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Temperature tests of cells - uncertainty considerations

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Abstract. The paper presents the estimation of the uncertainty in the measurement of the maximum surface temperature of voltaic cells exposed to specific tests for the type of intrinsic safety protection. For this purpose, equivalent test conditions using the short-circuit test stand are considered. In the first part, the risk of explosion is presented and it is mentioned that the risk of explosion arises due to the presence of technical equipment in areas where flammable substances may be present. In the second part, the requirements for testing cells are briefly presented. It also introduces the configuration of the stand used for testing. The third part of the paper was devoted to presenting and discussing the results obtained. The analysis of the test results revealed that the measurement uncertainty depends on the test conditions and the application of the temperature sensors. This result would help estimate the surface temperature of cells considering the favorable conditions in terms of minimum uncertainty.

Introduction

The criteria of efficiency, flexibility and safety are important and automation systems that ensure these criteria are met are playing an increasingly important role. These automation systems for feedback and control are weak current installations.

On the other hand, the growing need for mobility and autonomy for communications, remote measurement, remote control and so on has made voltaic cells increasingly important.

Flammable substances are frequently involved in technological installations either at the input side or at the process transition side of the output side. These lead to dedicated spaces around technological installations with an increased risk of explosion [1]. The access of machinery intended for use in potentially explosive atmospheres to the European market is regulated by European Directive 2014/34 / EU (2014) [2]. This specifies the conditions and parameters of the equipment that must be compatible with the premises in which they operate. The technical details of explosion protection of equipment are outlined by specific standards [3].

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The technical infrastructure for automation installations is realised using low-current equipment and installations [4,5]. They must also comply with specific requirements for operation in areas with the risk of explosive atmospheres caused by the presence of flammable substances [6,7].

The presence of technical equipment in atmospheres containing flammable substances may give rise to a risk of ignition due to electrical or thermal effects. On the other hand, many sources of ignition cause the risk of explosion in atmospheres with flammable substances, such as mechanical sparks, electric sparks [8-10], ultrasound, exothermic chemical reactions, hot surfaces [11-13], static electricity, etc.

Intrinsically safe explosion protection limits electrical and thermal ignition sources, reducing their ability to trap hazardous atmospheres [4]. This type of protection also uses a way of taking into account possible faults in components, connections, etc.

By considering possible fault scenarios, both normal and faulty operations are taken into account at the design stage. Depending on the number of faults, classification according to the ATEX Directive into categories 1 2, or 3 [2] is taken into account and the requirements of the IEC standard for protection levels a b and c [4] are also considered.

A concrete explosion protection situation is the temperature limitation of hot surfaces. In the context of cells, these are considered to be capable of igniting hazardous atmospheres due to a fault such as an internal short circuit leading to extreme heating of the outer surface. For this purpose, the intrinsically safe type of protection [5] provides for short-circuit testing of these cells and the determination of the maximum surface temperature.

The high complexity of the test system involving heat transfer by both conduction and convection causes propagation and even amplification of uncertainties in the final measurement result.

In this paper, the estimation of the uncertainty of the cell temperature measurement exchange during testing is addressed in particular.

As electronic systems have improved, consumption has decreased significantly and the range offered by the cells has also increased.

On the other hand, cells have benefited from new electrochemical systems and higher efficiency and capacity.

However, the possibility of recharging has maintained the trend, resulting in primary cells, i.e. non-rechargeable and secondary cells, i.e. rechargeable.

A special category of cells is supercapacitors. But these are also considered cells when making explosion protection assessments and specific tests for them.

Because explosion protection looks at both the risk of spark ignition and the risk of ignition from hot surfaces, tests on cells also look at these risks.

Material and methods

To determine by test the maximum surface temperature of galvanic elements, the cells when exposed in the short circuit test regime a thermocouple is placed in the middle of the galvanic element and the temperature is monitored during the course of the test. This test is conducted among other tests as it is presented in Figure 1.

During this test, the maximum short-circuit current is also determined, which is then used to determine the minimum internal resistance. And the minimum internal resistance is determined for assessing spark ignition safety.

Another result of the test is the confirmation of the ability of the cell to retain the substances of the electrochemical system inside.

Fig. 1. Tests for cells

The stand used to carry out this test has the structure shown in Figure 2 by the block diagram. The short-link device meets the requirements of the specific standard [4] and the measuring loop is calibrated. Figure 2 shows with arrows the direction of the data collection.

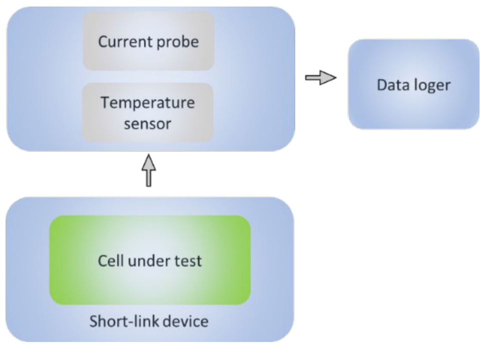

Fig. 2. Test stand-block diagram

The temperature measurement is made about the ambient temperature and for this purpose, a thermocouple is also used for the ambient temperature.

Preliminary tests carried out, confirm that the one-second resolution for the temperature measurement process and data recording is satisfactory.

To determine the measurement uncertainty, introduced by the particularities of the thermal contact of the thermocouple with the measured surface, the geometry shown in Figure 3 was considered.

The area of thermally conductive paste was considered as having the shape of a spherical cap, defined by the parameters height - h and diameter - d.

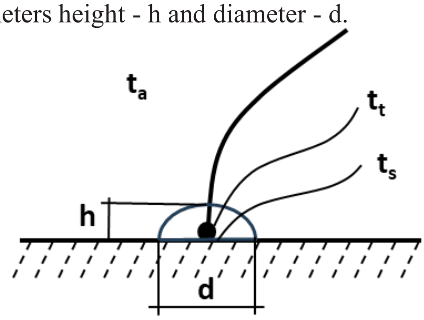

Fig. 3. The temperature measuring detail

It is further considered that the heat transfer between the conductive paste and the ambient medium is characterized by the same density as between the measuring surface without thermally conductive paste and the ambient medium.

Thus the slightly increased surface area of the spherical heat conductive paste cap may lead to a slight decrease in the measured temperature and possible variations in its dimensions will lead to some uncertainty in the temperature measurement. Under these conditions equations 1 to 4 result. It is also considered that the temperature of the thermally conductive paste is the same as the temperature of the thermocouple - t_t.

$$Q = k_t \cdot S_0 \cdot (t_s - t_a),\ Q = k_t \cdot S_1 \cdot (t_t - t_a) \quad (1)$$

$$\frac{t_s - t_a}{S_1} = \frac{t_t - t_a}{S_0} \quad (2)$$

$$S_0 = \pi \cdot \left(\frac{d}{2}\right)^2,\ S_1 = \pi \cdot \left(\left(\frac{d}{2}\right)^2 + h^2\right) \quad (3)$$

$$t_s = k \cdot (t_t - t_a) + t_a,\ k = 1 + \frac{4h^2}{d^2} \quad (4)$$

Where Q is the heat transferred to the environment; k_t is a heating transfer constant; S_1 is the surface of the thermo-conductive paste in contact with the environment and S_0 is its projection; k is a constant due to the cooling effect, t_a is the environment temperature, t_t is the thermocouple temperature and t_s is the surface temperature without thermo-conductive paste.

The assessment of the d and h values of these parameters, the size of the nozzle of application of the thermally conductive paste, is based on the diameter of the thermally conductive paste application nozzle 1.6 mm and the diameter of the thermocouple alloy 1-1.3 mm. The range of distribution of values was defined according to Figure 4.

To determine the uncertainty involved in the surface temperature measurement process using a thermocouple-based system and using thermally conductive paste, the dimensions of the thermally conductive paste portion: height and diameter were chosen to be considered as uniformly distributed in the size range shown in Figure 4.

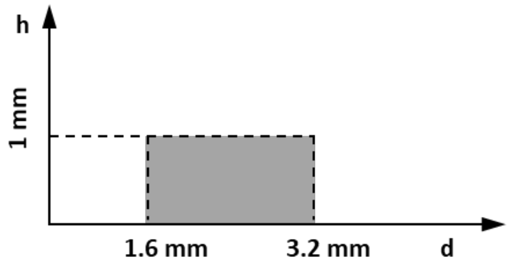

Fig. 4. Distribution of values for h and d

To take into account the uncertainty of repeated measurement, the temperature measured by the thermocouple placed at the measuring surface (t_{tc}) and the ambient temperature (t_{am}) was taken into account for 70 successive values. These are described in equations (5) and (6).

$$t_a = t_{am} + \varepsilon_{ta},\ t_t = t_{tc} + \varepsilon_{tc} \quad (5)$$

$$h_{sensitivity} = \frac{8h}{d^2},\ d_{sensitivity} = -\frac{8h^2}{d^3} \quad (6)$$

In equation (5) the terms ε_{ta} and ε_{tc} stand for error and all have mean zero.

Results and discussions

The surface temperature of the cell in the middle was measured and plotted in the diagram in Figure 5 together with the ambient temperature.

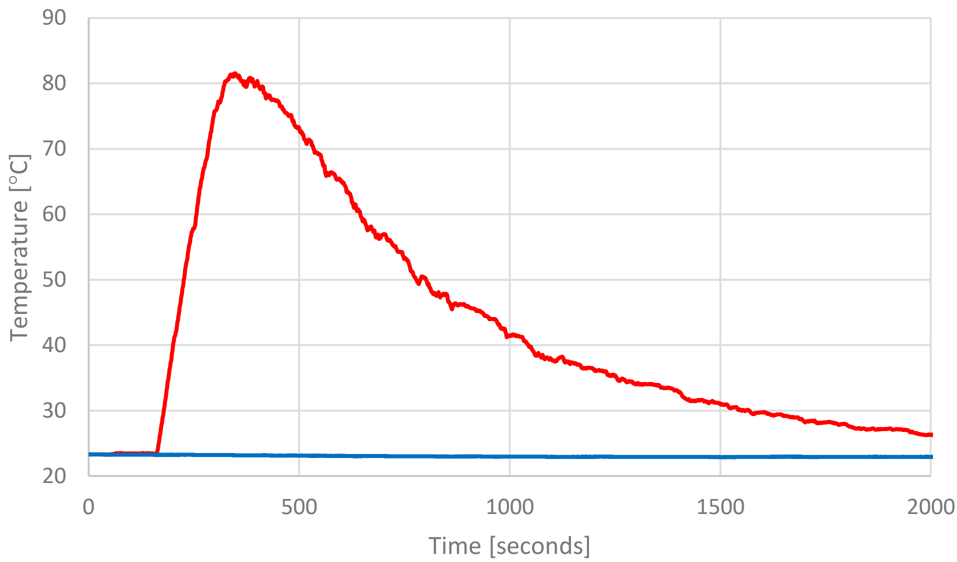

Fig. 5. The measured temperature of the cell (red) and the ambient temperature (blue)

The process of discharging a cell was carried out while monitoring the mid-cell temperature and ambient temperature for 2000 seconds at a rate of one measurement per second (1 Hz). In the diagram in Figure 5 it can be seen that a relatively short time after the triggering of the short-link device, the cell temperature reaches the maximum value where it is maintained for about 70 seconds after which the heating process slows down.

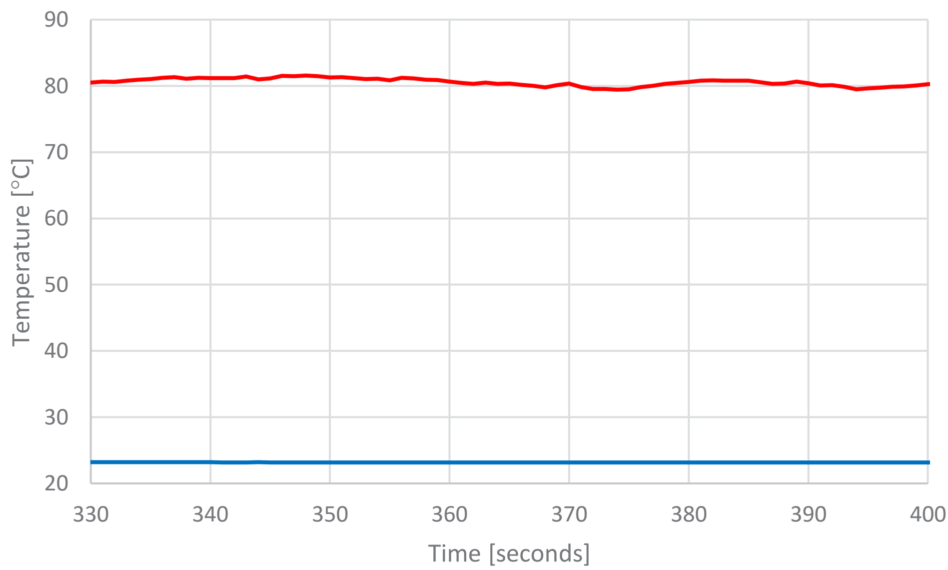

Fig. 6. The measured pick temperature of the cell (red) and the ambient temperature (blue)

The maximum temperature measured was 80.59°C, with a standard deviation of 0.583°C, 70 values and the ambient temperature at the same time was 23.17°C, with a standard deviation of 0.018°C, 70 values.

As can be seen in equation 4 the coefficient k depends quadratically on the height of the thermally conductive paste cap and the uncertainty will also be influenced by this behaviour. It should also be noted that this coefficient has an amplification factor of value 4. The calculated values of the coefficient k are shown in the diagram in Figure 7.

The sensitivity of the uncertainty of h and d are presented in equations (7) and the values are presented in Figure 7.

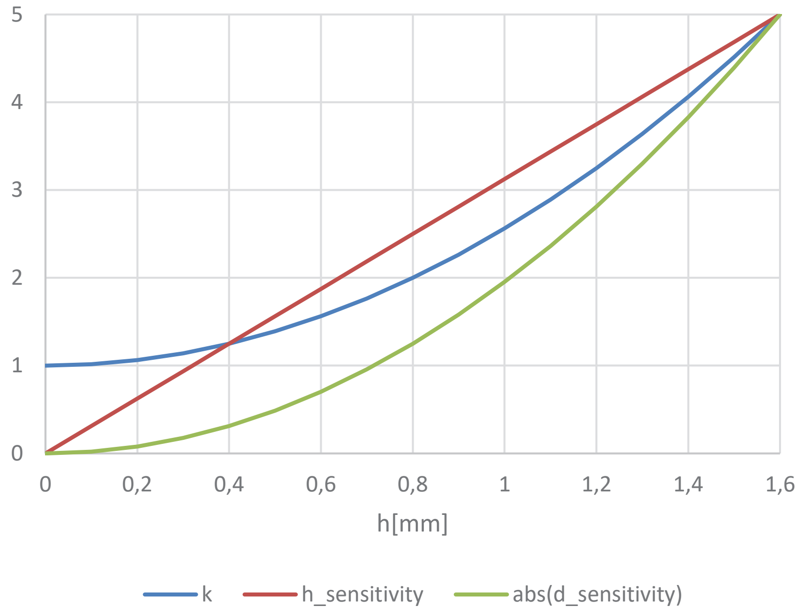

Fig. 7. Values of k, h_sensitivity, d_sensitivity coefficients in respect with h for d=1.6 mm

The coefficient k depends practically on the ratio of height to diameter and smaller values of nozzle diameter can lead to more problematic situations with higher values of k coefficient. Similarly, the parameters h_sensitivity and d_sensitivity have the same magnitude as the parameter k for the range of values for h and d considered.

Description of used quantities for the uncertainty estimation is: k is an interim result; h [mm] is the height of the thermo-conductive paste blob; d [mm] is the diameter of the thermo-conductive paste blob; t_t [°C] is computed temperature at the surface; t_{tc} [°C] is measured temperature at the surface; ε_{tc} [°C] is the error due to repetitive measurement of surface temperature; t_a [°C] is computed ambient temperature; tam [°C] is measured ambient temperature; ε_{ta} [°C] is the error due to repetitive measurement of ambient temperature; t_s [°C] is computed surface temperature.

Table 1 Uncertainty Budget

Quantity	Value	Standard Uncertainty	Degrees of Freedom	Uncertainty Contribution	Index
k	1.174	0.213	∞		
h	0.500 mm	0.289 mm	∞	12 °C	88.3 %

Quantity	Value	Standard Uncertainty	Degrees of Freedom	Uncertainty Contribution	Index
d	2.400 mm	0.462 mm	∞	-4.1 °C	11.4 %
t_t	80.590 °C	0.602 °C	79		
t_{tc}	80.590 °C	0.150 °C	50	0.18 °C	0.0 %
ε_{tc}	0.0 °C	0.583 °C	70	0.68 °C	0.3 %
t_a	23.170 °C	0.151 °C	51		
t_{am}	23.170 °C	0.150 °C	50	-0.026 °C	0.0 %
ε_{ta}	0.0 °C	0.0180 °C	70	$-3.1\cdot10^{-3}$ °C	0.0 %
t_s	90.6 °C	12.3 °C	∞		

According to the uncertainty budget, obtained uncertainty is 91°C±25°C normal distribution 95% with coverage factor 2.

Additionally, the thermally conductive paste is used to facilitate thermal contact between the thermocouple of the temperature measuring system and the surface whose temperature is to be measured. This, besides the desired benefit, has the disadvantage of increasing the measurement uncertainty. The theoretical model presented in equations 1 to 6 shows that the dimensions of the heat-conductive paste portions: height and diameter have a strong influence on the uncertainty with which the surface temperature is determined. This uncertainty is about one order of magnitude larger than the uncertainty due to the measurement system alone.

To reduce the cooling effect implied by the presence of the thermally conductive paste portion, as evidenced by the theoretical model shown in equations 1 to 4, the height of the thermally conductive paste portion should be much smaller than its diameter.

On the other hand, the h is not recommended to be lower than half of the diameter of the probe to facilitate the thermal contact of the probe with the surface. In this case, the uncertainty will increase more.

Conclusions

The process of deep discharging (short-circuiting) of the cells involves a heating process. For the tested cell, the highest recorded temperature was near 81°C.

The implemented model, based on heat transfer, involves the use of an amplification coefficient, which depends on the size of the thermally conductive paste portion. The value of this coefficient increases quadratically with the height of the thermally conductive paste portion.

One explanation for this behaviour is the cooling effect of the thermally conductive paste portion.

The uncertainty budget analysis revealed that the size of the thermally conductive paste portion contributes an order of magnitude larger uncertainty than the other quantities involved. This is due to the inherent variability taken into account when estimating the uncertainty.

In order of reducing the cooling effect involved by the use of the thermally conductive paste portion, the height of the thermally conductive paste portion should be much smaller than its diameter.

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References

1. D. Cioclea, A.G. Gaman, I. Gherghe, F. Radoi, C. Boanta, V. Pasculescu, *Possibilities to priorly establish the structures of ventilation networks affected by underground explosions*, The 24th International Mining Congress and Exhibition of Turkey, 14 – 17 April 2015, Antalya, Turcia, ISBN 978-605-01-0705-0, pp 991-997 (2015).
2. ATEX Directive, *Equipment for potentially explosive atmospheres (ATEX)*, available https://ec.europa.eu/growth/sectors/mechanical-engineering/ atex_en (2014).
3. V.M. Pasculescu, N.I. Vlasin, D. Florea, M.C. Suvar, *Improving the quality of the process for selecting electrical equipment intended to be used in potentially explosive atmospheres*, Quality - Access to Success, Romania, vol. **18**/issue S1, pp 97-102 (2017).
4. (SR) EN 60079-11: 2012 - Explosive atmospheres Equipment protection by intrinsic safety "i", (2012).
5. (SR) EN 60079-0: 2018 - Explosive atmospheres - Part 0: Equipment - General requirements (2018).
6. V.M. Pasculescu, M.C. Suvar, N.I. Vlasin, G.A. Gaman, D. Florea, *Computer modelling of flammable gas dispersion through leakages occurred in technological installations*, 15th International Multidisciplinary Scientific GeoConference SGEM 2015, www.sgem.org, SGEM2015 Conference Proceedings, ISBN 978-619-7105-34-6 / ISSN 1314-2704, June 18-24, 2015, Book 2 Vol. **1**, Albena, Bulgaria, pp. 77-84 (2015).
7. M. Prodan, E. Ghicioi, C. Lupu, I. Nalboc, A. Szollosi-Mota, *Flammability characterisation of a petroleum derivative for increasing the safety of personnel and environmental protection*, International Multidisciplinary Scientific GeoConference: SGEM; Sofia, Vol. **4** (2016).
8. M. Darie, J. Ionescu, S. Burian, T. Csaszar, L. Moldovan, *Ignition probability assessment of low current circuits designed for use in explosive atmospheres*, Environmental Engineering and Management Journal, volume **11**/2012, No.5 (2012).
9. M. Prodan, M. Mitu, D. Razus, D. Oancea, *Spark ignition and propagation properties of methane-air mixtures from early stages of pressure history*, Revue Roumaine de Chimie, 61(4-5), pp 299-305 (2016).
10. (SR) EN 1127-1: 2019 - Explosive atmospheres. Explosion prevention and protection. Basic concepts and methodology (2019).
11. E. Ghicioi, I.C. Jitea, N.I. Vlasin, A. Kovacs, G. Vasilescu, et al., *Computational study in the civil use explosives area*, International Multidisciplinary Scientific GeoConference : SGEM; Sofia Vol. **3**: 139-145. Sofia: Surveying Geology & Mining Ecology Management (SGEM) (2014).
12. L. Moldovan, S. Burian, M. Magyari, M. Darie, D. Fotau, *Factors influencing the determination of maximum surface temperature for explosion-proof luminaires*, Environmental Engineering and Management Journal, Vol.**16**, No. 6, pp 1309-1316 (2017).
13. C. Tomescu, M. Prodan, N. Vatavu, E. Chiuzan, *Monitoring the work environment using thermal imaging cameras in order to prevent the self-ignition of coal*, Environmental Engineering and Management Journal, Vol.**16**, No. 6, pp 1389-1393 (2017).