from a 2kW dc current supply, giving a maximum field of 700 Gauss.

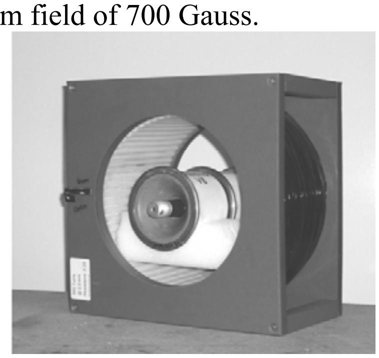

Fig. 7 A vacuum interrupter in position in the solenoid coil.

The high voltage supply provides up to 10kV dc, and has a current capacity of 10mA. The pressure measured is proportional to the height of the current pulse which may vary from about 2μA to 5mA.The captured pulse is displayed on a digital storage oscilloscope, fig. 2. Since we can expect one day to have a failed interrupter under test, it has to be assumed that the full 10kV could be input to the data capture electronics, and precautions are taken to mitigate the effects of this.

Comparison of SIM and DIM Discharges

The SIM mode and the DIM mode give different peak currents for the same vacuum level. The difference can be of the order of two or three times. This is significant enough, even on a logarithmic scale, that when the magnetron method is used to measure pressure during the manufacture of vacuum interrupters, it is necessary to calibrate the equipment separately for each type of discharge.

IV. CONCLUSION

After going through the operating principles of operations and the techniques of the above said methods and making the comparative study of them, we have come across few observations as a conclusion.

The method of Gaga ohm-meter is used by site (field) engineers only. Since the arrangement is bulky. This method is not handy. The application of the magnetron gauge principle becomes practical for a vacuum apparatus of the type described in the above-mentioned patent, the system described therein is impractical and is useless for other forms of vacuum interrupters in which the vapor condensing shield is not provided with an available electrical terminal or other connection provided with an available electrical terminal or other connection provided at the exterior of the vacuum interrupter structure thereby eliminating the possibility of use of the shield as one of the active electrodes in the formation of the magnetron gauge.

The method of logarithmic amplifiers requires ideal grounding for calibration of reading which leads to operators' safety issue and the insulation co-ordination of the test setup, Rounding off errors affects the accuracy, Critical in measurement and calibration, Analog instruments give better performance with this setup but scale crowding gives inaccuracy in reading and Digital instruments are not made sensible for the requirement of this function as ICs etc. get affected by High DC field.

Lastly in case of the vacuum interrupter testing equipment with a heavy solenoid, often the pulse occurs as soon as the fields are applied, but sometimes there may be a delay of a few seconds, and occasionally a delay of up to a minute before a discharge is observed. This delay appears to be longer with higher vacuum levels. We believe that when there is a good vacuum it is necessary for some event such as the arrival of a particle of natural radiation to provide the first ionization event. It is sometimes the case that no discharge at all occurs even after waiting for up to a minute. We interpret this as meaning that there is such a good vacuum, of the order of 10-7mbar, that it is very difficult to strike the discharge.

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