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An Analytical Relation Derivation for Threshold Voltage as a Function of Operation Time for Self-Quenching GM Counters

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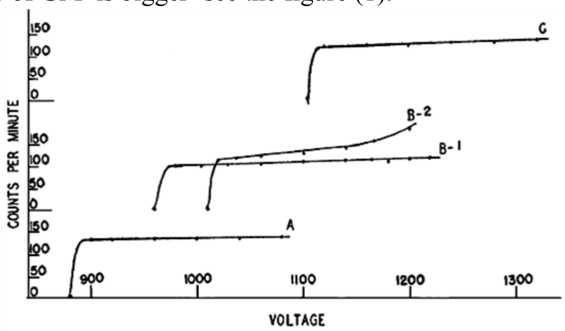
Abstract
At normal temperatures, it is known that The threshold voltage of GM counter tubes, which are filled mixture of inert gas and quenched organic gas, was shifted toward higher voltages during operation time because of disintegration of quenched organic molecules. While threshold voltage of GM counter tubes, which are filled mixture of inert gas and quenched halogen, was shifted towards lower voltages during operation time because of reaction of quenched halogen molecules with anode and cathode. In this article, assuming that the counter tube operates at constant temperature and constant activity exposure, we have derived an analytical relation of Geiger threshold voltage as function of operation time. This relation indicates that the Geiger threshold voltages of the tubes which contain organic gas are exponentially increased during operation time. the Geiger threshold voltages of the tubes which contain halogen are exponentially decreased during operation time.
Keywords: analytical relation ,threshold voltage, operation time, GM counter.

1. INTRODUCTION

Since 1934 the Theoretical and experimental investigations of the G-M counter behavior have already been made by many authors [1-8]. But that investigations can't explain the relation between the threshold voltage and the counter variables such as radii of the cathode wall and wire, and various gas mixtures، and it can't obtain on analytical mathematical equations to correctly describe for that relation[1,7,8]. Therefore، there is some Theoretical and experimental investigations which is nearly agreeable، such as the study which have been carried out by Spatz in 1943 which was experimentally studied the factors influence the characteristic self-quenching MG counters was filled with a various ratio (5% ،10% ،20%) From alcohol vapor and air with argon, with a total pressure of 10 cmHg، He was found that the starting potential and threshold voltage of GM being a function of the percentage of alcohol vapor in mixture. if quenched mixture ratio was bigger، the starting potential and threshold voltage of GM is bigger، see the figure (1).



Figure(1): Comparison of plateau characteristics of alcohol argon counter having a total pressure of 10 cm of Hg with different mixtures (A) 5 percent alcohol vapor, (B-1) 10 percent alcohol vapor, (B-2) 10 percent alcohol vapor and 2 percent air, (C) 20 percent alcohol vapor.

Therefore، we can conclude that when the quenched gas ratio in halogen counters decreased with aging due to that the halogen ions reacts with the cathode and anode surfaces, the starting potential and threshold voltage of GM Counters are decreased with operation time. And in good Theoretical investigations have been carry out by Motoo YOSHIDA in 1953[9], which is lead in derivation The relation between the threshold voltage and GM tube dimensions as:

$$\frac{V}{\log\frac{b}{a}}\exp\left\{-K\left(\frac{a\log\frac{b}{a}}{V}\right)^{\frac{1}{2}}\right\}=const.$$

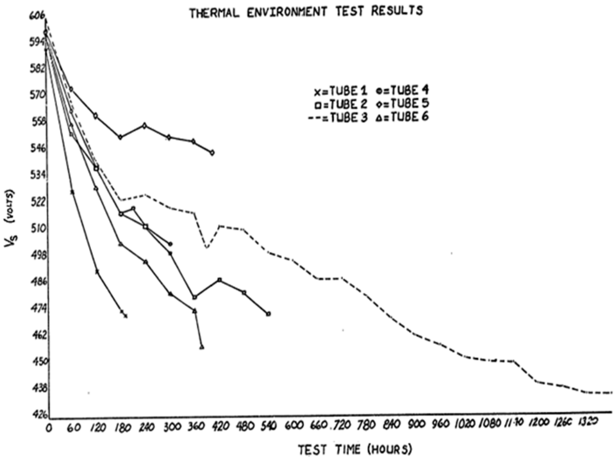
Where a , b are radii of counter wire and wall respectively, and K is a constant. And also derived the threshold voltage which is associating to the gas pressure in GM counter as:

$$\mathrm{V}\exp\left\{-\mathrm{A}\left(\frac{\mathrm{P}}{\mathrm{V}}\right)^{1/2}\right\}=\mathrm{const.}$$

Where A is a constant.

They have been found that the two relations above can't well describe of GM counter behavior, because the GM counter characteristics were changed with used(operation).

And from the significant investigations regarding GM counter threshold voltage changed with operation time which is carry out by Morin[10],from air force USA institute of technology, in 1972 in yours thesis (aging influence on the plateau characteristics for bromine- quenched GM counters).in this thesis, from the all precedent characteristics Morin ingratiate to explain that changing in plateau characteristics with aging as following: The length ,start potential and slope of this plateau, depends upon a number of variables. Some of these are: the pressure in the chamber, the type of filling gas, the percentage of halogen gas, and the cathode material[11,12]. The industrial company has been regard choosing the cathode and anode materials(Pt و ،Ni و ،Cr و ،Fe) where no react with bromine at less than 100°C temperature. And they are confirm that start potential of plateau V_s is decrease with aging which must be accompany with shifting start potential of plateau towards the minimum voltage, the figure (2), returns the decrease in start potential to decrease the bromine vapor. If this was true, we must be confirm that a gas of pressure decrease due to depletion the bromine of gas, and confirm that bromine founds in cathode and anode surfaces. They are confirm From many experiments that the gas pressure and start potential of plateau are parallel decrease with aging, as predicted. And for make sure from presence the bromine in cathode and anode surfaces, A variety of surface analyses for the new tubes and old tubes from the same company with Wet Chemical Gas Analyzer and Spark Source Spectrometer Analysis, it established from the first way that **:** If a old tube, then it should contain ~17 μ gms of bromine while If a new tube, then it should contain 108 μ gms of bromine, and it established from the second way bromine were found on the internal surfaces and most notably the anode for the old tubes. The results show there was an average of 8.5 times more bromine on the anode than on the cathode, because it has ten times the surface area. And in another tests which is establish that amount of halogen attack increases whenever the pulse is higher. Therefore, the threshold voltage value is evidence on the operational state for counter.



Figure(2): Decrease in the GM threshold Voltage against operation time, for six tubes.

2 .The Threshold voltage relation as a Function of operation time for GM counter $(\mathbf{V_s}=\mathbf{V_s}(\mathbf{t}))$**:**

To derive Threshold voltage relation as a function of operation time for GM counter that is, $V_s = V_s(t)$ it's enough to exist the Threshold voltage dependency for the total pressure of gas $V_s = V_s(P)$ or for quenched mixture pressure $V_s = V_s(P_{qu})$. it's known that ions mobility u is inversely proportional with pressure of gas P [13]. it have been established by The experiments that the relation $\mathrm{uP} = \mathrm{const.}$ is valid for a wide range from pressures from several millimeter to hundreds of millimeters. If we assume that every ion will accelerate by only electrical field within the free paths for gas molecules, and we also assume that the ion will lose all of its energy in every collision and then increase its velocity from zero until $\mathrm{v_E}$. since the thermal motion for molecules are randomly moved, so it is not contribute in ions orientation process, then, the mean velocity which every ion obtain it during one free path by electrical field is:

$$v_E = \frac{\tau e E}{2m} \qquad (1)$$

Because the momentum changing by collision ،it will be equal to electrical force which is $\frac{2\mathrm{mv_E}}{\tau} = \mathrm{eE}$

Where: E is the electrical field strength, and τ is the mean time between two collisions, and e, m are the charge and mass of ion respectively. In other hand, the time between subsequent two collisions is equal to $\tau = \frac{\lambda}{\bar{v}}$ where λ is mean free path, and $\bar{v}$ is the mean thermal velocity for molecules. therefore , the final velocity will be:

$$v_E = \frac{e\lambda}{2m\bar{v}} E \qquad (2)$$

The electrical field strength in GM tube is given as: $$E = \frac{V}{r \ln\frac{b}{a}} \qquad (3)$$

Substituting the equation (3) in (2) can be written: $$v_E = \frac{e\lambda}{2m\bar{v}} \frac{V}{r \ln\frac{b}{a}}$$

Therefore,

$$V = \frac{2m\bar{v}}{e\lambda} v_E r \ln\frac{b}{a} \qquad (4)$$

The critical distance which the ions must move it before the field at the wire recovers to threshold is called The critical radius r_c:

$$r_c = be^{-\frac{V-V_s}{2q}}$$

Where b is the cylinder cathode radius , V is the applied voltage, V_s is threshold voltage for GM counter and q is the charge per unit length of the ion sheath. When $r = b$, then $V = V_s$ and therefore can be rewritten the relation (4) as: $$V_s = \frac{2m\bar{v}}{e\lambda} v_E b \ln\frac{b}{a} \qquad (5)$$

Where that the mean free path λ is function of the pressure and temperature as:

$$\lambda = \frac{kT}{\sqrt{2}\,\pi\, d_{eff}^2\, P} \qquad (6)$$

and the mean velocity of molecule $\bar{v}$ is function of the temperature as:

$$\bar{v} = \sqrt{\frac{8\,k\,T}{\pi\, m}} \qquad (7)$$

Substituting the equation (6) and(7) in (5) can be written:

$$V_s = \frac{2m\sqrt{\frac{8\,k\,T}{\pi\, m}}}{e\frac{kT}{\sqrt{2}\,\pi\, d_{eff}^2\, P}} v_E b \ln\frac{b}{a}$$

$$V_s = \frac{8\sqrt{8}\, d_{eff}^2}{e} b \ln\frac{b}{a} \sqrt{\frac{\pi m}{8k\,T}} v_E P$$

And this is the relation which shows threshold voltage(V_s) as a function of the gas pressure(P) and the final velocity(v_E) between two collisions when the temperature and volume tube are constant, $V_s(v_E, P)$:

$$V_s(v_E, P) = \frac{8\sqrt{8}\, d_{eff}^2}{e} b \ln\frac{b}{a} \sqrt{\frac{\pi m}{8k\,T}} v_E P \qquad (8)$$

the final velocity(v_E) between two collisions is also function of the gas pressure $v_E = v_E(P)$, and then:

$$V_s(v_E, P) = \frac{8\sqrt{8}\, d_{eff}^2}{e} b \ln\frac{b}{a} \sqrt{\frac{\pi m}{8k\,T}} v_E(P) P \qquad (9)$$

In self-quenching-halogen GM counter, this relation refers to whenever decreases the gas pressure, the mean free path increases, then the final velocity becomes higher and threshold voltage is smaller. to derives the threshold voltage dependency to operation time, firstly must be derives the final velocity dependency to operation time $v_E(t)$ and secondly must be derives the gas pressure dependency to operation time P(t), therefore, we can write the equation(9) as:

$$V_s(t) = \frac{8\sqrt{8}\, d_{eff}^2}{e} b \ln\frac{b}{a} \sqrt{\frac{\pi m}{8k\,T}} v_E(t) P(t) \qquad (10)$$

now, We will exist $v_E(t)$:

The mean final velocity value which the ion will gain it between two collisions depend on the mean free path and the free path increases with decrease the pressure. then, The mean final velocity value inversely proportional with pressure of gas P. Since the ion motion between two collisions is regularly acceleration from zero (initial velocity on cathode radius extension), then its final velocity is:

$$v_E{}^2 = 2a\lambda$$

Where $a = \frac{e\,E}{m}$ is the ion acceleration, and m is the ion mass, and $E = b \ln\frac{b}{a}$ is the electrical field strength for the accelerated ion, therefore,

$$v_E{}^2 = 2\frac{e\; b \ln\frac{b}{a}}{m}\lambda \qquad (11)$$

Substituting the equation (6) in (11) can be written:

$$v_E{}^2 = 2\frac{e\; b \ln\frac{b}{a}}{m} \frac{kT}{\sqrt{2}\,\pi\, d_{eff}^2\, P}$$

Since the total gas pressure is function of the operation time, the final velocity will be function of operation time as:

$$v_E(t) = \sqrt{2\,\frac{e\ b\ln\frac{b}{a}}{m}\,\frac{kT}{\sqrt{2}\,\pi\,d_{eff}^2\,P(t)}} \qquad (12)$$

Substituting the equation (10) in (12) can be written:

$$V_s(t) = \sqrt{\frac{64\sqrt{2}\,d_{eff}^2\left(b\ln\frac{b}{a}\right)^3}{e}\,P(t)} \qquad (13)$$

In precedent paper [14], we have been derived the total pressure of gas as a function of operation time $P(t)$. For self quenching-halogen GM tube we can write:

$$P(t) = P(0)e^{-\alpha_2 t} \qquad (14)$$

Where α_2 is the halogen deposit constant in the anode and cathode during operation the counter. For self quenching- organic vapor GM tube we can write:

$$P(t) = P(0)e^{(\beta_2-\alpha_2)t} \qquad (15)$$

Where β_2 is a vapor disintegration constant, and α_2 is a organic gas deposit constant In the anode and cathode during operation the counter.
Substituting equation (14) in (13) and For self quenching-halogen GM tube we can rewrite:

$$V_s(t) = \sqrt{\frac{64\sqrt{2}\,d_{eff}^2\left(b\ln\frac{b}{a}\right)^3}{e}}\,\sqrt{P(0)e^{-\alpha_2 t}} \qquad (16)$$

Substituting equation (15) in (13) and For self quenching- organic vapor GM tube we can rewrite:

$$V_s(t) = \sqrt{\frac{64\sqrt{2}\,d_{eff}^2\left(b\ln\frac{b}{a}\right)^3}{e}}\,\sqrt{P(0)e^{(\beta_2-\alpha_2)t}} \qquad (17)$$

3. DISSECTION AND CONCLUSION

The two relations (16) and(17) were referred to that threshold voltage of GM counter depends on GM tube dimensions, kind of gas in tube and the initial pressure of gas. And also they refers to whenever operation temperature is higher , the threshold voltage shift is more. And the threshold voltage of GM counter was exponential decrease against operation time for self quenching – halogen GM counters, and there was a good agreement with results in figure (2). And the threshold voltage of GM counter was exponential increase against operation time for self quenching – organic vapor GM counters when quenched mixture disintegration constant β_2 is a bigger than quenched mixture deposit constant α_2 (in the anode and cathode) and vice versa.
When $t = 0$, then:

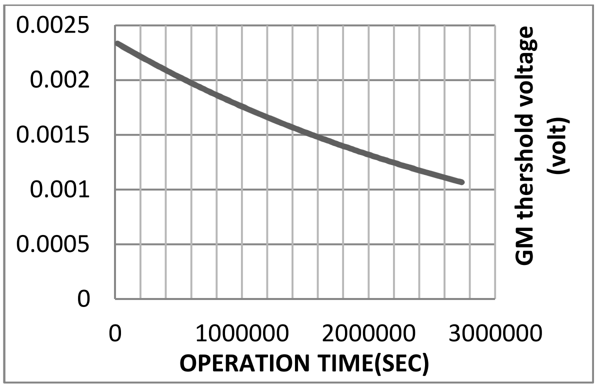
$$V_s(0) = \sqrt{\frac{64\sqrt{2}\,d_{eff}^2\left(b\ln\frac{b}{a}\right)^3}{e}}\,\sqrt{P(0)} \qquad (18)$$

$$V_s(0) = \sqrt{\frac{64\sqrt{2}\,d_{eff}^2\left(b\ln\frac{b}{a}\right)^3}{e}}\,\sqrt{P(0)} \qquad (19)$$

In order to test the validity of this relation Eq.(13) for a new tube of GM: instruction sheet for a new tube [15] is given from LD company as: anode radius is $a = 0.5$ mm, cathode radius is $b = 6.5$ mm, the tube Was filled of gas mixture (argon ,neon ,halogen), where the argon atom diameter is $d = d_{eff} = 3.10 \times 10^{-10}$m , the ion charge is $e = 1.6 \times 10^{-19}$C , to determines threshold voltage per five hours with regard that $P(0) \leq 1.013 \times 10^5$ pa and $\alpha_2 = 0.218 \times 10^{-7}s^{-1}$, with Substituting the parameters in equation (19)، can be written:

$$V_s(t) = \sqrt{\frac{64\sqrt{2}\times(3.10\times10^{-10})^2\times\left(6.5\times10^{-3}\times\ln\frac{6.5\times10^{-3}}{0.5\times10^{-3}}\right)^3}{1.6\times10^{-19}}}\;\sqrt{1.013\times10^5 e^{-0.576\times10^{-6}\,t}}$$

And then: $V_s(t) = 34.166 \times 10^{-4}\sqrt{e^{-0.576\times10^{-6}\,t}}$
And we are drawing this dependency, we obtain to figure(3):



Figure(3): GM counter threshold voltage dependency of operation time.

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