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RADIATION TREATMENT COMPLEX ON THE BASE OF THE "ELECTRONICS U-003" ELECTRON ACCELERATOR

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The electron accelerating complex is described which created on base of the electron accelerator "Electronics U-003". The complex is intended for organizing of the studies on the influence of the accelerated electrons on basic physical laws, mechanisms, characteristics and on properties of different objects and also the realization of radiation treatment of items, materials for modification of their properties and give to them of a new quality. Some the obtained experimental results are given.

INTRODUCTION

It is known that radiation as a source of external influence is used to study semiconductors, dielectrics, composite and optic materials in order to study the radiation effect on physical processes, defects formation, impurity centers, surface and volume structures. The scientific researches on the study of surface and volume defect formation, structural transitions and their relationships with properties, the formation of various centers and phases are purposefully conducted.

It should be noted that with the industry development, there is the growing need for various types of radiation treatment of products to improve and long-term preservation of properties, modification of characteristics and parameters. This refers to the production of medical, pharmaceutical, polymer products, as well as electronic and agricultural products. The products of these industries are processed in various ways, among which take a special place the radiation treatment, characterized by efficiency, speed and relatively low cost. For example, the maximum degree of sterility (10^{-6}) of medical products processed in industrial scale is only achievable by radiation treatment. The irradiation of electronic products (diodes, transistors, microcircuits, etc.) leads to the significant improvement in their properties and operation characteristics. As the result of radiation treatment of polymeric products, the cross-linking occurs, the heat resistance and mechanical strength [1] is increased, and the "shape memory effect" appears [2]. The radiation treatment of food and agriculture products leads to the increase of their storage period, shortening their germination period, increasing their yields. All of this is the prerequisite to the creation of the complex for studying the radiation effect on physical processes, laws and organization of radiation treatment of various materials and products. The electron accelerator was chosen as the source of radiation, which is associated with its greater universality and practicality in the organization and conduct the scientific researches and radiation treatment of medical products on the industrial basis [3–5].

Proceeding from the above-mentioned activities and taking into account the current trends in the development of condensed matter physics, the linear electron accelerator "Electronics U-003" was put into operation in order to study the effect of electrons, the bremsstrahlung on various physical processes and regularities and also to organize the radiation treatment of materials and products.

1. ELECTRONIC ACCELERATOR COMPLEX

The exploitation of the electron accelerator "Electronics U-003" is based on the of electrons resonant interaction principle with the traveling electromagnetic wave field of the ultra-high-frequency (UHF) range. The source of UHF wave is the magnetron MI-320. The UHF wave is transferred through the waveguide into the accelerating solenoid, and the electrons are injected into the accelerating solenoid by the electron gun. The electrons emission into the atmosphere is carried out through the titanium foil after the beam scanning in the vertical plane by reaming process.

The radiation treatment complex with the electron accelerator "Electronics U-003", auxiliary equipment, the transportation and construction system are located in the premises built inside the building.

In order to reduce the ionizing radiation effect on the environment and the operating personnel of the accelerator, the emitting part of the electron accelerator is placed at the depth of 3.5 meters from the floor level.

The electron accelerator "Electronics U-003" is installed in the accelerator hall together with the generator block in the rails and it can be moved horizontally up to the distance of 2.3 m, which makes it possible to select the optimal density and sufficient uniformity of current beam at the stationary target (samples, materials and products).

It is also possible to irradiate the volumetric targets (products) at different current flux densities and different positions when the target rotates around its own vertical axis or during reciprocating motion. The design of premises with the output maze (labyrinth) provides protection the personnel against radiation when the accelerator is operating at maximum power. The electron accelerator premise has two protective metal doors with the mechanical device for opening and closing. On the door, there is the lock that works when the accelerator is turned on and closes the access to the accelerator room during its operation. The supply and exhaust ventilation system for fresh air supply and local suction of gases formed during irradiation is installed in the accelerator premise.

The radiation situation is controlled by stationary and portable dosimetric devices of the type UIM2-2D with the detector BDMG-100, DKG-02U Arbitr-M, DKG-PM1621, SIG-PM1208. The absorbed dose is measured using high-precision dosimetric detectors B3002 and SO PD(F)R-5/50. The passage of the material through the irradiation zone is monitored by the dose indicator of CVID-3 from the color change (from red to yellow) after the radiation treatment.

In the electron accelerator complex "Electronics U-003", the transporter system of the conveyor type is provided for supplying samples and products to the irradiated zone and removing them from the irradiation zone. The conveyer system consists of the belt and chain conveyor, as well as the carousel. The transporter corridor is made two-level, the even part lies at the depth of 2 m.

The conveying system is reliable and provides the even irradiation of the object due to the automation of the controlled rotation speed and horizontal movement of the device during the pipelining radiation treatment.

Taking into account the variety of irradiated objects, the irradiation dose, the size of the irradiated products, in order to ensure the equability and high processing efficiency, the conveyor line of the Π-shape (Fig. 1) with a loading-unloading device and the electron accelerator (1) was proposed.

The conveyor line is located on four levels in order to prevent the over-irradiation of the accelerator's personnel from scattered radiation and to organize its reliable and efficient operation. The belt conveyor (2, 7) with the total length of 21 m has the inclination angle of 12^0 relative to the floor level of the belt conveyor, which excludes overturning of the transport container during the transportation to the chain conveyor with length 18 m (3, 5). The conveyor also includes the carousel conveyor table (4) and a roller conveyor (6).

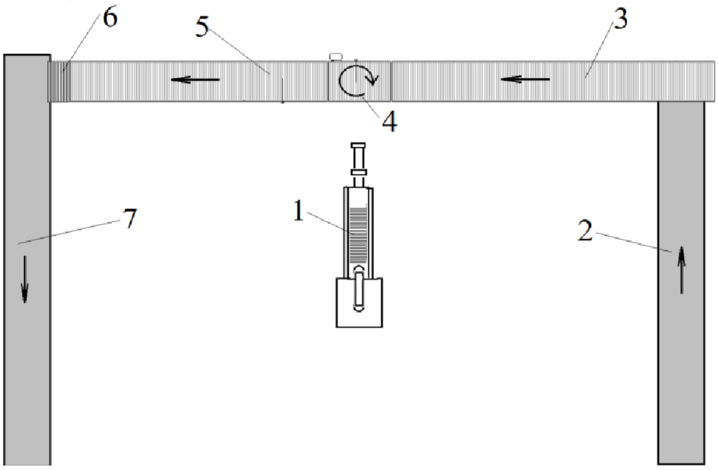

Fig. 1. Scheme of the conveyor line (top view): 1 – electron accelerator; 2, 7 – belt conveyor; 3, 5 – chain conveyor; 4 – carousel conveyor; 6 – roller table

Taking into account the variety of the irradiated material, the carousel conveyor operates in the following modes:

1. Radiation processing mode by linear movement of the object without speed adjustment.

2. Radiation processing mode by linear movement of the object with speed regulation.

3. Radiation processing by rotation the products taking into account the number of carousel turnovers: In the proposed mode, the electron beam acts only during the carousel rotation, i.e. the beam control scheme is locked with the conveyor rotation scheme. The developed device is highly productive and technological for serial processing of materials, products, and also samples. The accelerator complex in the radiation process can work in two modes: with direct supplying products for rotation or with adjustment the rotation speed of the carousel by change with the inverter of the motor power supply frequency (from 10 to 50 Hz).

The technical characteristics of the modes are as follows:

– acceptable number of carousel rotations – up to 99 turnovers;

– rotation speed, with direct supply – 1.07 Rpm; with adjustment – 0.14…1.07 Rpm;

– irradiation time at one turnover with direct supply – 64 s; with adjustment – 64…351 s.

4. Radiation treatment by rotation of the product with taking into account dose set. This mode is optimal, designed for processing objects with the high density of electron flux (0.3 $\mu A/(cm^2 \cdot s)$), requiring high absorbed doses. The process is controlled by the electrons flow falling on the irradiated object during radiation treatment. To control the set of absorbed dose, the integrating device has been developed. The action principle of the device is based on integrating the average density of electrons current beam and comparing the output voltage of the integrator with the given constant voltage level "U basic", with using the comparator that controls by the electronic key, which is controlled by the starting relayof accelerator injector.

After the certain set of doses, the command is given to cut off the electron beam and to unload the processed products.

5. The stationary radiation exposure is intended for processing small-scale objects, for example: samples of semiconductor materials, shrink sleeves, polymer and other products. In this mode, the processed material is not transported, but only installed in the carousel

conveyor by hanging on the device that is the prism in the form of the octagonal frame.

2. ELECTRON BEAM PARAMETERS AND RADIATION TREATMENT PROCESS DOSIMETRY

The electron accelerator is used in the scientific and applied researches, as well as in radiation-technological processes, therefore it is necessary to monitor all output parameters of the electron beam. For scientific and applied research, the main parameters that determine the of radiation materials treatment modes are the electrons energy range, the current beam value, and the spatial distribution of the electrons flux density.

The value of the electrons energy is one of the important characteristics of the accelerator, which determines the electrons penetration depth in the object and the spatial distribution of the electron flux density is especially important for accelerators used in radiation-technological processes. During radiation sterilization of products, the dosimetric support of radiation processes takes a special place.

MEASUREMENT OF THE ACCELERATED ELECTRONS FLOW DENSITY

To measure the flux density – φ_e of the accelerated electrons, the Faraday cylinder was used, which was installed at the center of irradiation zone of the accelerator at the distance of 1,35 meters from the reaming. The data on the current beam was transmitted to the high-precision micro-ammeter located on the accelerator control panel. The location of the Faraday cylinder at this distance is due to the fact that materials and products for radiation treatment are located at a distance of 1,35 meters from the exit window of the accelerator.

The error in measuring the beam density is determined by the following ratio:

$$\Delta\phi_{e^-} = \Theta_{c.F.} + \tau_{c.F.}. \quad (1)$$

Where $\Theta_{c.F.}$ – is the systematic error of determination φ_{e^-}, not exceeding ± 5%; $\tau_{c.F.}$ – error of measuring the current of the Faraday cylinder by an Ampervoltmeter

$$\tau_{c.F.} = \pm\left[0,15 + 0,05\left(\frac{I_\kappa}{y_x} - 1\right)\right], \quad (2)$$

where I_κ – is the current measurement limit; y_x – indication of the device.

Such a technique provides the measurement of the electron flux density φ_{e^-} with an error $\Delta\varphi_{e^-} \leq 15\%$.

THE SIZE OF A HOMOGENEOUS SQUARE OF ELECTRONS FLOW

One of the main parameters that ensure uniform processing of products is the area size of the falling electrons, which provides their relatively uniform distribution. To determine the size of this area, 11 Faraday cylinders were used. During the operation of the accelerator with the help of the infrared camera, the dimensions of the uniform area were roughly determined and on the basis of this, the distances between the Faraday cylinders were established, which were 10 cm horizontally and 20 cm vertically.

To determine the size of the relatively evenly irradiated area, the Faraday cylinders were placed strictly perpendicular to the direction of the electron beam. It is known that the current generator solenoid values, the current of the magnetron generator and the injection voltage of the electron accelerator influence on the electron beam characteristics. Therefore, the experiments were conducted to determine the beam density and the uniformity of the irradiation field for different values of the current generator solenoid, the current of the magnetron generator and the injection voltage at constant currents of the solenoids.

From the experimental data on the determination of the even area size, it is established that the area of 20×60 cm is relatively even at the current beam density of 0.02 μA/(cm^2·c) and the electron energy 3…7.1 MeV.

DETERMINATION OF ELECTRON ENERGY

To determine the electron energy, we used the standard measuring wedge Riso 2 Piece Aluminum (“GEX Corporation”, USA) made of aluminum, designed for measuring electron energy from 2 MeV to 10 MeV, film detectors such as B3110, Thermo Genesys 20 spectrophotometer and Windows for Excel software 2002, installed in the computer. In the measuring wedge, film detectors of type B3110 were placed in the amount of 30 pieces with the distance of 1 mm in height (in depth). The wedge was installed strictly perpendicular to the direction of the electron beam at the distance of 1 m from the radiation source. Thermo Genesys 20 spectrophotometer measured the optical density of film detectors with λ = 552 nm. By changing the optical density of the film detector B3110, the electron energy was determined. The following dependence was used [6]:

$$E_p = 5.09 \cdot R_p \cdot c + 0.2, \quad (3)$$

where E_p – is the electron energy, MeV; R_p – is the thickness of the aluminum wedge at which the absorbed dose is zero, cm; c – is a correction factor equal to $c = \dfrac{2.663\, g/cm^3}{2.7\, g/cm^3} = 0,986$; R_p – determined by the dependence graph of the absorbed dose on the aluminum thickness.

For constant monitoring of the electrons energy spectrum, the special device was made-the energy indicator of the accelerated electrons. The principle of device operation is based on measuring the current of absorbed electrons by aluminum plates [7]. The device determines the energies of accelerated electrons from 2 to 10 MeV in 1 MeV steps and consists of two parts: the gauge sensor and the energy meter block. The sensor of the energy meter consists of aluminum plates-absorbers, load resistors, protective plates, cover, connector, dielectric washers and pins [8]. The electrical diagram of the device (Fig. 2) of the energy meter channel is made on the chip type D1 – TL072 and D2 – KR140UD20.

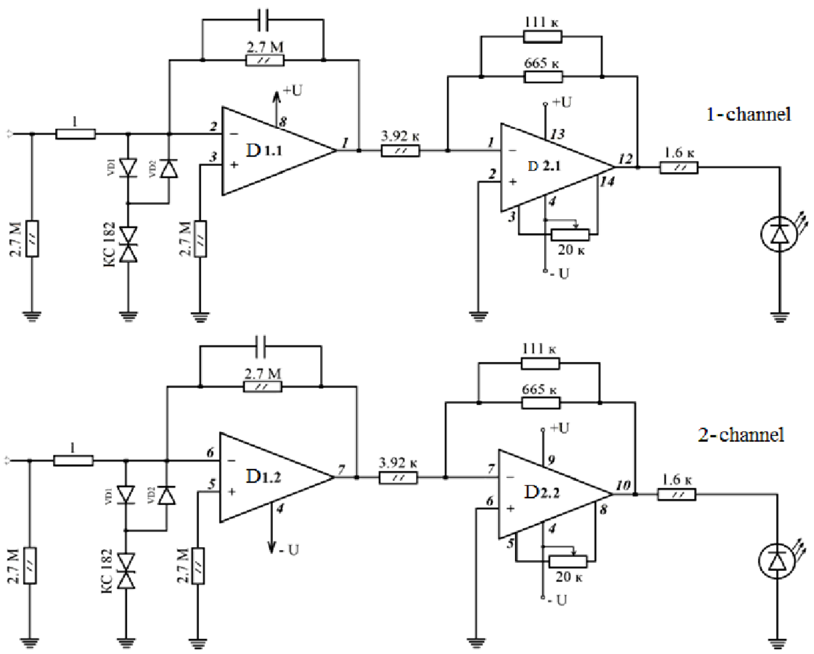

Fig. 2. The electrical diagram of the energy indicator accelerated electrons device

The energy meter is made as the separate unit. The unit is powered by a separate external source of constant current with a voltage of ± 15 V, the current consumption does not exceed 150 mA. On the front panel of the remote control are installed following units: power switch, network power indicator and 10 (ten) LEDs of the energy meter. Due to the fact that the current meter is supplied with currents within 10…100 nA, in the input cascade, the TL072 chip is used . In order to avoid overloads, the inputs of the chip are installed counter-parallel to the diodes. The next cascade is made on the chip KR140UD20 – voltage amplifier with negative reverse contact. The resistance of reverse contact is selected in such way that the luminescence brightness of the LEDs should be the same at the same input current. The circuit is made as the separate unit from the electronic measuring circuit (for TL072 and KR140UD20) and the display circuit (LEDs). The basic elements of the unit are the channel amplifiers - current converters connected to each plate of the absorber. In the input stage of each channel amplifier, the chips TL072 and KR140UD20 are used. The sensor of the energy meter is stationary, installed in the irradiation zone and does not interfere with the irradiation process. Advantages: difference between the energy meter and the indicator of the operated device [8]; Availability of more modern element base; In this work [8], transistors were used, and in this work – 10 microcircuits; More technological and easy to repeat; Regulating sensitivity is in more wide range.

DETERMINATION OF ABSORBED DOSE

For the purpose of metrological maintenance of radiation treatments at all stages of processing, the certificated standardized film chemical dosimetric detectors: B3002 and CO PD (F) P-5/50 were used. To determine the absorbed dose, the dosimeter B3002 in the case of sterilization of medical devices and raw pharmaceutical products was placed into the box with products that must be sterilized. Moreover, the detectors were installed inside the box in three positions: at the bottom of the front part of the box, in the middle at half the height of the box and at the end at the full height of the box. This is due to the need to monitor the uniformity of the absorbed dose throughout the volume of the box with products. After the radiation treatment of the products, the film dosimetric detectors B3002 were removed from the box and installed (by one) into the cuvette of the Genesys 20 spectrophotometer and the absorbed dose was determined from the change in optical density. A personal computer connected to the spectrophotometer automatically calculates and displays the absorbed dose values for each detector. The standardized film chemical detector SO PD(F)R-5/50 (copolymer with phenazine dye and sensitizer) was also used to determine the absorbed dose in the range of 5…50 kGy.

As it is known, the absorbed dose can be determined by calculation, taking into account the current beam parameters of the accelerated electrons and the density of the product irradiated in the electron accelerator. The absorbed dose (D, kGy) of accelerated electrons in the article is calculated by the following expression [9]:

$$D = \frac{EIt}{m}, \tag{4}$$

where E – is the electron energy, MeV; I – current beam, mA; t – is the irradiation time, s; m – is the mass, kg.

$$E = D(e) \cdot Z, \tag{5}$$

where $D(e)$ – is the absorbed energy by the unit surface area of the supply electrons (MeV cm^2)/g, Z – is the surface density, g/cm^2.

Taking into account (5), the absorbed dose (D, kGy) is expressed as:

$$D = \frac{D(e)ZIt}{m}. \tag{6}$$

3. SCIENTIFIC AND PRACTICAL APPLICATION OF ELECTRONIC ACCELERATOR "ELECTRONICS U-003"

Radiation sterilization of medical products and raw pharmaceutical products is widely carried out by the radiation method at the electron accelerator. The silk surgical threads that have manipulative properties, high strength and exceptional reliability of the unit, were sterilized in the accelerator with absorbed dose of 20 kGy. The breaking load of the silk thread and a simple surgical node after radiation treatment by electrons at the absorbed dose of 20 kGy varies up to ~ 13%. The dependence of the strength of a simple surgical node of the silk thread from the absorbed dose is shown in Fig. 3. The calculation results of the elastic module of the thread before and after the radiation treatment with a dose of 20.0 kGy showed deviations up to ~ 15% of the initial value, which does not significantly influence on its performance characteristics.

The surgical sutures thread catgut were sterilized by 3…7 MeV electrons, with impulse of current beam density from 0.05 to 0.16 μA/(cm^2·c). It has been established that the minimum sterilizing dose for the surgical suture thread catgut is (25±2) kGy, at which pathogenic spores, aerobic and anaerobic microflora are destroyed, and the strength of the filament and node meets the requirements for the absorbable suture filament catgut. The conditions for sterilization of the absorbable suturing filament catgut with a uniformity coefficient $K = D_{max}/D_{min}$ = 27.2/23.2 kGy = 1.17 are determined.

Radiation treatment of the potato and corn starch, used as disintegrators of the binding element and filler in tablets, was carried out by accelerated electrons with an energy of 3…6 MeV and the current beam density in the range 0.02…0.08 μA/(cm^{2}c). It has been established that potato and corn starch are sterile at the absorbed dose of 20 kGy [10].

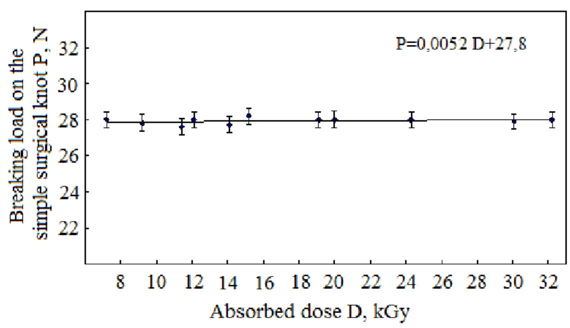

Fig. 3. Dependence of the strength of a simple surgical knot of the silk thread at the absorbed dose

One of the promising areas is the radiation cross-linking of polymer products. As is known, in the heat treatment of the heat shrinkable couplings, pipes, cuffs, tapes, films of polymeric material occurs the transverse cross-linking, heat resistance and mechanical strength increase, and a "shape memory effect" appears. When radiation tubes are insulated from polyvinyl chloride with the stream of the accelerated electrons with the energy of 3…5 MeV and a beam current density of 0.06…0.10 μA/(cm^2·s), the increase in the electrical strength value up to 23 kV/mm is established, i.e. for 25% at the absorbed dose of 80 kGy. At the same time, the value of the coefficient of thermal shrinkage of radiation-cross-linked PVC insulating pipes is 2: 1.

CONCLUSION

Thus, based on the carried out studies in the radiation treatment complex in the base of the electron accelerator, the following conclusions can be made:

– The complex of radiation processing created on the basis of the electron accelerator "Electronics U-003" allows to organize and carry out research on the effect of accelerated electrons on the physical laws, mechanisms, characteristics and properties of various objects, as well as carry out radiation treatment of products, materials in order to modify their properties and giving them new qualities;

– Conveyor line performs various functions with the ability to adjust the speed of horizontal movement from 1 to 10 m/min., rotation speed of 0.14…1.07 rpm. and the number of turnovers (up to 99), depending on the variety of irradiation materials;

– The dimensions of the uniformly irradiated area at different– currents of the electron beam are determined and it is established that the area of 200x600 mm is relatively uniform (15%);

– it is established that the "quadrilateral" irradiation of products by electrons with the energy of 3…7 MeV and the current beam density of 0.05…0.16 μA/(cm^2·s) is optimal for radiation sterilization of medical products, pharmaceutical raw materials and radiation treatment of various materials;

Radiation treatment of samples, products on the accelerator complex – is carried out in the automatic mode of their supply to the irradiation zone and the withdrawal from the irradiation zone;

A special indicator device has been developed and manufactured for constant monitoring of the electrons energy spectrum.

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КОМПЛЕКС РАДИАЦИОННОЙ ОБРАБОТКИ НА БАЗЕ УСКОРИТЕЛЯ ЭЛЕКТРОНОВ «ЭЛЕКТРОНИКА У-003»

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Описан ускорительный комплекс, созданный на базе ускорителя электронов «Электроника У-003», который предназначен для организации исследований по изучению влияния ускоренных электронов на физические процессы, закономерности, механизмы, характеристики и свойства различных объектов, а также для осуществления радиационной обработки изделий, материалов с целью модификации их свойств и придания им новых качеств. Приведены некоторые результаты исследований.

КОМПЛЕКС РАДІАЦІЙНОЇ ОБРОБКИ НА БАЗІ ПРИСКОРЮВАЧА ЕЛЕКТРОНІВ «ЕЛЕКТРОНІКА У-003»

М.Ю. Ташметов, Н.Б. Ісматов, Р.П. Саідов, Ш.М. Махкамов

Описано прискорювальний комплекс, створений на базі електронного прискорювача «Електроніка У-003», який призначений для організації досліджень з вивчення впливу прискорювальних електронів на фізичні процеси, закони, механізми, характеристики та властивості різних об'єктів, а також здійснення радіаційної обробки виробів, матеріалів з метою модифікації їх властивостей та придань їм нових якостей. Приведені деякі результати дослідження.