LONGITUDINAL PULSED ELECTRIC FIELD EQUIPMENT FOR TOBACCO: METHODOLOGY FOR CALCULATING PARAMETERS FOR AN ELECTRIC CIRCUIT

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Abstract: *Drying of tobacco leaves and stems is a high energy intensive process. Pulsed electric field treatment can be applied to decrease significant energy requirements. An analysis of the electrical circuits of the equipment for pulsed electric field treatment of plants has been accomplished and an electric circuit for longitudinal PEF equipment to treat tobacco leaves and stems with a buffer capacitor and a rectifier for high voltage has been proposed. A method for determination of the electric circuit parameters and for power supply to the equipment is given. Results of the calculation of the two electrical circuits are also presented.*
Keywords: *Leave pulsed electric field equipment, longitudinal treatment, buffer capacitor, charge resistor, pulse energy.*

Introduction

The main problem with the leaf drying of tobacco is connected with dehydrating the main vein due to higher moisture content in the vein compared to the leave blade. A similar problem is observed during the drying of entire plant due to higher moisture content in the stem compare to the leaf (Atanassov and Nestorov, 1981; Donev et al., 1981). Half of the oil expenses, electricity and drying time are spent in drying the main vein of tobacco leaves. The drying house can be used only once per season for the drying of tobacco plant.

Acceleration of drying process can be achieved by longitudinal PEF treatment of the main vain for the leaf drying and the core of the stems respectively. Experiments have been conducted using different electrical methods for longitudinal treatment of tobacco in Rouse University "Angel Kanchev" (Armyanov and Russeva, 1991; Armyanov, et al., 1999; Armyanov, et al., 2000). It has been concluded that PEF treatment of tobacco is more effective method compare to the treatment with electric current and high voltage or electric-arc treatment. PEF treatment obtained by supplying discharged circuit to DC source is the most effective variant of treatment. An electric circuit of longitudinal PEF equipment for treatment of tobacco should provide simultaneous and independent work of two or more pair of electrodes to have high efficiency.

The present work will be on finding out an electric circuit for longitudinal PEF treatment for tobacco leaves and a methodology for determination of the elements of the electric circuit. The calculated results for the parameters of the two circuits involved in the treatment of leaves and stems will be also presented.

Foundation for an electric circuit of equipment for PEF treatment of tobacco

One of the initial developments related to the PEF equipment of plant was done in Volgogradska national agricultural academy (USSR). Two variants of electrical circuit of mobile aggregate for longitudinal treatment of sunflower under the flower head were developed to stimulate the ripening of seeds.

The electric circuit of the first variant of the aggregate for PEF treatment of sunflower described in (Klimov, 1962) is presented at Fig.1. A three-phase synchronous generator G with high frequency was used to supply the power to the circuit. The generator was put in motion by shaft coupled to the tractor engine D. Resistors (R) were used to limit the current in the circuit and to connect the step up transformers (TV) to the generator. The secondary winding of every transformer was connected to a capacitor (C), which supplied four discharge gaps (F). To prevent simultaneous work of the discharge gaps, they were shifted at a one compared to the other to 1/5 of the distance between the plants in the row.

This variant had a disadvantage because it cannot provide simultaneous work of the four discharge gaps.

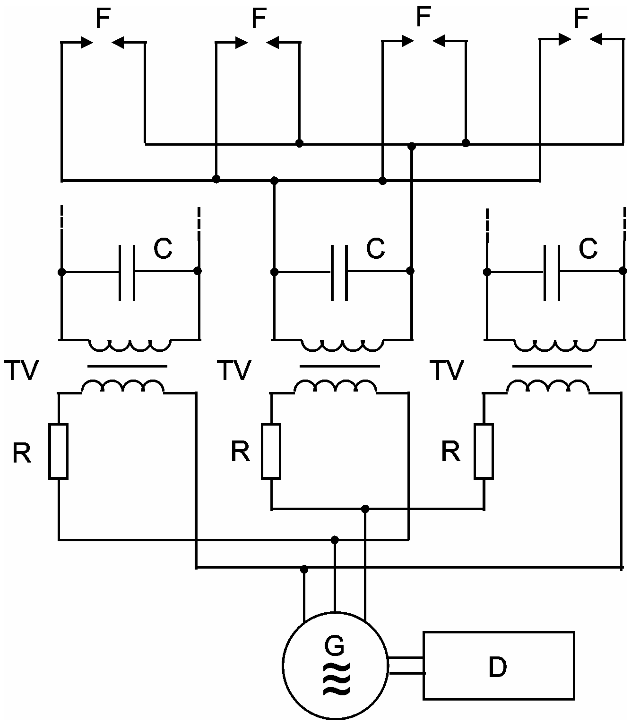

Fig.1. Electric circuit of the aggregate for electric spark of sunflower – first variant: D - engine; G - generator; TV - step up transformer; R - limiting resistor; C - discharge capacitor; F - discharge gap

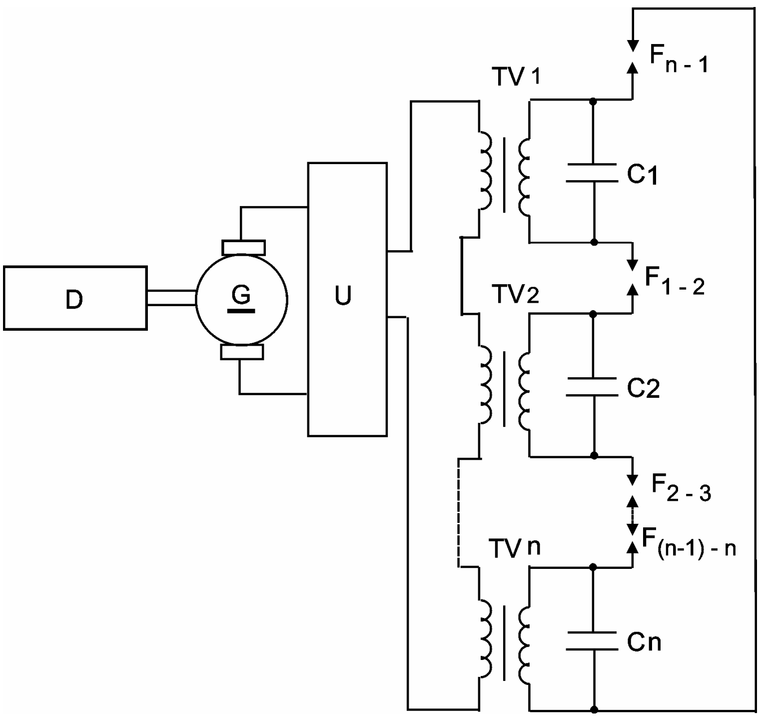

Fig.2. Electric circuit of the aggregate for electric spark of sunflower – second variant: D - engine; G - AC generator; U - inverter; TV1, TV2, … TVn - step up transformers; C1, C2, …, Cn - discharge capacitors; F n-1, F 1-2, …, F (n-1) -n - discharge gaps

The electric circuit of the second variant of PEF treatment aggregate for sunflower described in (Sokolovskii, 1975) is presented at Fig.2. A DC generator was used to supply power to the circuit. The generator in this equipment was also put in motion by shaft coupled to the tractor engine D. The generator was connected to the inverter U that converted DC voltage of the generator to AC voltage at a given frequency. A transformer group for impulse voltage, consists of n step up transformers TV1, TV2, … , TVn, was connected to the inverter. The secondary winding of the transformers were connected in series through the discharge gaps (F n-1, F 1-2, …, F (n-1) –n).

The second variant circuit had following disadvantages:

1. The circuit could not provide simultaneous work of the discharge gaps.

2. There were discharges in every gap when a stem was only supplied to one of the discharge gaps. This reflected in increase in the electric energy expenses.

3. The price of the equipment and the electrical consumption increases while using an inverter and a transformer group for impulse voltage.

A high efficiency of longitudinal PEF equipment for tobacco using a step up transformer feeding by a source with industrial frequency (50/60 Hz) can be obtained by using a buffer capacitor. Advantages of this circuit as was described in (Armyanov, 1987; Bayev et al., 1982) are:

1. The circuit could provide simultaneous and independent work of the individual discharge gaps.

2. Only one step up transformer could be used.

3. The circuit could be connected to a synchronous generator with frequency 50 or 60 Hz.

4. The circuit gives flexibility to change the pulse frequency by changing the value of the charge resistor of the discharge capacitor.

5. Asymmetrical system of electrodes can also be used by this circuit. This made the circuit to be a universal and it could be used for thin out of plant, treatment of weeds, tobacco leaves and others.

It has been developed and tested in real condition a mobile aggregate for longitudinal PEF treatment of two rows tobacco plants using to accelerate the maturing of the leaves (Armyanov, 1990) and a mobile PEF equipment using three electrodes to destroy weeds (Nedyalkov, 1993; Yudaev and Brenina, 2006).

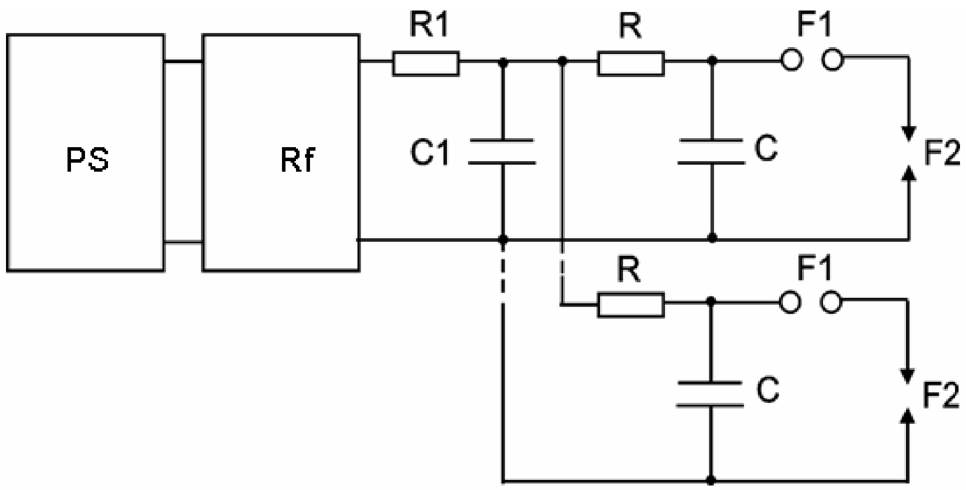

Fig.3. Electrical circuit of PEF equipment for treatment of tobacco using a buffer capacitor: PS - external power source; Rf - rectifier; R, R1 - charge resistors; C1 - buffer capacitor; C - discharge capacitors; F1 - spherical dischargers (spark gap switches); F2 - work electrodes (discharge gaps)

A PEF circuit using a buffer capacitor for longitudinal treatment of tobacco is shown at fig.3. According to (Armyanov, 1987; Bayev et al., 1982) the necessary frequency of the pulses using this circuit can be achieved by using buffer capacitor C, charge resistor R and a rectifier. Also, the parameters of the charge circuits of the buffer capacitor and the discharge capacitors should be chosen correctly. The circuit of Fig.3 has been tested in real condition for PEF treatment of tobacco leaves with regulated voltage using two work electrodes, described in Armyanov and Ruskov (2004).

Different types of voltage sources for PEF treatment equipment that have been used are presented in Fig. 4. Also, the different DC voltage sources for PEF treatment of tobacco are presented in Fig. 4b and 4c. They can be used to charge the buffer capacitor (Fig. 3).

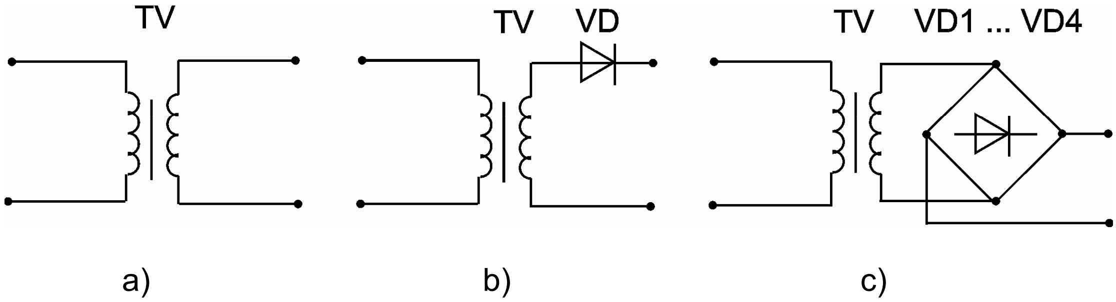

Fig.4. Source types using for charge circuit of PEF equipment for longitudinal treatment of plants: a) sinusoidal voltage source; b) half-wave rectifier; c) full-wave rectifier. TV - high voltage step up transformer; VD - high voltage diode; VD1 … VD4 - bridge rectifier made from 4 high voltage diodes

Methodology for determination of parameters of the electric circuit of equipment for longitudinal pulse electric treatment of tobacco

The basic treatment parameters such as treatment voltage V_0 and capacitance of discharge capacitor C should be known to determine the parameters of electrical circuit elements for the PEF treatment of tobacco leaves. This topic was a subjected to other investigation and for PEF treatment of tobacco leaves and stems has been examined in (Armyanov et al., 1999; Armyanov, 1990). An approach to determine the resistance of charged resistor R of the charged capacitor C is done by using the substitute electrical circuit of the discharged circuit (Klimov et al., 1970). The circuit is shown in Fig.5. The load in this circuit is the plant tissue placed between work electrodes.

The inductance of the discharged capacitor L_C and spark channel L_K are vastly smaller compared to the inductance of the connecting wires L_W for PEF equipment. Thus they can be ignored for an analysis of discharged circuit (Klimov et al., 1970).

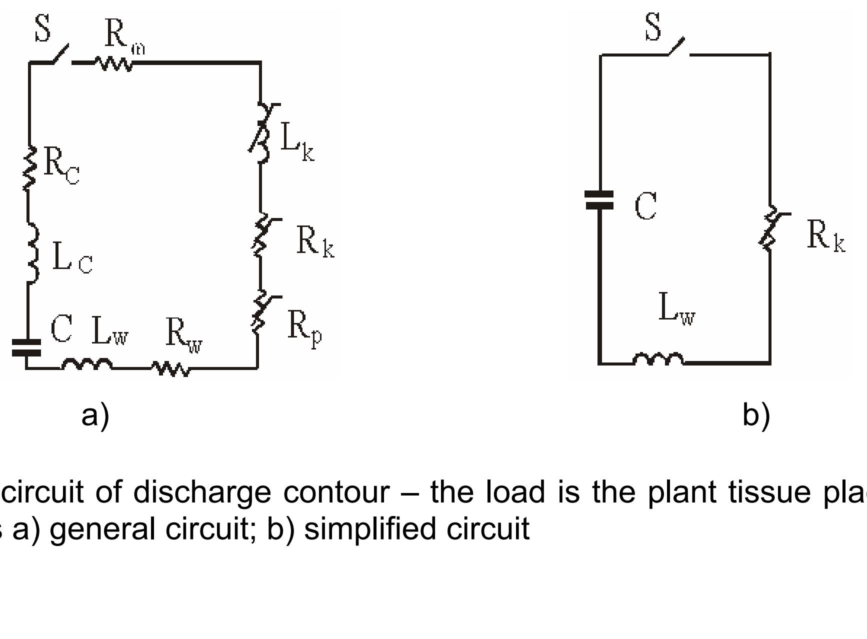

Fig.5 Electric circuit of discharge contour – the load is the plant tissue placed between the electrodes a) general circuit; b) simplified circuit

Let's assume that the switch S is closed when the voltage V_C of the discharged capacitor C reaches the treatment voltage value V_0. The elements L_k, R_k and R_p in Fig 5 are not linear and change their values during the discharge process.

The inductance L_K of the spark channel can be calculated by equation (Andreev and Vaniukov, 1961; Klimov et al., 1970):

$$L_k = 2l.[\ln(2l/r_C) - 1], \qquad (1)$$

where l is the length of the charge gap, mm;

r_C – the canal radius, mm.

The resistance of the spark canal R_k could be calculated with significant accuracy using Tepler's equation (Andreev and Orlov, 1965; Friungel, 1965):

$$R_K = k.l/Q, \qquad (2)$$

where k - the Teplers' constant, whose value for air is 0,8.10-4 Ω.C. mm-1;

Q – number of charges, passing through the spark gap for time t.

The number of charges Q is calculated by equation:

$$Q = \int_0^t i\,dt\ . \qquad (3)$$

There are some difficulties in the investigation of discharged contour when plant tissue is in the discharge gap due to the determination of treated subject resistance of the (the plant tissue) R_P.

The resistance of the plant tissue R_P varies for every individual discharge process. The dependence of the resistance R_P and pulse number can be approximated by exponential function as it was established from previous experiments (Armyanov, 2006a; Armyanov et al., 1998c):

$$R_P = An^a, \qquad (4)$$

where A - proportional coefficient, kΩ;

n - pulse number;

a - exponential coefficient.

The exponential coefficient is negative and less than one.

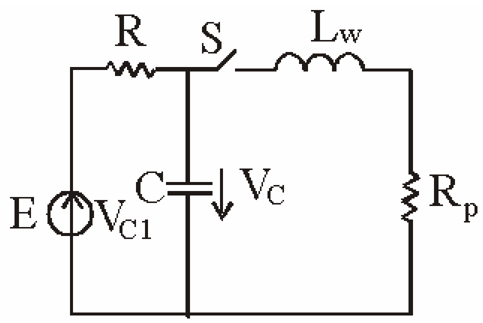

Fig.6. Simplified substitute eclectic circuit of discharge contour using buffer capacitor

As it is known, that the plant tissue resistance R_P is significantly higher compared to the sum of another resistances in the circuit of the discharge contour (Fig.5a) and also that the inductance of the contour depends mainly on the inductance of the connecting wires Lw therefore the circuit from Fig.5a can be simplified (Fig.5b).

The simplified substitute electric circuit of the discharged contour of PEF equipment for plants using a buffer capacitor is shown in Fig 6. The buffer capacitor C1 is replaced by a DC source V_{C1}.

The connecting wires inductance Lw can be calculated by equation [31]:

$$L_W = \mu.l_W/8\pi, \qquad (5)$$

where μ - the permeability around the wire;

l_w - is the wires length, m.

The critical resistance R_{cr} of the discharged contour should be calculated to determine the character of the discharged process of discharged contour when a plant tissue is used:

$$R_{cr} = 2\sqrt{L_w/C}\,. \qquad (6)$$

For a discharge process, terminate without surface charge, for the critical resistance R_{cr} should be implemented for the condition $R_{cr} < R_P$. This means that the discharged process is an over damped process. The conducted experimental tests for PEF treatment of the plant using an oscillograph to record the current curves $i = i(t)$ (Armyanov, 1987; Savchuk, 1971) showed that the character of the process was over damped.

Considering this it can be concluded that the remaining voltage V_{C0} of the discharged capacitor C is positive ($V_{C0} > 0$).

The time t_{ch} for charging of the discharged capacitor C to the treatment voltage V_0 could be determined by the equation:

$$V_0 = V_{C1} - (V_{C1} - V_{C0}).\exp(-t_{ch}/\tau_C), \qquad (7)$$

where V_{C1} - the voltage of the buffer capacitor, kV;

$\tau_C = R.C$ - the time constant of the charged process of the discharged capacitor C, s.

Since the time to charge of the discharge capacitor tch is much higher compared to the time for its discharge it can be assumed that the frequency of the pulses then is $f \approx 1/t_{ch}$.

The value of the charged resistance, used to charge discharged capacitor, can be obtained by calculating the logarithm of (7) and taking into account the dependence between frequency f and the charge time t_{ch}.

$$R = 1/\{fC \ln[(V_{C1} - V_{C0})/(V_{C1} - V_0)]\}. \qquad (8)$$

To simplify the analysis, the remaining voltage V_{C0} of the discharged capacitor C could be assumed to be zero ($V_{C0} = 0$). Then the equation (8) could be simplified to:

$$R = 1/\{fC \ln[1/(1 - \alpha)]\}, \qquad (9)$$

where $\alpha = V_0/V_{C1}$ - the degree of charge of the discharge capacitor.

In (Antonov et al., 1985; Armyanov et al., 1998) is shown that it is advisable the PEF treatment of tobacco leaves to be accomplished by direct contact of the electrodes to the plant and also the treated voltage should be set using a spherical discharger. In this case the frequency of the pulse can be calculated as in (Armyanov, 1987):

$$f = n_0.n_1.v_s, \qquad (10)$$

where n_0 - the necessary pulse number to treat a tobacco leaf, respectively tobacco stem;

n_1 - number of treated tobacco leaves, respectively tobacco stem for a meter;

v_s - the speed of the relatively movement of the electrode system toward the plant tissue, m/s.

The necessary pulse number n_0, for PEF treatment of a tobacco leaf respectively tobacco stem can be determined by conducting experiments. This will be considered in further discussion.

The capacitance of the buffer capacitor C1 should ensure simultaneous and independent work of the individual pair of electrodes. For this purpose the condition 11 should be realized (Armyanov, 1987).

$$C1 > n_{we}.C, \qquad (11)$$

where n_{we} - number of pair work electrode gaps of the equipment;

C - capacitance of the discharge capacitor.

Furthermore, according to Butcev (1975), it is suggest that $C1 > 7C$.

To calculate the capacitance of the buffer capacitor C1 should be calculated the sum energy ΣW_C of the process. For this purpose the energy W_C stored in the charged capacitor C should be determined ($W_C = 0{,}5CV_0^2$, where $V_C = V_0$ is the treatment voltage).

The buffer capacitor should ensure energy $W_C^{'}$ that will charge the discharged capacitor. For this purpose the efficient coefficient η_C of the charged process of the charged capacitor C should be taken into account.

$$W_C^{'} = W_C/\eta_C. \quad (12)$$

In case of simultaneous work of nwe pairs work electrode gaps (treatment chamber) the sum energy $\Sigma W_C^{'}$ should be calculated using follow equation:

$$\Sigma W_C^{'} = n_{we} W_C^{'} \quad . \quad (13)$$

After that the number of the charge-discharge processes (pulses), $n_{ch.dch}$ of the discharge capacitor C for one charge discharge process of the buffer capacitor should be determined. The calculation could be made using the equation:

$$n_{ch.dch} = f/f_{\approx}, \quad (14)$$

where f - the frequency of the pulses, Hz;

$f_{\approx}$ - the source frequency of the equipment, Hz.

If the sum energy $W_{C'}$ and the number of charged-discharged processes $n_{ch.dch}$ are known, the total sum energy ΣW_C of the process could be calculated by the equation:

$$\Sigma W_C = n_{ch.dch}\, \Sigma W_{C'}. \quad (15)$$

Since, the minimum voltage of the buffer capacitor C1, at which it is possible to begin discharge, is equal to the treatment voltage V_0, the total sum energy ΣW_C can be written:

$$\Sigma W_C = 0{,}5.C1.(VC_1^2 - V_0^2). \quad (16)$$

The capacitance of the buffer capacitor can be derived from the last equation:

$$C1 = 2(VC_1^2 - V_0^2)^{-1}\Sigma W_C. \quad (17)$$

To determine the resistance of the charged resistor R1 of the buffer capacitor C1, it can be used the proportion between its time constant $\tau_{C1} = R1.C1$ and the time constant $\tau_C = R.C$ of the charged circuit of the discharged capacitor. To insure, that the buffer capacitor would receive enough energy, it can be assume that:

$$\tau_{C1} = R1.C1 = 0{,}1\tau_C = 0{,}1RC, \quad (18)$$

Whence for the resistance of the charged resistor R1 and the capacitance of the buffer capacitor C1 can be written:

$$R1 = 0{,}1\tau_C/C1 = 0{,}1RC/C1. \quad (19)$$

Methodology to determine the power of the generator for longitudinal pulse electric field treatment of tobacco

The equipment for longitudinal PEF treatment of tobacco can be divided into two groups: stationary, when the treatment of tobacco is performed after harvesting of tobacco plant and mobile when the treatment is performed on the field. The second type of equipment could be assembled to a mobile aggregate that is used to harvest the tobacco. It is important to know the power of the generator especially for the second case when a mobile aggregate is used.

It is advisable to consider the requirements of the discharge contour supply for determining the power of the generator PG. This includes exterior energy source and the charged circuits of the buffer and charged capacitors. The parameters will be: treatment voltage V0, power supplied to the discharged circuit and minimal frequency of the pulses fmin. It should be noted that the parameters have to meet the requirements of the technological process.

The treatment voltage depends on the parameters of discharge gap and the treatment plant (Savchuk, 1971), this means it depends from the technological process.

The time for treatment of a tobacco leaf and a tobacco stem should be experimentally obtained to determine the power supply to the discharge circuit. These times can be determined if the pulse numbers for PEF treatment of a tobacco leaf and a tobacco stem and the pulse frequency are known:

$t_1 = n_0/f.$ (20)

Substitute the equation in the equation (10) for the treatment time can be obtained:

$t_1 = 1/(n_1.v_s).$ (21)

If the minimum energy $W_{\sum min}$, necessary to treat a tobacco leaf respectively a tobacco stem and the time t_1 are known, the power can be calculated using following equation:

$P = W_{\sum min}/t_1.$ (22)

It is necessary to know the minimum pulse frequency fmin in connection with efficiency of longitudinal PEF equimpment of tobacco and treatment quality. When the frequency of the pulses is smaller than fmin it will lead to incomplete treatment due to the smaller energy that will be applied to the treatment plant. In this case, to ensure necessary damage of the plant tissue the speed of the electrode system compare to the treatment object should be decreased. This would decrease the efficiency of the system.

To calculate the frequency fmin when the treatment voltage V_0 and capacitance of discharged capacitor C is known, we should first calculate the discharge energy $W = 0{,}5CV_0^2$. After that, the pulse number needs to be calculated:

$n_0 = W_{\sum min}/W.$ (23)

Then from the equation (20) for the frequency fmin can be written:

$f_{min} = n_0/t_1.$ (24)

So far it was considered to use only one pair treatment electrodes. If the longitudinal PEF equipment of tobacco is designed to treat tobacco leaves using more than one pair treatment electrodes then each of the pairs should be supplied by separated capacitor.

In this case the power $P_{n_{pe}}$ necessary to work npe pair electrodes could be calculated by equation:

$P_{n_{pe}} = n_{pe}.P,$ (25)

where n_{pe} - number of pair treatment electrodes;

P - power applied to the charge circuit.

Finally, the supplied power P_G to the generator is:

$P_G = P_{n_{pe}}/\eta_G.\eta_t.\eta_{ch},$ (26)

where η_G, η_t and η_{ch} are the efficient coefficient of the power source, step up transformer and discharged circuits respectively.

Results and discussion

Determination of the parameter of the elements of the electric circuit and the power supply of the longitudinal PEF equipment of tobacco leaves

From the presented methodology and our previous results for PEF treatment of tobacco leaves shown in (Armyanov et al., 1998a; Armyanov et al., 1998b) it makes possible to calculate the parameters of the elements of the electric circuit and the power supply. For convenience the parameters of the supplied generator of the equipment should be determined in the beginning, then the values of the parameters of the electrical circuit elements.

These parameters were determined for treatment of tobacco leaves variety Birley and Virginia. The speed of the transport length v_l was 0,5 m/s, the number of pair treatment electrodes npe was 2 and the leaves number for a meter n_1 was 2. The value of the speed v_l was chosen on the basis of the developed test equipment.

The calculations were made for the values of the treatment parameters: treated voltage V_0 = 10 кV, capacitance of the discharged capacitor C = 40 nF and pulse number, necessary t_0 treat a tobacco leaf, $n_0 = 400$. The value of the parameters V_0 and C were chosen the same as in (Armyanov et al., 1998a). The consumed energy and the pulse number for the treatment of a leaf were obtained for the case of treatment of tobacco leaves from the base to the peak of the main vein. The results of the calculation are presented in Table 1.

Table1. Calculated results of the electric circuit elements parameters and the supplied generator power for longitudinal PEF treatment equipment of tobacco leaves when the number of pulses for treatment of a leaf is 400

n_l	n_{pe}	v_l	V_0	C	n_0	V_{C1}	R	W_C
leaves number	number pair tr. electrodes	m/s	кV	nF	pulse number	кV	кΩ	J
2	2	0,5	10	40	400	20	90	2

continue

ΣW_C	C1	R1	P	f_{min}	η_G	η_t	η_{ch}	P_G
J	nF	кΩ	W	Hz	-	-	-	кW
16	106,67	3,37	800	400	0,80	0,98	0,5	4,08

The treatment time of one tobacco leaf could be calculated when the value of n_0 and v_l are given by using the equation (20).

If the pulse number n_0 and treatment time t_l are known by using the equation (24), the minimum frequency of the pulse fmin can be determined. In this case the frequency is 400 Hz. This value of the frequency fmin is significantly smaller than the value 20 кHz, at that the electric spark charges grow up steadily in the air (Smirnov and Terentev, 1964). This means that the transport length speed of the equipment for longitudinal PEF treatment of tobacco leaves was quiet low at that value of the calculated frequency fmin. The efficiency of the equipment then would not be limited of the pulse frequency. Up to now it was considered only one pair treatment electrodes. If the equipment has two pairs treatment electrodes ($n_{pe} = 2$), then the necessary power according to the equation (26) would be $P_{n_{pe}} = 2P$.

It was assumed that the efficient coefficient of the power source η_G was 0,80 and the efficient coefficient of the step up transformer η_t was 0,98 (Andriyanov, 1971). The efficient coefficient of the charged circuit η_{ch} was assumed to be 0,50, as it was reported by (Butcev, 1975) for charging of RC circuit from a DC generator containing a rectifier VD and a buffer capacitor C1. The remaining voltage V_{C0} of the discharged capacitor C was assumed to be 0. If the remained voltage $V_{C0} > 0$, then $\eta_{ch} > 0,50$.

It should be noticed that the calculated value of the generator power of the equipment P_G by using equation (26) was approximate. The efficient coefficient τ_{C1} of the charged circuit of the discharged capacitor should also be taken into account for more accurate determination of the power. The ratio of the time constant of the buffer capacitor ($\tau_{C1} = R1.C1$) and the period of supply voltage is smaller than 0,1 (for this case $\tau_{C1}/T = 0,018$), then according to (Butcev, 1975) the efficient coefficient of the charged process of C1 can be assumed that $\eta_{C1} \approx 1$, this means that $\eta_{ch} \approx \eta_C = 0,5$.

The given calculations allow the determination of the values of the elements of the electric circuit of equipment. The resistance of the charged resistor R was calculated by using the equation (8). It was assumed that the frequency $f = f_{min}$ and the voltage of buffer capacitor was $V_{C1} = 2V_0 = 20$ кV. The values of the buffer capacitor capacitance C1 and the charged resistor resistance R1 are calculated using equation (17) and (19). A special consideration of the charged processes of the capacitors C and C1 should be made for more accurate determination of the value of the elements R, C1 and R1. This question is objective to further investigation.

The results of the calculations show that the power of the equipment for longitudinal PEF treatment of tobacco leave having two pair electrodes is approximately 4 кW and the efficiency of the equipment would not be limited by the pulse number.

The consumed energy W_Σ for PEF treatment of the plant can be determined by using the charged energy $W = 0{,}5CV_0^2$ (V_0 is the treatment voltage, and C – the capacitance of the discharge capacitor), and the pulse number n, this means $W_\Sigma = n.W$. When the discharged energy W is given, the pulse number would determine the treatment duration and from there the efficiency of the equipment.

The values of the parameters of the eclectic circuit elements and the applied power to the longitudinal PEF equipment for treatment of the main vain of tobacco leaves were calculated for pulse number n0 according to (Armyanov et al., 1998b). This number should ensure full damage of the plant tissue of the main vein of tobacco leaves. The damage of the tissue was obtained by using the damage degree index $S_п$, determined using the conductivity method (Armyanov, 1987; Savchuk, 1971; Armyanov et al., 2000) as a ratio of the electric impedance before electric impact to the its impedance after the treatment ($S_п = z_0/z$).

As it is shown in (Armyanov, 1987) the full damage of the plant tissue in the impact place was not necessary using longitudinal PEF treatment. Actually to achieve a technological effect due to the treatment certain damage of the core of the stem and the conductive tissues realizing connection between over-ground parts of the plant and its root should to be obtained. On the basis of the anatomical structure of the tobacco leaves and stems it could be assumed that no full damage of the plant tissue should be achieved after the longitudinal PEF treatment to have desired technological effect. This would lead to decrease of energy expenses and increase of the efficiency of the equipment.

There have been investigations for longitudinal PEF treatment of tobacco leaves and stems to verify the upper assumption. The results of these investigations are presented in (Antonov et al., 1985; Armyanov et al., 1998a).

An investigation of treatment of tobacco leaves has been made using tobacco leaves variety Birley 21. The treatment parameters were the same that had been used for calculation of the circuit: treatment voltage $U_0 = 10$ кV and discharged capacitor capacitance $C = 40$ nF, as was discussed in (Armyanov et al., 1998b). It was established (Armyanov et al., 1998a), that to obtain the necessary technological effect using longitudinal PEF treatment of the main vein of the tobacco leaves it was not necessary to have full damage of the plant tissue (such damage of the tissue was obtained when the damage degree of the plant tissue became constant and farther increasing of the pulse number did not changed it). The same effect was realized using significantly smaller pulse number. Approximately 8 times smaller pulse number was necessary to damage enough the plant tissue and close to 7 times smaller of this, that was used for the calculation in Table 1.

In Table 2 are presented the calculated results using the same treatment parameters as in Table 1. The calculation was made for number of charges $n_0 = 60$. The results are recorded in Table 2.

From the obtained date presented in Table 2 it can be concluded that the charge from the generator can be realised by applying energy with a significantly weaker power (about 7 times less) compared to the applied energy from Table 1. This was proven by conducting laboratory experiments using PEF equipment for longitudinal treatment of tobacco leaves, with two systems, working electrodes, and with a regulated voltage of treatment and electric circuit Fig. 6. Also, as it was shown in (Armyanov et al., 2004; Armyanov and Ruskov, 2005) for full usage of the transformer energy a two-way rectifier could be used to charge the buffer capacitor so this could be double the charge energy.

Table 2. Calculated results of the electric circuit elements parameters and the supplied generator power for longitudinal PEF treatment equipment of tobacco leaves when the number of pulses for treatment of a leaf is 60 ($n_0 = 60$)

n_l	n_{pe}	v_s	V_0	C	n_0	V_{C1}	R	W_C
leaves number	number pair tr. electrodes	m/s	кV	nF	pulse number	кV	кΩ	J
2	2	0,5	10	40	60	20	601,12	2

Continue

ΣW_C	C1	R1	P	f_{min}	η_G	η_t	η_{ch}	P_G
J	nF	кΩ	W	Hz	-	-	-	кW
9,6	64	37,57	120	60	0,80	0,98	0,5	0,612

Determination of the parameter of the elements of the electric circuit and the power supply of the longitudinal PEF equipment of tobacco stems

In the experiments using to determine the way of applying the energy to the tobacco stems, mentioned in (Antonov et al., 1985), was established to reach necessary technological effect and it was not necessary full cutting of the plant tissue of the stems. Tobacco type Burley-2115 with the stem length of $\lambda = 0,8$ m were used in the experiment. Treatment parameters were: voltage $U_0 = 15$ кV; capacitance of the capacitor $C = 40$ nF; input power $P_2 = 400$ W. The excess water during drying of the entire tobacco plant was measured. It was concluded that only 40 s ($t_0 = 40$ s) was sufficient to reach the desired technological effect.

It was shown in (Armyanov et al., 1988) that for a full damage of the plant tissue, it was necessary treatment time t_0 from 80 to 160 s. This means that a desired technological effect could be obtained using 4 times less energy than the energy necessary for the full damage of the stems.

It’s necessary to take into account the influence of the resistance of the plant tissue on the characteristics of the discharged process of the discharge contour when the load is a plant tissue during of development of PEF equipment for tobacco. This is important for determination of the parameters of the electrical circuit elements and the productivity of the equipment.

While conducting experiments using the PEF equipment for tobacco stems with length of stems $\lambda \geq 120$ cm and using a two-way rectifier to charge the buffer capacitor, it was determined that in the beginning of the treatment there was an arc discharge (Armyanov, 2006b). This lasted until the electrical impedance z decreased to 4,5 - 14 кΩ and after that the ark disappeared. In (Armyanov, 2006b) it was established that while an ark discharge occurred the energy consumption during of the PEF treatment of tobacco stems significantly increased. According to (Armyanov and Russeva, 1992; Armyanov et al., 2000), the effect of the treatment was significantly reduced. This is why the occurrence of an ark discharge has to be avoided during the treatment.

According to the facts shown in (Armyanov, 2006b) to avoid an ark discharge during the PEF treatment of tobacco stems it is necessary the resistance of the discharge contour to be decreased. This could be realized if the treatment is done from the pick to the base as it was done for the leaves. This question is a subject on future experiments.

On the basis of the shown methodology and the experiments mentioned above, it can be calculated the parameters of the elements of the electrical circuit and the applied energy supplied to the PEF equipment for tobacco stems. And here, as in the calculations for the PEF equipment of tobacco leaves, in the beginning the parameters of the applied energy supplied the equipment should be determined, and afterwards the calculation of the parameters of the elements of the electrical circuit.

The determination of these parameters were done by treating tobacco stems variety Birley with a relative speed of the electrodes according to the stems $v_s = 0{,}1$ m/s, using two treatment electrode systems ($n_{pe} = 2$) and two plants for a meter ($n_1 = 2$). The speed vод was chosen with the base of the consumed energy during the treatment.

The calculations are made using following treatment parameters: treatment voltage $V_0 = 15$ кV; capacitance of discharged capacitor $C = 40$ nF, pulse number n_0, necessary to treat one tobacco stem, $n_0 = 2000$. The values of the parameters V_0 and C are chosen the same as in (Antonov et al., 1985). The pulse number n_0 is calculated from equation (20) for the treatment time $t_0 = 40$ s. It was assumed that the pulse frequency is the same as the frequency of the applied voltage to the generator which is equal to 50 Hz. The results are shown in Table 3.

After determining the time t_1 using formula (21) for treatment of one tobacco stem, the minimal pulse frequency fmin is calculated by (24). For this case it is 400 Hz. This frequency is significantly lower than 20 кHz, where the electrical charges are stable in the air. The obtained result shows that in this case the efficiency of the equipment is practically not limited to the pulse frequency.

As with the equipment for treatment of tobacco leaves, and here for the residual voltage V_{C0} of the discharged capacitor C is assumed to be zero ($V_{C0} = 0$). The efficient coefficient of the power source η_G, step up transformer η_t and the efficient coefficient of the charged circuit η_{ch} is assumed to be 0,80; 0,98 and 0,50 respectively. For the examined case the ratio of the time constant of the charged circuit of the buffer capacitor $\tau_{C1} = R1.C1$ and the period of the supply voltage T is smaller than 0,1 - for the case it is $\tau_{C1}/T = 0{,}018$.

Table 3. Calculated results of the electric circuit elements parameters and the supplied generator power for longitudinal PEF treatment equipment of tobacco leaves when the number of pulses for treatment of tobacco stems

n_1	n_{pe}	v_s	V_0	C	n_0	V_{C1}	R	W_C
stems number	number pair tr. Electrodes	m/s	кV	nF	pulse number	кV	кΩ	J
2	2	0,1	15	40	2000	30	90,17	4,5

continue

ΣW_C	C1	R1	P	f_{min}	η_G	η_t	η_{ch}	P_G
J	μF	Ω	кW	Hz	-	-	-	кW
72	0,213	1693	1,8	400	0,80	0,98	0,5	9,18

Further it can determine the values of the electric circuit elements of the equipment. The resistance of the discharged resistor R is calculated by (9), as for the frequency is assumed to be $f = f_{min}$ and the voltage on the buffer capacitor $V_{C1} = 2V_0 = 30$ кV. The values for buffering capacitor $C1$ and the resistance of the discharge resistor $R1$ are determined by formulas (17) and (19).

The results from the calculations show that power supplied to PEF equipment for tobacco stems with two pair treatment electrodes should be about 9 кW and that the efficiency of the equipment will not be limited by the pulse frequency.

The calculated values of the parameters of the elements of the electric circuit and the energy of the power supply of PEF equipment tobacco stems are tentative. They will be specified in future experiments.

Conclusion

Electrical circuit of equipment for longitudinal PEF treatment of tobacco with a buffer condensation and high voltage, ensuring a simultaneous and independent work of several numbers of pair electrodes and allowing achievement of necessary efficiency of the treatment using a power supply with a net frequency was established.

Proposed methodologies allow determining the parameters of electrical circuit elements and the applied power to the equipment for longitudinal treatment of tobacco.

On the basis of the offered methodologies and taking into account the established possibility for reducing the consuming energy during longitudinal treatment of tobacco leaves and specially tobacco stems, parameters for the elements of the electrical circuit and the applied energy to the equipment were determined.

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