INSULATION CO-ORDINATION AND THE ENLARGEMENT LAW FOR THE GM COUNTER TUBE

by

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In this paper we analyze application of contemporary methods of insulation co-ordination and the enlargement law in designing a GM counting tube. It has been shown that by applying insulation co-ordination methods the counting tube can be optimally dimensioned. The application of the enlargement law was demonstrated in generalizing the results of test obtained by the GM tube to those obtained by the counting tube with m-times greater dimensions. The investigations were conducted both theoretically and by experiment. Using theoretical analysis, we derived the expressions that may be applied if a performance function of a random variable breakdown voltage is known. The experiments were conducted on a GM counter model under well controlled laboratory conditions.

Key words: GM counter, insulation co-ordination, enlargement law

INTRODUCTION

The Geiger-Muller counter is a gas detector based on the gas multiplication principle like any other proportional counter. However, in the GM counter, a stronger electrical field is applied making the avalanche process more intensive. If the electrical field value is above critical each avalanche triggers at least more than one additional avalanche, thereby producing self-sustaining chain reaction known as Geiger discharge. By further increasing value of the electrical field the number of avalanches during the discharge increases.When a certain fixed number of avalanches during one discharge is produced the collective effect of all avalanches stops the chain reaction and terminates the discharge. Since approximately the same number of avalanches terminates every discharge, all impulses of the GM counter are within the same amplitude regardless of the number of primarily created ionic pairs which start the process. The GM can function as a detector of events caused by ionizing radiation, but not as a spectrometer because the information about the energy transmitted from the incident quant of radiation to the gas is lost. By analyzing the described mechanism of the GM counter it is clear that its functioning is based on the electrical breakdown of a gas [1-3]. The aim of this paper is to demonstrate the possibility of applying contemporary insulation coordination approach and the enlargement law in designing the GM counting tube.

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When insulation structures like the GM counter tube are designed or dimensioned an entirely empirical approach is often adopted. First, efforts are made to estimate the desired dimensions of the GM tube [4-6] using empirical values, and sometimes using half empirical methods of calculation. Next step involves making a prototype unit which is laboratory- tested and refined. [7, 8]. One should be aware of the fact that this approach can hardly produce an optimal solution. Consequently (to be close to the optimal solution) it is required to at least estimate the performance function, test it experimentally and finally grade an insulating capability using some method. Various insulation clearances must be coordinated according to their significance and regeneration capability [9]. It is also of interest for practical application to know to what extent a change of counting tube dimensions affects the GM counter functionality. This kind of insulation coordination of the GM counter tube must satisfy the set out rules of insulation coordination and make additional optimization of equivalent (in terms of insulation coordination) insulation clearances.

INSULATION CO-ORDINATION OF THE GM COUNTING TUBE

By observing the described function of the GM counter it is clear that during its design the principle of insulation coordination must be applied [10]. Surely,

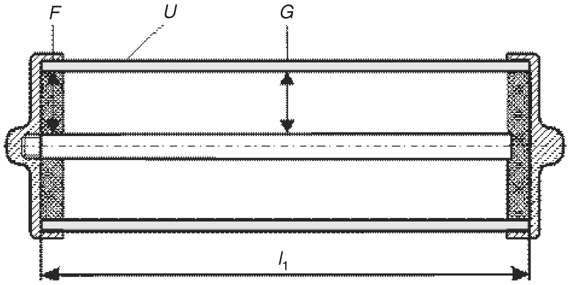

Figure 1. Segment of a GM counter chamber

there is a close connection between knowing physical picture of a breakdown process and specification of insulation coordination, *e. g*. problems of insulation load are analysed with impulse voltages whose waveforms are different from standard atmospheric and commutation voltages [11, 12].

We will here discuss GM counting tube, *i. e*., insulation coordination in a cylindrical model, fig. 1.

Part of the GM tube is shown in fig. 1. It consists of a metalized glass cylinder,a central (coaxial) electrode, and an insulator for holding the central electrode in the axial position.Therefore, the segment of GM counting tube can be divided into: G – gas breakdown distance, U – flashover distance over spacer, and F – solid breakdown-distance in spacer.The GM counter which consists of five segments identical to the abovementioned GM counter is shown in fig. 2.

Insulation in GM counter has very different insulation characteristics: in gas (*G*) insulating capacity is completely regenerated after a breakdown (*e. g*. in a test); at the interface (*U*) it is partly restored; and in the solid material (*F*) it does not recover *et al*. Besides, solid breakdown voltage is greatly dependant on a unit and working conditions. Partial discharges must not be permitted in none of the distances/clearances, since the inception voltages and breakdown voltages coincide. For the proper functioning of the GM counter it is necessary that all breakdowns occur in the gas. In order to relieve points in the insulation from the start, that are electrically critical and at the same time represent technical problem, keep discharge occurring in the test away from these points and minimize maintenance, it is advisable to grade the insulating capacity of these insulating structure elements for the 2 % breakdown voltages, for example

$$U_{d02}^{G} \quad U_{d02}^{U} \quad U_{d02}^{F} \tag{1}$$

Using the method to precalculate the performance function of the breakdown voltage in a gas [11], it is possible to design geometry of the insulation clearances in such a way that the coordination required by eq. 1 is achieved.To do this, one must start from the rated withstand voltage $U_{\rm nst}$ of a test section consisting of m units, fig. 2. If a type of distribution is known, the rated withstand voltage of the unit $U_{\rm Bst}$ can be calculated from the rated withstand voltage of the test section $U_{\rm nst}$ using the enlargement law [12-14]. Assuming a double-exponential distribution, which is suitable for a gas insulation [15], for example

$$U_{Bst} \quad U_{nst} \quad \gamma^{*} \ln m \tag{2}$$

where γ* is estimated value for dispersion of double-exponential distribution.

In the procedure, one must take into account possible impreciseness of the preliminary calculation (precalculation). It can be obtained by proceeding in accordance with classical methods [16], with a condition given by $U_{Bst} \quad U_{d02}^{B}$ (U_{d02}^{B} is the 2 % breakdown voltage of the unit). In addition, a precision level δ = = (0.02 – 0.05) $U_{\rm Bst}$ can be adopted for the calculated 2 % breakdown voltages of the GM counting tube basic model. The desired values of 2 % breakdown voltages can be calculated using eq. 1, the characteristics for $U_{\rm Bst}$ can be obtained using eq. 2, as well as δ and ε (statistical reliability). For the gas clearance we obtained

$$U_{Bst} \quad \delta \quad U_{d02}^{G} \quad U_{Bst} \quad 2\delta \tag{3}$$

For the flashover distance

$$U_{Bst} \quad 2\delta \quad \varepsilon \quad U_{d02}^{U} \quad U_{Bst} \quad 3\delta \quad \varepsilon \tag{4}$$

For the solid distance

$$U_{Bst} \quad 3\delta \quad 2\varepsilon \quad U_{d02}^{F} \quad U_{Bst} \quad 4\delta \quad 2\varepsilon \tag{5}$$

EXPERIMENT

The insulation co-ordination of GM counting tube has been experimentally tested using a designed model (segment) of the part of GM tube, shown in fig. 1 and fig. 3. Also, five more chambers have been designed in the same way, which consisted of segments 2-5 and 6 of the GM counter (five- segment chamber is shown in fig. 2). In addition, two holders/spacers for the central electrode have been designed. The first one with straight edges and the other one with processed edges, in order to extend the path of the surface flashover, fig. 4. Furthermore, an extra chamber has been designed to facilitate measurement of the

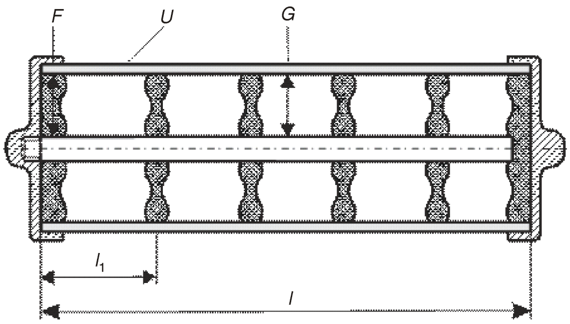

Figure 2. Five segment GM counting chamber

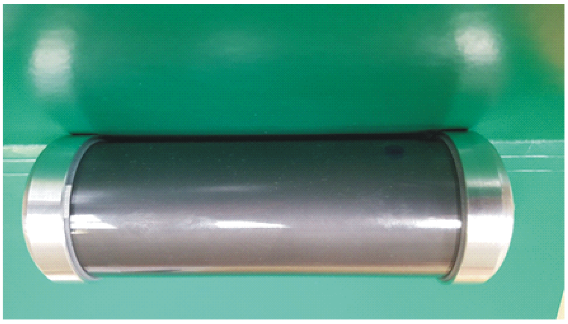

Figure 3. Model of a one segment GM counter

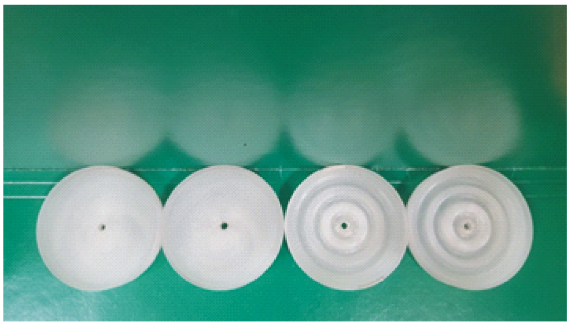

Figure 4. Spacers/holders for the central electrode (type I and II)

flashover spacer (surface breakdown). In this chamber, the composition and pressure of the insulating gas were the same as they were in the model of GM tube. The value of a breakdown voltage in a spacer has been measured only once. It has been shown that this value was much greater than the values of breakdown voltages in the gas and over spacer, and it should not be taken into consideration. During the measurement, the applied models have been filled with the He gas and alcohol vapour. The pressure in the chambers has always been at 40 mbar. According to the measurements, the pressure in the GM counter model has not changed more than 1 mbar during 24 hours.

The experiment involved the following steps: 1– measuring 100 values of the coaxial geometry breakdown voltage, 2 – measuring 100 values of flashover across spacer type I and type II in the chamber (for this part of the experiment 100 identical spacers have been designed for both spacer types – I and II), and 3 – the unit designed (the GM counter model) consisted of 1-4 and 5 identical segments, fig. 5. One hundred values of breakdown voltage have been measured in these multi-segment units. Combined measurement uncertainty has been less than 5% [17].

The obtained statistical samples of the random variables: breakdown voltage in the gas, flashover voltage on spacer, and breakdown voltage in the multisegment units, were treated in the following manner: 1 – using Chauvenet's criterion each sample was cleared of suspicious results, 2 – remaining sampleswere divided in 10 chronological samples and tested using *U*-test to check whether the samples belong to unique random variable, and 3 – obtained statistical samples were tested graphically, using $\chi 2$ – test and Kolmogorov test to check if they belonged to Gauss, double-exponential and Weibull distribution.

Double-exponential voltage 250/2500 μs was used. The pause between two breakdowns was 1 min. The breakdown voltage was measured using a capacitive divider. During the measurement the 100 MHz oscilloscope was placed in a protective chamber with the protection greater than 100 dB.

If a final geometry is optimized in such a way that the calculated 2 % breakdown voltages are within desired range, than the test samples should be collected and its breakdown voltage performance function should be changed. It should be more or less equal to that of the gas clearance. For a gas insulation which can be approximated with double-exponential distribution (parameters U^B_{d63} and γ^B) the value of the rated withstand voltage can be tested in accordance with the standard procedure

$$U_{nst} \quad U_{d10} \quad U^B_{d63} \quad \gamma^B (2.25 \quad \ln m) \qquad (6)$$

RESULTS AND DISCUSSION

Figures 5 and 6 represent experimentally obtained statistical samples of the following random variables: 1 – breakdown voltage in GM counter model in fig. 1, with type I and type II spacer; 2 – sur-

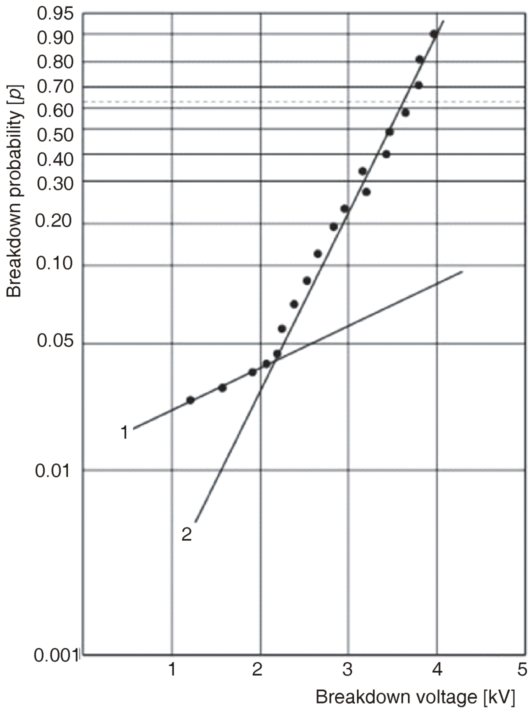

Figure 5(a). Breakdown voltage of the GM counter model (fig. 1) with type I spacer, displayed on probability paper of the double-exponential distribution

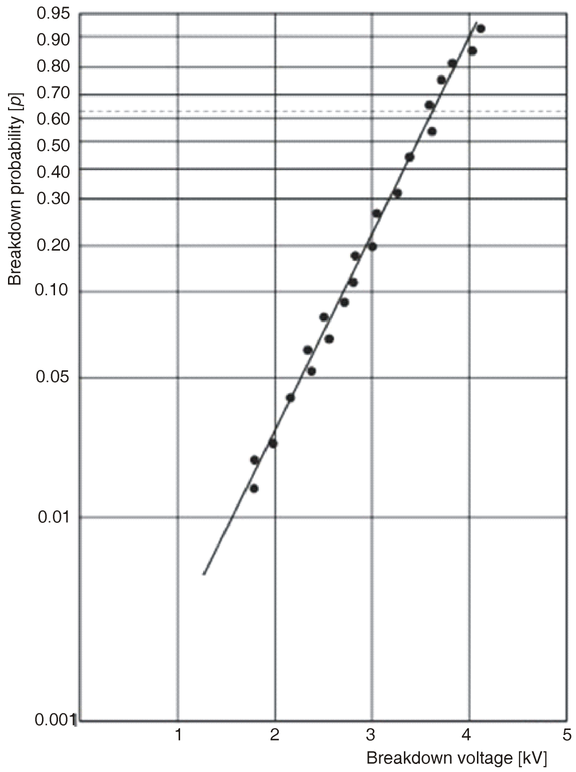

Figure 5(b). Breakdown voltage of the GM counter model (fig. 1) with type II spacer, displayed on probability paper of the double-exponential distribution

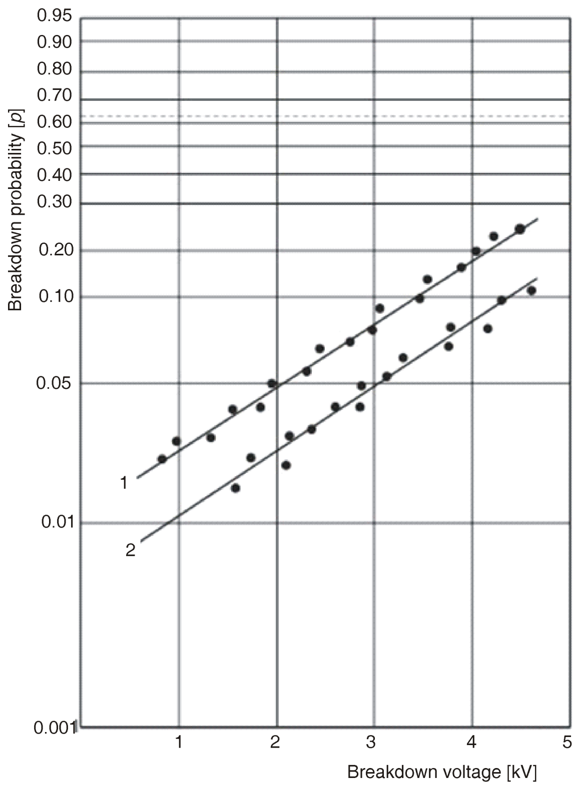

Figure 6. Surface breakdown voltage over spacer, displayed on probability paper of the double-exponential distribution; 1 – type I spacer; 2 – type II spacer

face breakdown voltage over spacer (for both type of spacers), displayed on a probability papers to which they best correspond.Using χ^2 and Kolmogorov test (with statistical uncertainty of 5 %) it was confirmed that the selection of the probability paper for the random variables shown in figs. 5 and 6 was appropriate. It can be seen in fig. 5 that the random variable breakdown voltage in the gas of GM counter model behaves according to double-exponential distribution. It is observed in fig. 6 that the random variable surface breakdown voltage across spacer (for both types of spacer) also behaves according to double-exponential distribution. Thereby, it can be noted that the values of the random variable surface breakdown over spacer, in the case of type II spacer, are by 60 % greater than the values obtained for type I spacer. In fig. 6 it can be seen that the values of surface breakdown voltages are by 30% greater than the corresponding values of breakdown voltages in the gas. It is observed in fig. 5 that the random variable breakdown voltage of the GM counter (with type I spacer) belongs to complex additive distribution which consists of two double-exponential distributions. Thereby it can be noted that for the GM counter model with type II spacer, the participation of the breakdown voltages lower values (*i. e.* first part of additive distribution) equals zero.

Figure 7 shows breakdown voltage of the five-segment GM counter as a function of enlargement factor m.Variation coefficient of the random variable GM counter breakdown voltage as a function of enlargement factor, as well as corresponding theoretical dependencies in the case of double-exponential, nor-

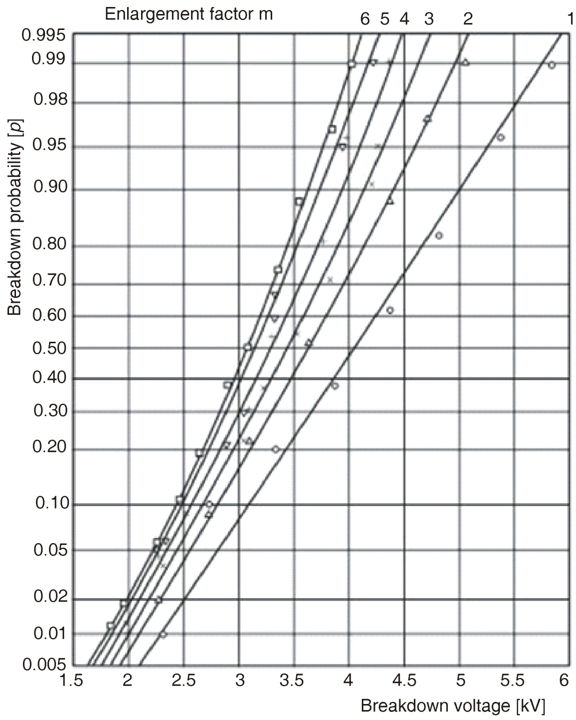

Figure 7. Validity of the enlargement law for the m segment GM model

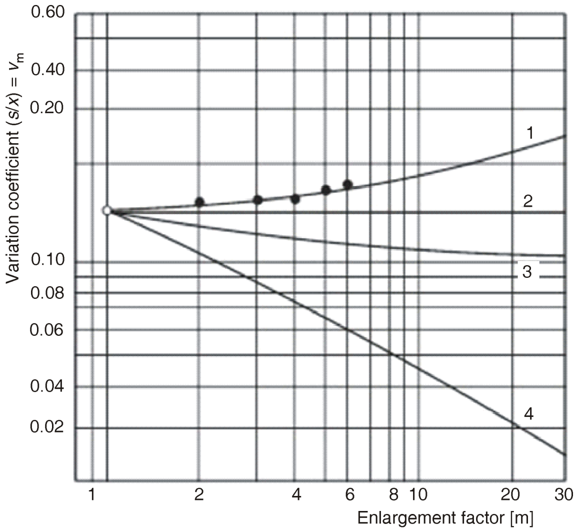

Figure 8. Random variable variation coefficient as a function of enlargement factor m (number of segments) and the appropriate theoretical dependencies for: 1 – double-exponential distribution, 2 – two parameter Weibull distribution, 3 – normal distribution, 4 – three parameter Weibull distribution

mal, two parameter Weibull and three parameter Weibull distributions, are shown in fig. 8. Based on the results shown in figs. 7 and 8 it can be seen that the assumption claiming the random variable GM tube breakdown voltage belongs to double-exponential distribution is satisfactory. In addition, it is observed that the enlargement law for breakdown in m-multiple configuration is applicable under the abovementioned assumption. It facilitates estimation of double-exponential *g* dispersion value based on the random variable performance function shown in figs. 5 and 6. Based on a calculation of the GM tube nominal voltage (DC breakdown voltage), the value 1800 V is obtained. Substituting this value in the eq. 2, U_{Bst} is obtained. U_{d02} value can be calculated based on the specific value of U_{Bst}. The calculation of U_{d02} for the breakdown in the GM counter gas and for the flashover over spacer shows that the condition (1) is satisfied, in the case of GM counter model with type II spacer. The condition (1) is not satisfied for the type I spacer.

CONCLUSION

In the paper we analyzed the application of contemporary methods for insulation co-ordination and the enlargement law in constructing and testing the GM counting tube. Mathematical procedure has been shown for the optimal choice of the GM counter insulation structure. Also, we demonstrated the method which facilitates estimation of effects in counting tube insulation structure caused by changing counting tube dimensions. Obtained results give us a possibility to optimize GM counting tube in the design phase and predict potential defects such as the appearance of false impulses caused by surface breakdown over spacer.

AUTHORS' CONTRIBUTIONS

Theoretical analysis was carried out by E. Ć. Dolićanin and I. S. Fetahović. Experiments were carried out by Dj. R. Lazarević and E. Ć. Dolićanin. All of the authors have analysed and discussed the results. The manuscript was written by E. Ć. Dolićanin. The figures were prepared by I. S. Fetahović.

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КООРДИНАЦИЈА ИЗОЛАЦИЈЕ И ЗАКОН ПОРАСТА ЗА БРОЈАЧКЕ ЦЕВИ ГМ БРОЈАЧА

У раду се разматра примена савремених метода координације изолације и закона пораста на конструкцију ГМ бројачке цеви. Показано је како је применом метода координације изолације могуће оптимално димензионисати бројачку цев. Демонстрирана је могућност примене закона пораста на уопштавање резултата испитивања добијених ГМ бројачком цеви на резултате који би се добили бројачком цеви m-пута већих димензија. Разматрања су обављена теоријски и експериментално. Теоријском анализом изведени су обрасци које је могуће применити ако се зна функција изводница случајне променљиве, пробојни напон. Експерименти су вршени на моделу ГМ бројача под добро контролисаним лабораторијским условима.

Кључне речи: ГМ-бројач, координација изолације, закон пораста