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PASSIVE ELECTRICAL CIRCUIT FOR CONTROLLED STATIC ELECTRICITY PUMPING

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Abstract. *In this paper is explained the working principle of the simplest passive electrical circuit for controlled static electricity pumping. The formation of static electricity on the outside surface of the metal insulated tank is a consequence of technological action of pouring the liquid or gas phase state (oil and petroleum products or other hazardous and flammable or combustible liquid or gas). The research conclusion is given at the end.*

Key words: *passive electrical circuit, controlled static electricity pumping, metal tank, elimination of static electricity*

1. INTRODUCTION

The removal or controlled static electricity pumping is done from the liquid phase, where the zone of discharging is performed by naturally established differential capacitance $C_d(t)$ between the liquid phase and the inner wall of the tank, to the outer metal tank wall by the principle of passive parametric amplifier [1]. It is necessary to pump both the established induced and static electricity from the metal tank walls by the passive electrical circuit in a controlled way. Grounding of metal tank outer walls eliminates only the free electricity by cumulative discharge. In doing so, it interferes with the natural synchronization of the parametric amplifier with a variable capacitance $C_d(t)$, which can result in the appearance of spark discharge.

Let us consider the real case of connecting the metal tank outer walls (insulated from the ground with the value of electrical resistance R_c) to the passive circuit for controlled pumping of static electricity coming from inside of the tank. The simplest passive circuit for static electricity pumping is shown in Fig.1a), with an equivalent scheme in Fig.1b), where a lamp T is used as the switch. T represents neon gas pipe where the pressure is dozens of times lower than

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atmospheric. At voltages lower than the breakdown voltage u_p of the gas mixture in the tank, the lamp T acts as a resistor with a very high resistance features, order of a few tens of MOhms whereas at voltages higher than the breakdown voltage lamp resistance is of the order of tens of kOhms which determines its current-voltage characteristic. Thereby lamp T can be represented as a switch P in Fig.1b) which is described by the switching characteristic [2]:

$$p = \begin{cases} 0 \ , & u_1 < u_p \\ 1 \ , & u_1 < u_g < u_p \end{cases} , \quad (1)$$

where u_1 and u_2 are corresponding voltages of capacitors C_1 and C_2; u_p = 83 V and u_g = 62 V on/off voltages of the lamp; $p = 0$ denotes the open and $p = 1$ closed state of the switch P.

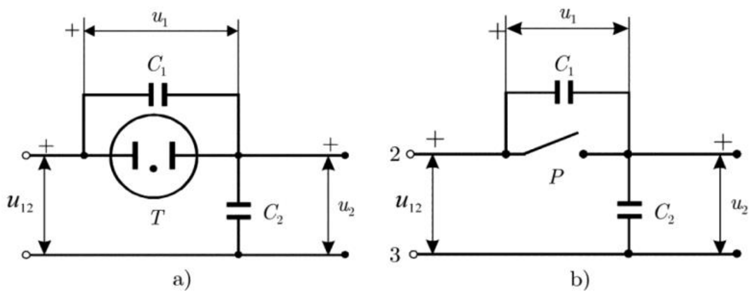

Fig. 1 Schematic representation of the simplest passive electrical circuit for pumping static electricity with the lamp in Fig.1a), represented as the switch P in Fig.1b)

2.PRINCIPLE OF PASSIVE ELECTRICAL CIRCUIT

Voltage u_{12} is the DC voltage at the input of electrical circuit from Fig.1a) and Fig.1b). If the switch P is opened, the voltage of capacitor C_1 is u_1 and the voltage of capacitor C_2 is u_2, whereas $u_{12} = u_1 + u_2$. When the voltage on the capacitor reaches the value of the ignition voltage $u_1 = u_p$, the capacitor is discharged at the time moment t_1 to the extinction value of the voltage u_g, while the capacitor C_2 is charged to the value $u_2 = u_{12}$, as can be seen from Fig. 2a) and Fig.2b). Conducting of the lamp T at the time moment t_1, i.e. closing of the switch P, leads to a decrease in the voltage u_1 at the capacitor C_1 for the value

$$\Delta u_1 = u_g - u_p < 0 \,, \quad (2)$$

which causes an increase in voltage u_2 on the capacitor C_2 for the value

$$\Delta u_2 = u_{12} - (u_{12} - u_p) = u_p > 0 \,. \quad (3)$$

In this way the energy W_1 of the capacitor C_1 reduces for the value

$$\Delta W_1 = \frac{1}{2} C_1 (\Delta u_1)^2 = \frac{1}{2} C_1 (u_p - u_g)^2 \,, \quad (4)$$

whereas the energy W_2 of the capacitor C_2 increases for the value

$$\Delta W_2 = \frac{1}{2} C_2 (\Delta u_2)^2 = \frac{1}{2} C_1 u_p^2 \,. \quad (5)$$

Because of the finite internal resistance of the conductive lamp T, slow discharge of capacitor C_1 and charging of capacitor C_2, its voltage reaches the extinguishing value. Then the voltage of the capacitor C_2 is of the voltage source value u_{12} at the time moment t_2; from the moment t_2 to t_3 voltage on the capacitor C_1 increases to the ignition voltage value, whereas the voltage of capacitor C_2 decreases from the value u_{12} to the value $(u_{12} - u_p)$.

This process is further repeated and for a variety of conditions is shown with dashed line in Fig.3. The coefficient of pumping which is characterizes the suction of electricity, and therefore of the energy by the capacitor C_2 from the rest of the circuit. Under the influence of lamp T as a switch P in Fig.1, we define the ratio

$$k_p = \frac{\Delta W_2}{\Delta W_1} \,. \tag{6}$$

where ΔW_1 and ΔW_2 are the energy changes of the capacitors C_1 and C_2 given by the expressions (4) and (5). By using expressions (4) and (5) in (6) we get

$$k_p = \frac{C_2}{C_1} \frac{u_p^2}{(u_p - u_g)^2} \,. \tag{7}$$

For the selected lamp T the borderline case of the pumping coefficient in choosing relation between capacitances C_2 / C_1 has the value

$$k_p = \frac{C_2}{C_1} \frac{u_p^2}{(u_p - u_g)^2} \geq 1 \,, \tag{8}$$

so we find that

$$C_2 \geq \frac{C_1}{\left(1 - \frac{u_g}{u_p}\right)^2} \,. \tag{9}$$

By adding a resistor R_2 in series with the capacitor C_2 in the circuit from Fig.1 we obtain the simplest scheme of the circuit for pumping static electricity, which is shown in figure Fig. 2a), and the corresponding diagram of the voltage, current and power in Fig.2b). In time interval T_1 the capacitor is discharged through the lamp resistance R_T from the ignition voltage value u_p to the extinction voltage value u_g while through the lamp the current flows

$$i_1(t) = \frac{u_p - u_g}{R_T} e^{-\frac{t}{R_T C_1}} \,, \quad t \in (t_1, \quad t_1 + T_1) \,, \tag{10}$$

which leads to the release of electrical power

$$p_1(t) = i_1^2(t) R_T = \frac{(u_p - u_g)^2}{R_T} e^{-\frac{2t}{R_T C_1}} \,, \quad t \in (t_1, \quad t_1 + T_1) \,. \tag{11}$$

The energy in the time interval $t \in (t_1, t_1 + T_1)$ that is dissipated across the resistor of the conductive lamp is

$$W_1 = \int_{t_1}^{t_1+T_1} p_1(t)dt = \frac{(u_p - u_g)^2}{R_T} \int_{t_1}^{t_1+T_1} e^{-\frac{2t}{R_T C_1}} dt \;=\; \frac{1}{2} C_1 (u_p - u_g)^2 \left(1 - e^{-\frac{2T_1}{R_T C_1}}\right) \tag{12}$$

Let us analyze expressions (10) and (11) with the following conditions

A1.) Requirement of the maximum of accumulated charge $Q_{1\max}$ in the capacitor C_1 is that the charging time t of the capacitor is as long as possible, $t \to \infty$. In this case, while the capacitor discharges through the resistor R_T through the conductive lamp T is flowing the current $i_{1\max}$ with electric power $p_{1\max}$ and energy $W_{1\max}$.

A2.) The analysis of expressions (10) and (11) gives that after the discharge of capacitor C_1 the charge Q_1 is in steady state when $Q_1 \sim 0,01Q_{\max}$, and time to reach $Q_{\max}$ is $t = R_T C_1 \ln(1/0,99)$.

A3.) Accordingly, let us analyze expression (12) from which follows that the condition is fulfilled

$$R_T C_1 = T_1 / 2.3 \tag{13}$$

and expression (12) in that case has the value

$$W_1 = \frac{0.99}{2} C_1 (u_p - u_g)^2 = 0.99 W_{1\max} \,. \tag{14}$$

Thus, during the time interval $t \in (t_1, t_1 + T_1)$ capacitor C_2 discharges through series connection of the resistors R_2 and R_T of the conductive lamp T lamps with the current

$$i_{2pr}(t) = \frac{u_p}{R_2 + R_T} e^{-\frac{t}{(R_2 + R_T)C_2}}, \quad t \in (t_1,\ t_1 + T_1)\,, \tag{15}$$

providing electrical power (from μW to mW)

$$p_{2pr}(t) = \frac{u_p^2}{R_2 + R_T} e^{-\frac{t}{(R_2 + R_T)C_2}}, \quad t \in (t_1, t_1 + T_1)\,. \tag{16}$$

Power $p_{2pr}(t)$ at the resistor R_2 provided that

$$(R_2 + R_T)C_2 = T_1 / 2.3\,, \tag{17}$$

releases energy (from μWs to $\text{mW}s$)

$$W_{2pr} = \frac{0.99}{2} C_2 u_p^2 \,. \tag{18}$$

In time interval $t \in (t_1, t_1 + T_1)$ the lamp has negligible current (from μA to mA) so that the power $p_1(t)$ is negligible, while the series connection of capacitors C_1 and C_2 is charged via the resistor R_2 with the current

$$i_{2pu}(t) = -\frac{u_p}{R_2} \mathrm{e}^{-\frac{t}{R_2 C_1 C_2 /(C_1 + C_2)}}, \ t \in (t_2, t_2 + T_2)\,. \tag{19}$$

There is the electric power

$$p_{2pu}(t) = \frac{u_p^2}{R_2} e^{-\frac{2t}{R_2 C_1 C_2 /(C_1 + C_2)}}, \ t \in (t_2, t_2 + T_2)\,, \tag{20}$$

that under the condition

$$R_2 C_1 C_2 / (C_1 + C_2) = T_2 / 2.3\,, \tag{21}$$

in the time interval $t \in (t_2,\, t_2 + T_2)$ across the resistor R_2 releases the energy

$$W_{2pu} = \frac{0.99}{2} \frac{C_1 C_2}{C_1 + C_2} u_p^2\,. \tag{22}$$

The described process of pumping charge is performed in the interval [1] $t \in (t_1,\, t_1 + T_1, ..., t_n,\; t_n + T_n)$ until the end of the controlled charge pumping from the outer metal surface of the tank and until bringing technological action of streaming (liquid or gas phases) into the harmless technical conditions [2],

$$W_{n\ pu} \le W_{\min} = 0.4 \cdot W_{\text{ignition gas mixtures}} \tag{22a}$$

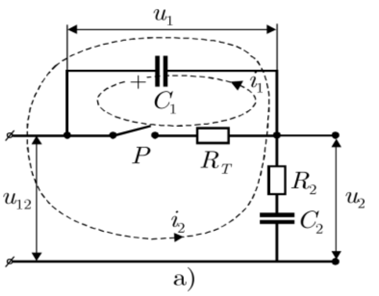

Fig. 2a) Schematic representation of the simplest passive electrical circuit for pumping static electricity is given with an analogy from the image Fig.1b).

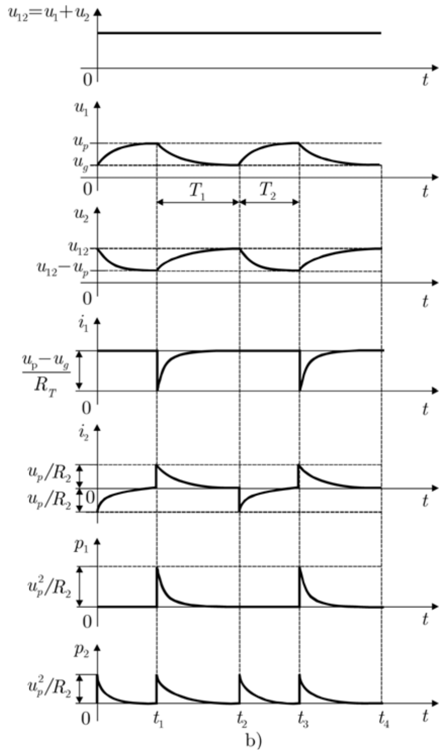

Fig.2b) For the passive electrical circuit in Fig.2a), the corresponding voltage, current and power diagrams are in Fig.2a)

3.CRITERIA FOR THE TIME CONSTANTS CHOICE

The criteria for choosing the time constants and parameters of the passive electrical circuit are the following [4]:

$$2.3\times C_1R_1 = T_1,\ \ 2.3\times C_2R_2 = T_2,\ \ ...,\ \ 2.3\times C_iR_i = T_i,\\ ...,\ \ 2.3\times C_nR_n = T_n \tag{23}$$

where *n* denotes the total number of eliminating contours of the passive electrical circuit and

$$2.3\times (C_jR_j)_{sr}{}^{+} = (T_j)_{sr}{}^{+} = T_{sr}{}^{+}$$

$$2.3\times (C_kR_k)_{sr}{}^{+} = (T_k)_{sr}{}^{-} = T_{sr}{}^{-}, \tag{24}$$

where the averaging is done over index "*j*" for positive and over "*k*" for negative impulse changes of the static voltage u_{12} [KV] . In the case that voltage u_{12} from the outer wall of the tank changes the sign, which is a realistic case and possible while working with petrol and petrol derivatives with variable content of various impurities, we conclude that this last variant of passive electrical circuit as a static electricity eliminator will not optimally meet the demands for high quality elimination. In this case is necessary to add to each polarity of the voltage u_{12} a certain number of elimination contours in the passive electrical circuit, then to separate these contours according to the values of periods T_j^+ and T_k^- for certain directions.

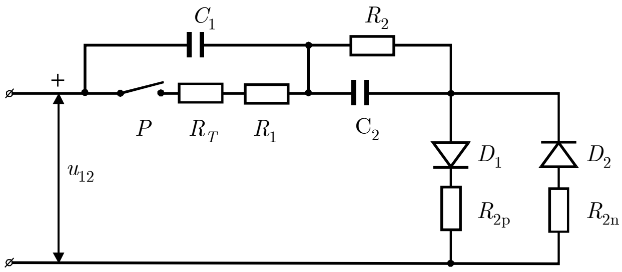

Fig. 3 Passive electrical circuit for the controlled static electricity pumping from the outer walls of the metal tank.

4. CONCLUSION

Obviously the quality of the static electricity pumping in this particular example is growing and with the increase in the value of the pumping coefficient k_p given with (6) which is the quotient of energy changes of capacitors C_2 and C_1. Expression (6) thus determines the choice of certain passive electrical elements as a function of pre-defined time constants, in order to achieve a condition of controlled pumping of the static electricity. Also these conditions are determining the approach to construction and design of herein described passive electrical circuit with all necessary contours [1]. Therefore, a requirement for a quality controlled charge pumping shown in Fig.3, are:

4.1) The capacitance of capacitor C_2 has to be much greater than the capacitance C_1, (so that $C_2 >> C_1$).

4.2) The value of the ignition voltage u_p has to be as close to extinction voltage u_g of the lamp T, i.e. $u_p \rightarrow u_g$. This means that in an ideal situation for these purposes characteristics of the lamp should ideal, infinite resistance for voltages below the ignition voltage u_p and resistance of zero at the ignition voltage u_p, which tends to the extinction voltage u_g. At the other hand, if the capacitance C_1 is lower than the capacitance C_2, then the capacitance of their series connection is less than C_1, resulting in short charging time t until lamp T does not conduct, not allowing the amount of electricity and voltage in the gas mixture of the tank to increase significantly.

4.3) The easiest way to separate the elimination contours according to the polarity of the voltage u_{12} from the model of the tank is shown in Fig.3. The principle of operation of this circuit is as follows:

4.3-1.) When the input voltage is of the positive sign, i.e. $u_{12} > 0$, and the switch P is closed, i.e. the lamp is conducting, the capacitor C_2 is charged via a series connection of the lamp R_T, resistor R_1, negligibly low resistance of the conducting diode D_1 and resistor R_{2p}, with the time constant

$$\tau_{p,pu} = C_2(R_T + R_1 + R_{2p}) \tag{25}$$

The discharge of the capacitor C_2 is achieved via a resistor R_2 with the time constant

$$\tau_{p,pr} = C_2 R_2 \,. \tag{26}$$

4.3-2.) If the voltage is of the negative sign i.e. $u_{12} < 0$, and the lamp is conducting, the capacitor C_2 is charged via a series connection of the conducting lamp R_T, resistor R_1, negligibly low resistance of the conducting diode D_2 and resistor R_{2n}, with the time constant

$$\tau_{n,pu} = C_2(R_T + R_1 + R_{2n}) \,. \tag{27}$$

The discharge of the capacitor C_2 is achieved also via a resistor R_2 with the time constant as in the previous case, that is,

$$\tau_{n,pr} = \tau_{p,pr} = C_2 R_2 \,. \tag{28}$$

4.4) Note that the passive device which has passive electrical circuit with its contours and elements for the controlled pumping of the static electricity in its application and exploitation can have a problem of discharge from residual electromagnetic and electrostatic energy. It can be concluded that, due to security and technology requirements for refilling, such a passive device should be carried out in the accordance with Explosion Safety, Ex. [2]

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