Monte Carlo Simulations of Proficiency Testing for Geometric Distributed Test Results

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Abstract. The scope of the paper is the investigation of the effect of probability value variations on the dispersion of extreme values of geometric random process results. The practical background of the investigation is the study of values obtained in the process of low currents testing in explosive gas mixtures. In the first part of the paper, the process of testing by using spark test apparatus and explosive test gas mixtures was briefly shown. In the second part of the paper, the geometric type of distribution process associated to tests results was emphasized. In the third part, the simulation method used together with Monte Carlo simulation process were introduced. The simulation results and discussions were presented in the last part.

1. Introduction
The modernization process of industrial and energetic field is closely supported by a new complex infrastructure based on intelligent systems.

These intelligent systems are interconnected with technological installations which process combustible substances (gases, vapours, mists, dusts, lint, fibres) whose storage and processing involves the existence of explosion risk Cioca et al [1, 2].

The areas affected by the presence of dangerous concentrations of combustible substances are grouped EU [3].

The entire technological equipment can represent an ignition source for such explosive atmospheres.

To reduce the risk of explosion, several types of protection were conceived in the last century, which applied to equipment (even from the design and production phase) and significantly reduce the possibility of ignition of explosive atmospheres from such equipment.

A distinct category of electrical equipment is the low current equipment. This category includes all the electrical equipment systems designed for transfer and processing of information.

Explosion protection of this type of equipment and systems is easily accomplished by using the intrinsic safety type of protection IEC [4, 5].

Implementation of the intrinsic safety type of protection involves the limiting of the stored and transmitted energy through circuits at non-dangerous values from the point of view of ignition possibilities for the given explosive atmospheres.
2. Brief description of the spark test apparatus
Low current electrical equipment is tested regarding the capacity of non-igniting of the explosive atmospheres by using a device that performs electrical discharges in an explosive testing mixture.

Electricity is taken from the equipment under test and transferred to an assembly of mobile elements. The elements that get into intermittent contact to produce the sparks are four tungsten wires and a cadmium disk. In fact, from the electrical point of view, this equipment generates electrical resistance variations between the closed circuit and open circuit. Due to the complex relative movement between the wire and disc, the disc surface becomes grooved so that the mere passage of the wire will determine a variable profile of the contact resistance. The explosive test mixture used in the experimental tests was a mixture of 21% H₂ in air. Electrical parameters of circuits connected to STA were 24 V; 30 mA; 87.94 mH. 30 tests were performed. The parameters of the test electric circuit were chosen according the ignition diagram A.6 from intrinsic safety type of protection specific standard for inductive circuits (safety coefficient 1).

![Figure 1](image1.png)

**Figure 1.** Test rig for compliance testing on ignition by spark test apparatus (STA)

![Figure 2](image2.png)

**Figure 2.** Diagram of the number of revolutions at which the ignition of the test mixture occurred

![Figure 3](image3.png)

**Figure 3.** Density distribution diagram of the decimal logarithm of the revolutions number at which the ignition of the explosive test mixture has occurred
The number of rotations of the holder disc at which the ignition of the explosive mixture occurred are shown in Figure 2. Also the distribution density of the decimal logarithm of values of the revolutions number at which ignition occurred during testing is shown in the diagram in Figure 3.

3. The type of distribution probability for the rotations number at which ignition occurs

Random processes associated with the values of the revolutions number at which ignition occurred are discrete processes without memory that could be described by the geometric distribution probability.

The associated geometric distribution for the probability distribution density of the (X) vector of values regarding the revolutions number at which the ignition of the explosive test mixture occurred is shown in (1).

\[ pmf(X, k) = \frac{1}{X} \left(1 - \frac{1}{X}\right)^{k-1} \]  

(1)

The hypothesis of geometric distribution of the revolutions number is supported by Cullen and Frey diagrams Delignette-Muller [6] in Figure 4 which use 3rd order values (skewness) and 4th order values (kurtosis) of moments. These values have been calculated for the number of revolutions at which the ignition occurred in the calibration circuit and in the test circuit. This diagram reveals that the experimental distribution is near to the exponential type but having in view that the values number of rotations to ignition are integer. Therefore, it is a discrete distribution and this probability distribution is a geometrical type.

![Figure 4](image.png)

Figure 4. Cullen and Frey diagrams of the distribution of the revolutions number at which ignition of the test mixture occurred in the test circuit

4. Numerical simulation

For the purpose of proficiency testing, simulation with the the Monte Carlo method was used. Input parameters used are: the geometric probabilistic distribution type; the normal distribution probability by Johansmeyer [7], Darie [8] for value of the rate with the mean of $10^{-3}$ and the standard deviation as a variable fraction of the mean with values of 0%, 5% to 100%; number of test laboratories- 40, number of tests for each laboratory- 20, number of scenarios for each fraction- 5000.

The process of numerical simulation is shown below:

- Initiation of fraction value “IF” (0%, 5% to 100%)
- Running scenarios (1 to 5000)
- Generated probability for each laboratory “LP” (normal distributed, mean=$10^{-3}$, standard deviation=IF*mean)
Generate 20 times number of rotations to ignition (geometrically distributed, probability – obtained before) for each laboratory;
Calculate the mean for all tests and each laboratory;
Calculate the mean of all means;
Calculate and retain relative differences of the mean for each laboratory;
Calculate and retain maximum and minimum relative differences of the mean for each laboratory;

5. Simulation results
After the simulation has finished, the obtained values were read and density distribution was plotted for each fraction value.

The density distribution of the mean for each fraction is shown in Figure 5 and the distribution of extremes values for laboratory means is shown in Figure 6.

The variation in the mode of distribution for extremes is shown in Figure 7.

![Figure 5](image1.png)

**Figure 5.** Density distribution for relative value of means. Red curve is for 75% factor of standard deviation

![Figure 6](image2.png)

**Figure 6.** Density distribution for extremes of relative value of means. Red curve is for 75% factor of standard deviation
Analyses of graphs in Figures 5 to 7 implies the following:

- increasing of fraction (which quantifies the dispersion of laboratory probability) moves density distribution mode to the left (skewness increase);
- difference of extremes (minimum and maximum) increase with value of fraction;
- increasing the fraction value makes the relative maximum value more scattered.

6. Conclusions

The main achievement of the conducted study is proof that the proficiency testing process amplify ignition probability variations. The values greater than $0.2 \times 10^{-3}$ for the ignition probability standard deviation cause value of relative differences to the mean rapidly increase. Variations from -100% to 400% for relative differences to the mean could be explained by value of $0.75 \times 10^{-3}$ for ignition probability standard deviation. The skewness value for the density distribution of the mean increase with the value of ignition probability standard deviation. Also mode for the density distribution of the mean decrease with the value of ignition probability standard deviation.

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For performing the calculus and diagrams were used the R language and R Studio Environment R [9], [10] along with the moments Komsta [11] and fitdistrplus Delignette-Muller [6] packages.

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