

## Acoustic effects of single electrostatic discharges

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**Abstract.** Electric discharges, depending on their character, can emit different types of energy, resulting in different effects. Single electrostatic discharges besides generation of electromagnetic pulses are also the source of N acoustic waves. Their specified parameters depending on amount of discharging charge enable determination of value of released charge in a function of acoustic descriptor (e.g. acoustic pressure). Presented approach is the basics of acoustic method for measurement of single electrostatic discharges, enabling direct and contactless measurement of value of charge released during ESD. Method for measurement of acoustic effect of impact of a single electrostatic discharge on the environment in a form of pressure shock wave and examples of acoustic descriptors in a form of equation  $Q=f(p_a)$  are described. The properties of measuring system as well as the results of regression static analyses used to determine the described relationships are analysed in details.

### 1. Introduction

Parameterization of the phenomenon and assessment of hazards caused by electrostatic discharges is directly associated with their proper measurement. Charge transferred during the discharge is one of the parameters of a single electrostatic discharge (ESD). Measuring methods that have been used so far are mainly electrical measuring methods [1], [2], [3], [4]. Analysis of conditions and technical requirements included in the methods for measurement of charge of a single electrostatic discharge, made by the author, has shown limitations and possible technical problems. Measuring method presented in EN 13463-1 Standard does not enable detection of discharges following one after another in a short time (shorter than time constant of electrostatic voltmeter). This leads to overestimation of measurement of discharge from the tested sample. Moreover, this method is sensitive to electrostatic background (saturation of capacitor by approaching the discharging electrode to the tested material without discharge) and coexistence of measuring system and discharge system. Simplicity of measuring system and uncomplicated mathematical relationship  $Q=UC$  for determination of charge is the advantage of this method. Von Pidoll [2] suggested another method, based on continuous measurement of current in a circuit during discharge to determine the charge, which has no disadvantages described above.

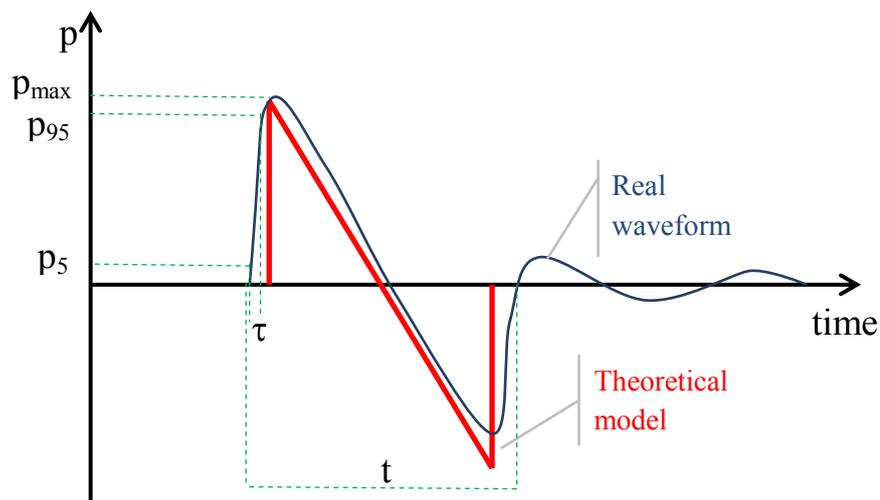
### 2. Analysis of the acoustic phenomenon during electrostatic discharge

Acoustic effects, especially in the frequency audible to humans (20 - 20 000) Hz are the result of released energy action, in a form of medium ionization in a strong electric field. The most intensive ionization is in the front of the channel, what manifests with the light effect of discharge, caused by



rapid temperature increase up to few thousand degrees (Kelvin). Speed of spark propagation significantly exceeds speed of sound and reaches  $10^6$  m/s. It causes violent (practically explosive) pressure change in the channel, causing strong acoustic effects [5].

Acoustic shock N-wave (*N-wave*, – name comes from similarity of the acoustic waveform, close to the source, to the letter *N*), which theoretical and real shape is the result of the phenomenon (e.g. explosion, spark electrostatic discharge) and is presented in below figure.



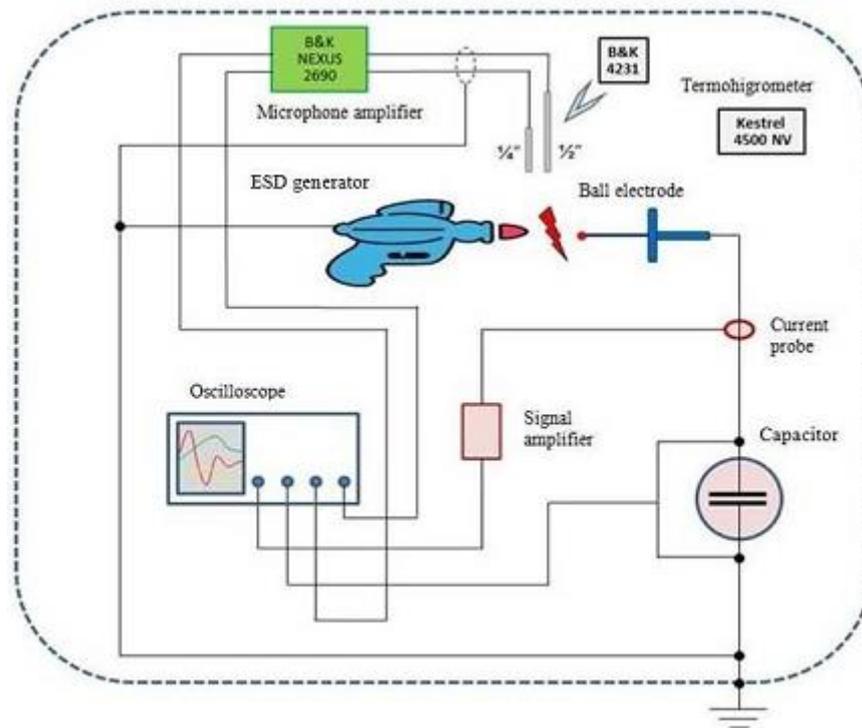
**Figure 1.** Graphical presentation of N-wave with the main descriptors (own report)

Reference of mechanism of generation of N-wave, presented in a micro scale, to the situation, where the electrodes (discharge electrode and earthed electrode) are placed in a short distance from each other, means that generated wave has a conical shape only at the small distance between these electrodes. In a macro scale, geometrical boundary conditions of such system of electrodes (a distance of up to a few centimetres) cause that the generated shock wave, which propagates, has a spherical shape and audible acoustic effect is its physical effect. Single electrostatic discharges generate short acoustic “thunders” of pulse time process and fuzzy frequency spectrum. Such properties of electrostatic discharge require the use of proper technologies for recording and analysis of measuring signals [6], [7]. The results of laboratory acoustic tests on electric sparks are presented by Klinkowstein R. [8]. He proved the possibility of using the spark discharges as repeatable reference source of acoustic pulses, and confirmed theoretical energy relationships of sound waves for quick-changing processes with fuzzy frequency spectrum in a distant field (free field).

### 3. Acoustic test of ESD

Part of scheduled tests included the measurements of time process of acoustic pressure during single electrostatic discharge generated by the simulator of single high-energy discharges. The measurements of acoustic pressure were taken with use of two microphones of diameters  $\frac{1}{2}$ " and  $\frac{1}{4}$ " arranged perpendicularly to the axis of discharging electrode. The housings of the microphones were earthed. The distance between the microphones and the electrode axis was equal to 0.5 m. Moreover, time processes of momentary voltage on a capacitor connected in series in the circuit of discharge electrode as well as momentary discharge current in this circuit were recorded.

The measuring system for high-energy single ESD from the discharge generator was created for the testing purposes. The measurements were taken by approaching the electrode of armed discharge generator to the earthed electrode of discharging system with the capacitor of known and constant capacitance, connected in series. When a distance between the electrodes was short enough to overcome the resistance of the medium with charge flashover, EDS occurred. Current of the circuit (of the amount proportional to the released electrostatic charge) charged the capacitor connected in series.



**Figure 2.** Diagram of the system for realization of first part of measurements (own report)

On the basis of analysis of regression tests of the specified group of acoustic parameters and electrostatic discharges generated by the simulator it was found that uncorrected level of effective acoustic pressure determined for 360  $\mu$ s (duration of acoustic pulse until decay of wave amplitude) best matches to the acoustic descriptor, which describes high-energy electrostatic discharges generated by ESD simulator. This parameter as well as peak value of amplitude of acoustic process for microphone  $\frac{1}{2}$ " and its placement at a distance of 0.5 m recreates the amount of charge with accuracy described by  $R^2$  coefficient equal to 0.93.

Identified regression equation, which determines electrostatic charge on the basis of measurement of acoustic parameters, is as follows:

$$Q \text{ [nC]} = 0.4397 \cdot p_{a360}^2 \text{ [dB]} - 22.4256 \cdot p_{a360} \text{ [dB]} + 33.6560 \cdot p_{amax}^2 \text{ [Pa]}$$

where:

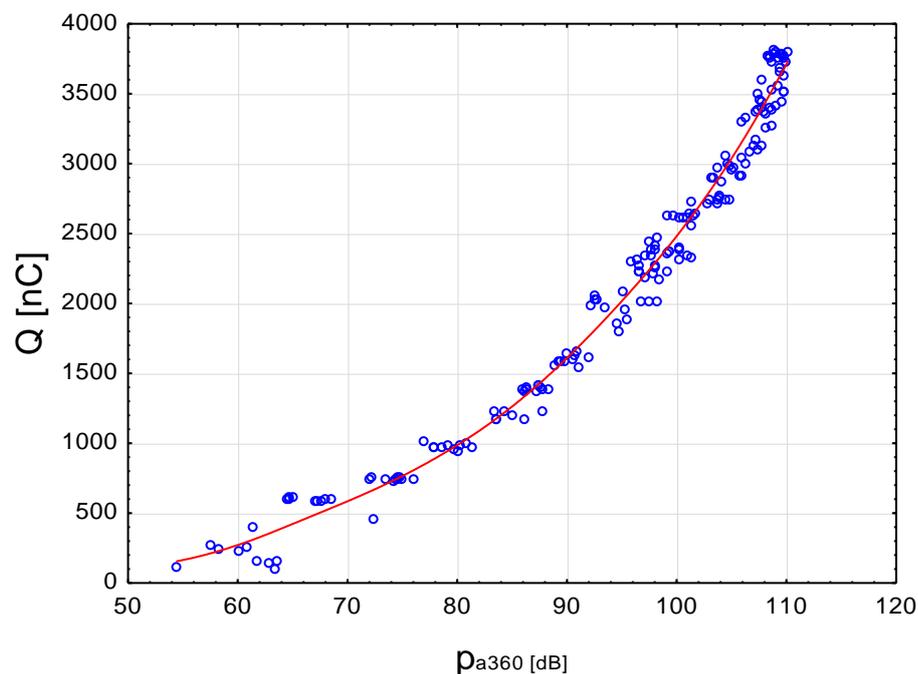
$Q$  – electrostatic charge expressed in nC,

$p_{a360}$  – level of effective acoustic pressure for 360 $\mu$ s expressed in dB,

$p_{amax}$  – maximum amplitude of acoustic wave expressed in Pa.

This relationship is presented in Figure 3.

The relationship ( $p < 0.001$ ) enables determining the charge on the basis of measurements of acoustic pressure during single electrostatic discharges (for a given position of microphone) with maximum error determined by a distribution of raw residuals determined from a difference between observed results and the results predicted by the regression model.



**Figure 3.** Diagram presenting relationship between electrostatic charge and effective acoustic pressure for high-energy discharges from generator (own report)

#### 4. Summary

In the work, possibilities of using in practice the alternative method of measuring the electrostatic charges from single discharges from the generator of electrostatic discharges, by the measurement of acoustic pressure wave, which is a result of impact of discharges on the medium in which they occur were presented and analyzed. The method is an important element completing the current methods for electrostatic discharge measurements, adding the knowledge, which cannot be acquired by the traditional methods mentioned in the standards, e.g. multiplicity of discharges. Contactless (indirect) measurements of the transferred ESD charge enable eliminating the electrostatic interferences, so they do not affect the measurement results.

#### References

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