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NEW POSSIBILITIES FOR THE PASSIVE ELIMINATION OF STATIC ELECTRICITY

Abstract: *The new possibilities of passive elimination of static electricity, both in production processes and in everyday life are given in this paper. The paper considered passive solutions for elimination of static electricity which are the result of years of research in technological processes in which the concentrations of explosive and flammable mixtures and dust are present. The proposed solutions have the status of an internationally protected patent. A comparison between offered passive solutions and the present state of technology in both passive and active devices for the elimination of static electricity is made. Computer simulation of work and the level of the elimination of static electricity of the proposed passive devices for the elimination of static electricity for all phases of state (solid, liquid, gas and powder) is made and processed in a computer software MATLAB / Simulink v7.6 (R2010b). The obtained results are commented in the paper, and the risk assessment of possible electrostatic discharge in hazardous areas is made as defined by the Directive ATEX 137.*

Key words: electricity, passive devices for the elimination of static electricity, hazardous area, risk assessment, ATEX 137.

INTRODUCTION

The problem of eliminating static electricity in production processes in which there are concentrations of explosive and flammable mixtures (and thus the dust) is a very complex technical and technological issue; if they are not resolved in a safe manner they will be a major threat to the technological process and the personnel and for the total safety of the production units and the work environment in general.

The solutions that are offered today in the field of the elimination of static electricity can be divided into two basic groups: the active and passive devices and static electricity eliminators.

Our studies are conducted both in laboratory and real conditions of the here considered passive eliminator of static electricity [1]. In the process of the elimination of static electricity in conditions where there is the concentration of flammable and explosive mixtures (and thus the dust) (vol.%) on technological machines, herein described and proposed device for the elimination of static electricity is used. Obligatory international procedure ATEX 137 requires and obliges employers to solve safe elimination of static electricity in these technological conditions and developments of the technological processes [1].

By the procedure ATEX 137 passive elimination of static electricity is recommended, and in this paper we give our contribution to the research of the here described patented and internationally protected passive solution for the elimination of static electricity.

TECHNOLOGICAL PROBLEM

Cumulative discharge of static electricity in the form with plasma properties with values of ignition energy Wp (J) is created, which can ignite an explosive (flammable and dust) compound that is present in the area affected with concentration of explosive mixture (vol.%).

Such technological processes are mainly present in the gas industry, petroleum and petroleum products, paint, pharmaceutical and other related industries.

State of technology

A safer solution was necessary and a solution for design of eliminators and devices for the elimination of static electricity that basically have external power supply or built in radioactive element has been proposed. The idea to power up the eliminator of static electricity with an external power supply is aimed at creating an electric field that will bombard and ionize the space at places where the static electricity appears; the needle eliminator makes "breakdown" of resulting electrostatic field, thus assuming a controlled drain of caused charge q(t). Installation of radioactive elements in the eliminator had task to ionize the surrounding area, thus allowing eliminator to "breakdown" the localized electrostatic fields with the aim of eliminating static electricity.

These solutions developed big problems and caused many accidents and damages in technological processes with unpredictable consequences.

A research of new solutions in the field of passive elimination of static electricity followed. Such a solution was presented in this paper as a new feature of passive elimination of static electricity [1].

IGNITION OF EXPLOSIBLE MIXTURE

The technological process of movement through the polypropylene film coated tow tension rollers at high speed *v(t)* (m/s) in an area with an increased concentration of explosive mixtures *vol%(t)*, leading to the formation of electrical load *q(t)* and ionized molecules *n(t)* on both sides of the surface of film. Such distributed electrical loads *q(t)* on the surface of coated foil participate now in the process of discharging the charge to each other and between the earthed metal parts of the machines [1,3]. Such a discharge can reach and have values of minimal ignition energy (MIE) of present concentration of explosive mixtures *Wmin* (J). In this way, electrostatic energy $w_s(t)$ that is localised in surrounding space polypropylene film - needle sensor (Fig.1 a) i b)) is created. The law on conservation of energy shall be implemented so that, in the chain of natural energy transformation, electrostatic energy *Ws* (J) is first transformed into electrokinetic W_k (J) and then into heat energy W_t (J), $W_s \rightarrow W_k \rightarrow W_t$, thus we get [1,2]:

$$\frac{1}{2}C_e U^2 = \frac{1}{2} n m_M v_M^2 = \frac{1}{2} nkT = = \frac{1}{2} nRT = \frac{1}{2} C_{ds} U_{ds}^2 \approx W_{paljenja} \quad (1)$$

$$W_{paljenja} \approx 0,4 W_{\min} \quad (2)$$

$$U_{ds} \approx \left(\frac{2W_{paljenja}}{C_{ds}} \right)^{\frac{1}{2}} \quad (3)$$

where: C_e (nF) corresponding values of capacitance of observed vapor-air geometric space in which an electrical (electrostatic) discharge appear, and thus the potential difference U (V) manifested through voltage $u(t) = \varphi_1(t) - \varphi_2(t)$; *n* – number of ionised molecules; m_M i v_M – mass and mean square speed of each individual ionized molecules of flammable paint or varnish (which is based on benzene) of polypropylene film; $k = 1,38 \times 10^{-23}$ (J/K) $= 8,617343 \times 10^{-15}$ (eV/K) – Boltzmann constant; i *T* (K) – thermodynamic temperature or absolute temperature, while the basic amount of positive charge has a value $1,602176487 \times 10^{-19}$ (C). Here appears the notion *Wpaljenja* (J), which represents above discussed heat energy *Wt* (J), which can ignite concentration of explosive mixture in the surrounding area of coated polypropylene; $R=8,314$ (J/molK) - universal gas constant; C_{ds} (nF) – capacitance of double layer of polypropylene film and diffuse mid-concentration resulting from an explosive mixture of polypropylene coating set by the technological machine to polypropylene coat first to be lacquered and then dried; $W_{min.}$ (J) - an experimentally determined the estimated value of the minimum energy that can ignite concentration of explosive mixture of coated polypropylene; U_{ds} (V) – estimated value of voltage established in double layer of polypropylene film and diffuse space with concentration resulting from an explosive mixture of polypropylene, which is also the criterion of estimated value of dangerous electrostatic voltage *Uds* (V) of the technological process of the polypropylene

A similar method is applied for analysis of hazards of other technological processes in terms of the danger of static electricity as an aspect of risk assessment. On the surface of the polypropylene film, electrostatic voltage $u_{sr}(t)$ in form of the unit (Heaviside) function, $u_{sr}(t)=(o, t \geq t_{sr}) \wedge$ or $(U_{sr}, t \succ t_{sr})$ is generated, where t_{sr} (ns)- a time for establishing the assessed value U_{sr} (V) as the unit/pulse function, where $t_{sr} \geq t_{0+}$, [1,3].

An important setting for the simulation presented in this paper is to first estimate the value of dangerous electrostatic voltage *Uds* (V) for polypropylene film which has an electrical resistance greater than 10^{15} **Ω**, applying clearcoat based on benzene C_6H_6 in the same case. The consequence of such varnish layers has the effect of creating mixtures with air and benzene concentration of explosive mixtures *vol 4,7%*, which is common to the category of MIE $W_{min.} \geq 0,24$ (mJ) [1]. In this case and for given conditions, heat energy *Wt* (J) will be developed at a temperature 62 (^{0}C), or 325(K), and then ignition energy of explosive mixtures is $W_p = 0,4 \times W_{min.}$ (J) . From equation (1) the value of the hazardous electrostatic voltage *Uds* (V) can be estimated, and in this case it is [1]:

$$\frac{1}{2} C_{ds} U_{ds}^2 = \frac{1}{2} nRT \approx W_{paljenja} \approx 0,4 W_{\min} \quad (4)$$

From the references [1,5,6], it is known that C_{ds} □ *3,6* (nF), and in the given circumstances clear coat is based on benzene, which is applied to the polypropylene film with air temperature $T = 62$(°C) or *325*(K), and it follows that:

$$U_{ds} = \left(\frac{2 \cdot 0,4 \cdot W_{\min}}{C_{ds}} \right)^{\frac{1}{2}} = \left(\frac{2 \cdot 0,4 \cdot 0,24 \cdot 10^{-3}}{3,6 \cdot 10^{-9}} \right)^{\frac{1}{2}} = \quad (5)$$

$$= 230,94 [V] = 0,23094 [kV]$$

Value of *Uds* (V) is the estimated value of dangerous electrostatic voltage described in the technological process of painting and drying of polypropylene film. The value of the resulting electrostatic field is the value in the vapor-air space with increased concentration of flammable and explosive mixture (vol.%) that fills the space of polypropylene film and (important for us) the set of passive static electricity eliminator. A distance between the foil and the eliminator is d = 10.00 (mm) and a value of resulting electrostatic field is described with E = U/d (V/m) which indicates that dangerous assessed value of the resulting electrostatic field has a value Eds = Uds/d = 230.94/10.00 = 23.094 (V/mm). The results give us the requirement for hazard analysis and risk assessment caused by static electricity manifested through fires and explosions [1].

We conclude that the value of established voltage U_{ds}, and a localized electrostatic field E_{ds} with values

$U_{ds} \leq 230{,}94$ (V) and $E_{ds} \leq 23{,}094$ (V/mm) does not represent a possible latent danger caused by static electricity here in the technological process, which is consistent with Pashen’s curve [3,5].

The installation of proposed passive induction eliminators of static electricity with needle electrostatic sensors described in the production process will result in strengthening of the resulting localized electrostatic field E at the sensor. Thus, the effect caused by peak gain field will manifest itself in improved condition for electrostatic (voltage) sparkover from polypropylene film to needle-like sensor [3,4].

Demonstrated accidents proven [1,3,6]: If the passive induction eliminator with the specified sensor is electrically connected with the joint grounding, the effect of electrostatic characteristics of sparkover will have a plasma properties with a possible value of the MIE *Wmin* (J), which can ignite created and presented explosive mixture (vol%).

APPROACH TO PROBLEM SOLVING

In this paper we present a new approach to passive elimination of static electricity [1] for a specific technological problem in the process of polypropylene painting, drying and printing. When there is a contact of double layer with polypropilene as solid phase state on one side, and the contact of tightening rubber rollers for tensioning polypropylene as solid phase on the other side, charge - static electricity is being formed. Purpose-designed and built passive eliminator and device for elimination of static electricity is shown in Fig.1 a), and had a research objective of simulation and efficiency in real conditions. To start the exploration, a described passive static electricity eliminator that consists of 8 blocks of electrostatic needle-like sensors is made, each separated by the width of one described sensors, which are then each individually electrically connected to a passive device for elimination of static electricity (as a whole declared as non-electrical equipment and installations, which is in accordance with EN 13463-1) [1, 6]. In Fig.1 b), a described solution is shown as another research opportunity, in which described passive eliminator is electrically connected to the joint grounding technological equipment and the study is conducted to get the results of the research and a method for comparison of the obtained results.

The researchers aim to prove the validity of the solutions shown in Fig.1 a), in terms of both safe operation of production process, and controlled pumping of created charges, planned duration *t* (s) of prepared correct and regular experiment in real conditions with prepared and secured technological security measures. First, we perform necessary measurements of i1(t), u1(t) and i2(t), u2(t) in real conditions and compare them with obtained comparative estimation.

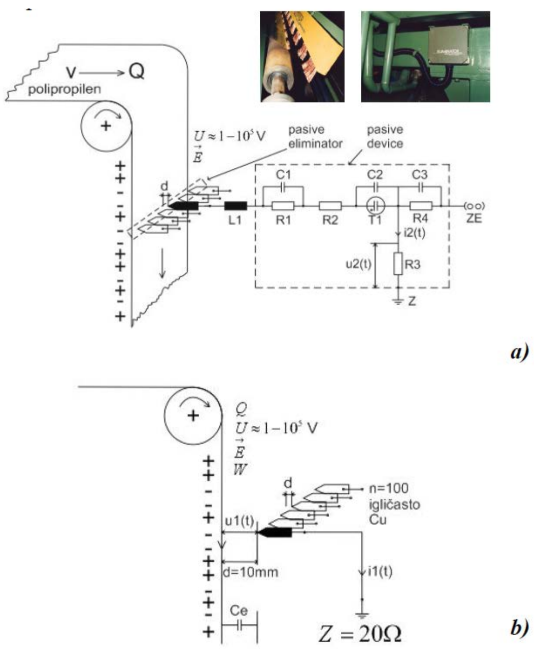

Figure 1. *Passive elimination of static electricity in the tech. process of painting and drying of polypropylene film:*

a) New solution proposed in this paper
b) Present and frequently used solution

Thus, the obtained results of the safe operation of technological equipment provide the conclusion about the validity of the research and the use of the proposed new features for passive elimination of static electricity in terms of practical research work, which had to be verified and validated through the comparison with results of simulation in MATLAB / Simulink v7.6 (R2010b).

Evaluation criterion for elimination of static electricity in the described technological process from the point of safety is to prevent the ignition of concentration of explosive mixtures in the process of here proposed passive elimination of static electricity.

COMPUTER SIMULATION

A scheme of here proposed new passive eliminator of static electricity is given in Fig.1 a), so that only one current branch of the block, here marked electrostatic Cu needle-like sensor, is being displayed. Individual Cu sensor of passive eliminator is compiled as a block/section which has 100 Cu needle-like sensors, which is further electrically connected individually to the here proposed passive device for elimination of static electricity. Each of the electrostatic blocks is composed of LRC elements that do not have the same values because of the necessary technical requirements of phase displacement (which is obtained by calculation). Electrostatic balancing over width of polypropylene film, from which different values of surface charge appear should be achieved (mC/m2) [1]. Thus, the passive eliminator of static electricity has as much electrostatic blocks as band width of lacquered polypropylene film requires (a calculation depending of given purpose [1]).

The proposed passive device for elimination of static electricity has the same number of electrical RLC blocks as a passive eliminator has electrostatic blocks. The unit has space for electrical connection to the joint grounding of technological equipment (Z) and the electrical connection for the elimination of residual charge in contact solid state phase of metal construction of machine and solid state phase of the dried paint protection of technology equipment (ZE). It is proposed to take values for resistance, for *Z* up to □ *20* **Ω** and for *ZE* up to □ 10^4 **Ω**. Information required to make the necessary block diagram for simulation in Matlab / Simulink v7.6 (R2010b) from Figure 1 a) are: if we consider the electrical diagram of one block of electrostatic needle-like Cu sensor (*Cu, n =100* needles, *length 100* mm) with performed calculation, and so the estimated values, follows: $L_1=50\times10^{-6}$ (H); $C_1=10\times10^{-12}$ (F); $R_1=10^6$ (Ω); $R_2=10^8$ (Ω); $C_2=100\times10^{-12}$ (F); $R_4=10^8$ (Ω); $C_3=200\times10^{-12}$ (F); $R_4=10^8$ (Ω), [1,3]. In the Fig.1 a), it is indicated where we collected data of performed computer simulations about flow of current i2 (t) (A) and the establishment of voltage u2 (t) (V) with different/discussed the value of electrostatic voltage established on the surface of considered polypropylene film. Fig.1 b), reperesent a condition of herein described passive eliminator electrically connected directly to the joint grounding of technological equipment Z, in order to collect the results of this simulation flow of current i1 (t) (A) and voltage u1 (t) (VSimulations are conducted in order to compare results obtained in the cases given in Fig.1 a) and b) with the purposes of a research conclusion about the validity of using the proposal of solutions given in Fig.1 a).

RESULTS OF COMPUTER SIMULATION

The conducted simulation of events from Fig.1 a) and 1 b) are only and only valid for the here described technological process. Measure of values of currents i1, i2, voltage u1, u2, and time t of the simulation conducted here is determined on the basis of (3), follows $W_{min.}$ □ 0,24 (mJ)= 0,2 4 (mWs) , follows [1], 0,24 (mWs)= $U_{ds}\times I_{ds}\times t$ = $((230{,}94\times10^3)$ (mV)) $\times((I_{ds}\ x\ 10^3)$ (mA) $\times$ t (ms)) (mWs).

Criterion for assessment of safety against static discharges and to prevent ignition of flammable mixtures of considered case follows from the established relationships: 0,24 (mWs) $=(230{,}94\times10^3)\times(I_{ds}\times10^3)$ x(t) (mWs), therefore permissible value of established electrical current Ids (A) when there will be no ignition of explosive mixtures, it follows that: $I_{ds}=1{,}14613\times(10^{-6}/t)$ (mA), where is t (ms) and for t (ns), the term I_{ds} has a value $I_{ds}=1{,}14613\times(10^{-6}/t\ x10^6$ (ns)) (mA) = $1{,}14613\times(10^{-12}/t)$ (ns)) (mA) $=1{,}14613\times(10^{-9}/t$ (ns)) (A); provided that $t\succ0_+$ (ns) = t_{0+} □ 0,001 (ns), follows that is $I_{ds0+}=1{,}14613\times10^{-6}\times(1/t_{0+})$ (A), that is $I_{ds0+}=(1{,}14613\times10^{-6})\times(1/10^{-3})$ (A) = $1{,}14613\times10^{-3}$ (A)

Table 1. The results of the simulation for the solution proposed on Fig.1 a) and solutions on Fig.1 b)

Review of research results: 1) reviewed the results of the simulation in real time t_{0+} (ns) $\succ$ 0 (ns) **;** *2) the analysis of conducted computer simulations assumed to be* t_{0+} □ **0,001** (ns); *so after the calculation* $\mathbf{I_{d\,s\,0+}}$ =1,14613 *x* 10^{-6} *x* (1 / t_{0+}) (A), *follows* $\mathbf{I_{ds\,0+}}$ □ $\mathbf{I_{ds}}$ **=** 1,14613 *x* 10^{-3} (A) *i* $\mathbf{U_{ds\,0+}}$ □ $\mathbf{U_{ds.}}$**=** 230,94 (V)**;** *3) duration of computer simualation in MATLAB/Simulink* v7.6 (R2010b), $t_{simulacije}$ = 500,0 (ns) **.**

E (V/mm)	**D** (mm)	**U** (V)	**U_1** (V)	**U_2** (V)	**I_1** (A)	**I_2** (A)	**m_u**	**m_i**	Provided	
									Safety work	Controlled elimination
Assumed values			*Values obtained from computer simulation*				*Criterion*		*Research commnet*	
30	10,0	300	278,1	135,4	$0{,}7\times10^{-3}$	$1{,}35\times10^{-6}$	0,487	0,002	yes	yes
50	10,0	500	463,5	228,1	$1{,}2\times10^{-3}$	$2{,}28\times10^{-6}$	0,491	0,002	yes	yes
10^2	10,0	10^3	927,1	452,4	$2{,}3\times10^{-3}$	$4{,}52\times10^{-6}$	0,488	0,002	yes	yes
5×10^4	10,0	5×10^5	$4{,}64\times10^5$	$2{,}28\times10^5$	1,24	$2{,}23\times10^{-3}$	0,491	0.002	yes	yes

Established current of sparks at established ectrostatic discharge in vapor-air space must not exceed the current value of 1,14613 x 10^{-3} (A), which is in further analysis taken as a criterion, therefore $U_{ds}\geq230{,}94$ (V) $\wedge$ $I_{ds}\geq(1{,}14613\times(1/t_{0+})$ (A).

There is another criterion that we have not considered here, such as micro-climatic conditions of the environment where an explosive mixture is formed (vol.%); this mixture is considered harmless and is one of the lower explosion limit LEL (%) or lower flammability limit LFL (%) [1].

Criteria for the assessment of the controlled discharge of static electricity, and that there is no spark (cumulative) discharge and then ignition of combustible mixture in the considered case is obtained by comparing the ratio of absolute values of currents i1 and i2 as and voltages u1 and u2 from Fig.1 a) and b). The ratio $(\left|i_2\ /\ i_1\right|\prec1)\wedge(\left|u_2\ /\ u_1\right|\prec1))$, follows $(\left|m_i\right|\prec1)\wedge(\left|m_u\right|\prec1)$, so that by comparing obtained less absolute value is taken as a mark of a successful controlled discharge of static electricity [1]. Since it is a discharge with pulsed characteristics described by Heaviside or step function $u_{sr}(t)=(o,t\geq t_{sr})$ $\wedge$ $(U_{sr},t\succ t_{sr})$, where $t_{sr}\geq t_{0+}$, [1], it follows that the time duration t of performed simulations has to be studied and analyzed in the time domain interval $t_{simulacije}$ (ns) [2,3]. The results of the simulation with solution proposed in Fig.1 a) and solutions from Fig.1 b) are given in Table I.

CONCLUSION

Elimination of static electricity in hazardous areas according to ATEX137, have to and should be solved by method of passive controlled elimination of static electricity. This method is called controlled pumping of charge and represents safety operation in technology process of machinery and production, as well as for employers in terms of eliminating generated static electricity. We have shown and proved that in this paper.

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BIOGRAPHY

Mićo Gaćanović was born in 1952. He is recognized and known internationally as a scientist in the field of applied electrostatics, where he has given his contribution through original solutions, which are patented in 136 countries throughout the world and applied in production.
He received many prestigious world-known awards and certificates for his creative work. Hence, he is included in the work of world groups of creativity, research and new technology in Brussels, Moscow, Pittsburgh and other world cities. He is also involved in research projects in the field of theoretical electrical engineering in Germany, Belgium and Russia.

NOVE MOGUĆNOSTI PASIVNE ELIMINACIJE STATIČKOG ELEKTRICITETA

Mićo Gaćanović, Nikola Dragović

Rezime: *U radu su date nove mogućnosti pasivne eliminacije statičkog elektriciteta, kako u tehnološkim procesima tako i u životnoj svakodnevnici.U radu su razmatrana riješenja pasivne eliminacije statičkog elektriciteta i rezultat su dugogodišnjeg istraživanja u tehnološkim procesima u kojima su prisutne koncetracije eksplozivnih i zapaljivih smješa a i prašina.Ponuđena riješenja imaju tretman međunarodno zaštićenog patenta. Napravljeno je upoređivanje sa ponuđenim pasivnim riješenjima i sadašnjim stanjem tehnike kako pasivnih tako i aktivnih eliminatora a i uređaja za eliminaciju statičkog elektriciteta. Kompjuterska simulacija rada i nivo eliminacije statičkog elektricitea predloženih pasivnih uređaja i eliminatora statičkog elektricitea za sve vrste faza stanja (čvrsta, tečna, gasovita i praškasta) je urađena i obrađena u računarskom programu MATLAB/Simulink v7.6 (R2010b). Dobijeni rezultati simulacije u radu su komentarisani i data je procjena rizika od mogućeg pražnjenja statičkog elektriciteta u ugroženim prostorima definisanim po Direktivi ATEX 137.*

Ključne reči: *pasivni uređaji i eliminatori statičkog elektriciteta, ugroženi prostori, procjena rizika, ATEX 137 statički elektricitet.*