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Surface irradiation installation based on URT-0.5M accelerator

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Abstract. It was developed the surface irradiation installation based on the URT-0.5M accelerator (~0.45 MeV, 1 kW). It includes built-in radiation protection and a radiation-resistant conveyor of products under the beam. The circuit of high voltage pulse generation is located in the oil-filled tank of the accelerator, which has detachable side covers for easy installation and maintenance. For double-sided irradiation with a beam diameter of ~100 mm is used a vacuum diode. The pulse transformer core is made of 1V-M magnetic conductors. Tests of the installation showed the sufficiency of the resulting doses of the electron beam for surface disinfection of eggs (~12 kGy) simultaneously on both sides at a rate of movement of egg cassettes of 3.1 cm/s. It provides a productivity of up to 5400 eggs/hour. The designed protection provides the required level of safety, as the dosimetry showed.
Keywords: radiation surface disinfection, electron accelerator, electron beam, chicken eggs, radiation shield.

1. Introduction

To use an electron accelerator in radiation technologies, it should have good consumer qualities, namely, be cost-effective, have high maintainability and repairability, have good parameter stability and high reliability. These qualities has the repetitive nanosecond electron accelerators of the URT series [1], created according to the scheme of thyratron – pulse transformer – semiconductor opening switch. Using such an acceleration voltage generation scheme can significantly simplify, and, by about an order, reduce the design costs of accelerators, compared with market leaders – accelerators such as ILU or ELV [2].

The advantage of the pulse-periodic mode of operation of the accelerator consists in the simplicity of controlling the absorbed dose at the irradiation object by changing the repetition rate of operation of the accelerator. Due to the fact that the dose per pulse at the output of the accelerators of the URT series lies in the range of 200–600 Gy [1] the spread of the dose set (10–100 kGy) for the most common radiation technologies (disinfection, radiation oxidation, etc.) does not exceed several percent.

To the disadvantages of the circuit used belong: the complexity of generating voltage pulses of more than 1MV, the formation of low-energy electrons on the front and rear fronts of the high-voltage pulse. Compensating for the failure of the dose distribution on the surface characteristic of monoenergy electrons, the latter, however, increases the dose on the surface of irradiated objects. There are other bounds for this type of accelerators: the energy in the pulse is not more than 100 J, the operating repetition rate is not more than 300 pps, and the beam width is not more than 50 cm. These bounds are associated with the operation of the cold cathode, the pumping speed of the vacuum system, the parameters of the thyratrons used, the power of high voltage sources, the possibility of heat removal, etc. All this set limits for the average power in an electron beam in the order of several kW.

Various modifications of URT-0.5 accelerators [3] are successfully used for industrial modification of film polymers, radiation sterilization [4], production of nanopowders [5] and nanocomposites [6], development of new sorbents [7] and dosimeters [8], i.e. in radiation technologies on the surfaces, in gases and layers of liquid, bulk or solid materials with layer thickness up to 0.3 g/cm^2. An approximate analogue is EBE-300 accelerator (up to 300 keV) used for surface sterilization in the manufacture of tetrapax packages [9].

The gamma radiation is customary irradiation of food. Usually accelerators (with high electron energy ≥5 MeV) are applied at processing agricultural products to reduce contamination with microorganisms in order to increase storage life and reduce the number of food poisonings, in which various strains of microorganisms of the Salmonella type are implicated, at limited doses ("eggs to eat" by "gamma radiation ≤3kGy [10]. At the same time, the products are completely irradiated with all the emanating consequences, for example, the death of the embryo [11].

Has been proposed a complex solution method to this problem, which consists in control of distribution of dose load over the depth of processed product by changing energy of electrons [12]. This makes it possible to perform the disinfection of the surface only, avoiding irradiation of internal egg contents with electrons [12]. Dosimetric control showed [13] that in case of surface disinfection of chicken egg with a dose of 5 kGy, sufficient for Salmonella inactivation, at electron energy of ~0.4 MeV, due to bremsstrahlung the dose inside the yolk will not exceed 50 mGy (up to 80 mGy in white). At the same time, it was determined that there is no negative effect on the food and hatchery egg at doses of up to 40 kGy on the surface. There were found no negative differences in the process of chick withdrawal and broiler cultivation. However, it was established that the period of chick hatching from eggs was reduced to 16–18 hours (control 22–24 hour). It was also determined almost complete absence of chick morbidity – 4 against 84% in the control group. Chicks from eggs subjected to surface electron treatment showed higher activity in behavioral reactions than the chicks from control group [12]. It is most promising to treat the eggs by surface radiation before loading them into an incubator, which is easily embedded in the existing technological chain.

The accelerators of the URT type are most suitable for the implementation of surface disinfection technology. In them it is enough to simply control the energy of electrons in a wide range of values, by changing the charging voltage [1]. The accumulated experience in the operation of accelerators of the URT type made it possible to identify some design shortcomings. In particular the URT-0.5M accelerator that has been used in the production line since 2006 for more than 15 000 hours. In the work [1] are given the main directions of improvement of the reliability and serviceability of URT type accelerators.

The goal of this work was to upgrade the URT-0.5M accelerator for use in a surface disinfection installation, as well as to develop a number of new units for this installation based on the peculiarities of application in industrial poultry farming.

2. Description of the surface irradiation installation design

The surface irradiation installation includes the following units: an oil-filled tank with elements of a high voltage pulse generation circuit, a vacuum diode for two-sided irradiation (VDTSI) [14] with a vacuum generation system; high voltage source (HVS, 40kV, 5 kVA), built-in radiation protection (BRP), radiation-resistant conveyor (RRC), control rack, oil and water-cooling systems and control laptop with program control. External view of the unit is given in Fig.1.

For ease of installation and maintenance, there are two detachable side covers on different sides of the oil-filled tank (770×620×650 mm), which make up 3/4 of the tank length. The tight arrangement of the circuit elements made it possible to reduce the length and height of the tank, for example, the installation of a second circuit capacitor on a dielectric support above the through vacuum insulator. For switching a pulsed thyratron TGI1-2500/50 is used for an operating voltage of up to 50 kV, while its incandescent transformer is transferred to the tank and installed next to the thyratron, which made it possible to abandon the use of long wires of large cross section for filament current (~200 A). Special circuit in control rack is used to generate thyratron start pulses.

The core of the pulse URT-0.5M transformer made from two 1B-M TU 14-123-233-2012 magnetic conductors [15] in K375×305×25 mm size made from the fast-tempered ribbon from the magnetosoft amorphous AMET-1SR alloy developed and produced by Ashinskiy metallurgical factory (Russia). This material has a magnetic field strength in the range of 900–1100 A/m at the rate of induction increase of 5 T/µs and induction span of 2.5 T.

Fig.1. Photo of experimental.

Magnetic conductors are fixed by grips made of organic glass, which are attached to load-bearing rods made of the same material. Grips and tie-rods are secured by caprolon bolts with screws. This design provides high electrical and mechanical strength. The transformation factor is 10. Capacitance of the primary circuit capacitor C_0 is 60 nF. It consists of 30 parallel UHV-9A capacitors from TDK (40 kV, 2000 pF). The primary circuit capacitor was charged from HVC (5kW, U_0 up too 40kV) manufactured by Avangard LLC in Yekaterinburg. The capacity of the second circuit is 560pF (7 UHV-9A capacitors connected in series). Semiconductor opening switch consist from three SOS-180-4 diodes connected in series. The vacuum diode operates at a pressure of ~10^{-2} Pa, pumped by a NVD-160 diffusion pump. The vacuum diode insulator is sectioned, with shielding of the dielectric surface with protruding skirts on gradient metal rings, and consists of 6 rings made of organic glass with a thickness of about 30 mm.

VDTSI is used to generated an electron beam, which has two output windows (100 mm in diameter) with a 30 µm aluminum foil. Windows are opposite each other to irradiate of objects on both sides [14]. The metal dielectric cathodes [16] are generating a 100 mm electron beam in diameter with a rather uniform (±15%) distribution of the current density.

All systems are operated and controlled from a personal computer connected to the control panel The design and operation of the accelerator is described in detail in [1]. The time between failures of the accelerator exceeds ~200 hours, most components of the high-voltage electrical circuit have a lifetime of ≥2000 hours, are manufactured by industry and are easily replaced. The most critical element is the cathode, which requires the cleaning procedure after 40 hours. It should be noted that this procedure is an easy procedure which can be executed when the vacuum system is stopped or put into operation [17].

BRP serves to protect personnel from bremsstrahlung. BRP consists of two parts: fixed (Fig.2) and movable (Fig.3). RRC is located in the movable part that moves along guides rigidly coupled with the fixed part. In the fixed part there is a VDTSI. (Fig.2). BRP is connected to ventilation for pumping out ozone and another radiolysis products. The gates have a movable side and upper flaps, with the help of which the size of the hole in the gate can be controlled to minimize the release of scattered X-rays. BRP and RRC manufactured by Rostekhpodderzhka LLC in Yekaterinburg.

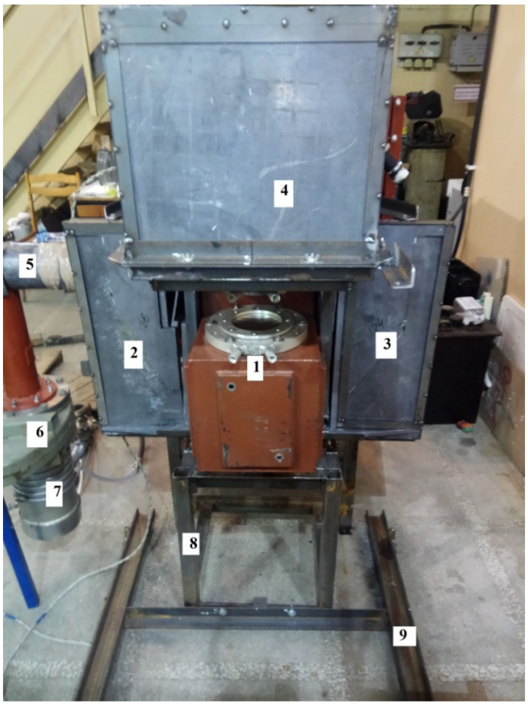

Fig.2. Photo of the fixed part BRP: 1 – bottom flange VDTSI, 2, 3 – side lead panels, 4 – top lead cap, 5 – protection of vacuum pipe to DP, 6 – vacuum lock, 7 – DP, 8 – stand, 9 – rails of the mobil part.

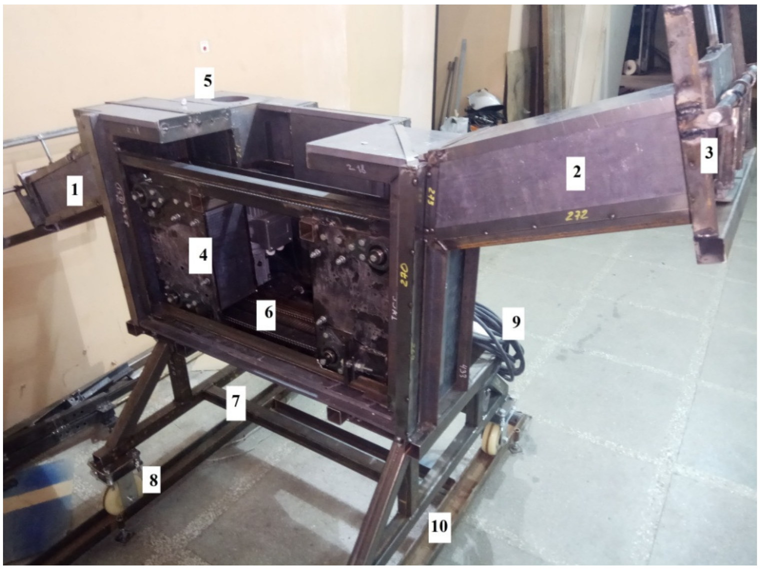

Fig.3. Photo of the mobil part BRP with RRC: a) 1 and 2 – outlet and inlet fittings of protection for RRC chutes with gates 3, 4 – RRC with metal grid 6, 5 – ventilation branch, 7 – platform with wheels, 8, 9 – electric cable RRC, 10 – rails.

The thickness of the sheets (grade S3 lead) of the BRP is based on the calculation, using the dose limit 20 mSv/year (NPB-99/2009) at a distance of 1 m from the beam axis during operation 2000 hours/year. (Fig.1).

RRC consists of a console and a conveyor. The mesh tape of the conveyor is made of stainless-steel wire with a diameter of 1 mm. Its transparency (>95%) makes it possible to efficiently pass electrons from the lower outlet window of the VDTSI. The design of the cassettes allows reliable egg fixation when moving along the RRC, while there is a minimum area of contact between eggs and the cassette, in order to minimize the shielding zones of the electron beam during irradiation.

3. Experimental results

Characteristic voltage oscillograms at the output of the pulse transformer are given in [17]. Replacement of the core of the pulse transformer did not lead to a change in parameters, the difference between the measured voltages at different cores lies within the range of measurement error (7%). The accelerating voltage was ~450 kV, the current of the electron beam was ~ 350 A at a repetition rate up to 50 pps. To check the efficiency of the BRP, X-ray radiation was measured at a distance of 1 m from the beam axis using the DKS-AT1123 (device at different repetition rates of the accelerator. Dosimetry results show that at a repetition rate of 50 pps the dose rate does not exceed 0.62 μSv/hour, there is more than 10 times less than the dose limit (10 μSv/hour).

Experimental tests of surface irrigation installation at the poultry farm (Veliky Novgorod) were started. The experiment is carried out by treating the hatching egg at different conveyor speeds: high (8 eggs per second are irradiated, group 3, Table 1), medium (4 eggs per second, group 2, Table 1) and low (2 eggs per second, group 1, Table 1). Dosimetry results using SO PD (F) R-5/50 type showed that the dose on egg cassettes at high conveyor speed and an accelerator repetition rate of 50 pps) was 13.7 and 11.7 kGy from above and below, respectively, which is more than sufficient for complete surface disinfection [12].

Egg supplier: TD "Reserve" production France, farm: FR059AV66202, age of the parent herd: 32 weeks. Total number of eggs for the experiment: 2355 pcs. Chicken withdrawal in group 1 was higher than in the control group (Table 1). Unfortunately, due to the disruption of feeding, the results of growing chickens were not obtained.

Table 1. Experimental results

№	Characteristics	1 group	2 group	3 group	Control group
	Qualitative characteristics				
1	Hatchability, head number, pcs	686	655	648	44 000
2	Hatchability, %	91.5	87.3	86.4	90.7
3	Average weight of the chicken, gr	46	45	45	45
	Results of incubation waste opening				
4	Infertiles, %	4.7	5.3	6.8	4.6
5	Early dead, %	0.7	1.1	1.1	0.7
6	Blood ring, %	1.1	1.5	1.3	0.9
7	Dead in shell, %	1.2	1.6	1.3	1.1
8	Late dead, %	0.2	1.6	1.1	1.2
9	Exploder, %	0.1	0	0.5	0.7
10	Teratosis, %	0	0	0	0
11	Weaklings, %	0	1.6	1.1	0.8
12	Breakage (check), %	0.5	0	0.5	0.7
	Total, %	8.5	12.7	13.6	10.7

4. Conclusion

Therefore, a surface irradiation installation for eggs based on an URT-0.5M accelerator was developed, which includes built-in radiation protection and a radiation-resistant conveyor of items under the beam. Tests of the installation showed that the produced electron beam doses are sufficient for the surface disinfection of eggs on both sides simultaneously at a rate of movement of the egg cassettes of 3.1 cm/s, which provides a productivity of up to 5400 eggs/hour at a radiation utilization ratio of 0.6. Dosimetry showed that the protection design provides the required level of safety.

Experimental tests carried out on surface irrigation installation at the poultry farm showed that the hatchability percentage and weight of the chicken was higher in 1 group of irradiated eggs than in the non-irradiated control group. This gives cautious optimism.

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