Accelerator URT-1M-300

S.Yu. Sokovnin[1,2], M.E. Balezin[1], S.V. Shcherbinin[1,2]

[1] *Institute of Electrophysics, Ural Branch of Russian Academy of Sciences, 106 Amundsen Str., 620016, Yekaterinburg, Russia*
[2]*Ural Federal University, 19 Mira street, Yekaterinburg, 620002, Russia.*

The electron accelerator URT-1M-300 for mobile installation was created for radiation disinfecting of clothes, footwear, documents and personal belongings from pathogenic microorganisms in field conditions to correct drawbacks that were found the URT-1M electron accelerator operation (the accelerating voltage up to 1 MV, repetition rate up to 300 pps, electron beam size 400x100mm, the pulse width about 100 ns). Accelerator configuration was changed that allowed to reduce significantly by 20% oil tank volume where is placed the system of formation high-voltage pulses, thus the average power of the accelerator is increased by 6 times at the expense of increase in pulses repetition rate. Was created the system of the computerized monitoring parameters (output parameters and thermal mode) and remote control of the accelerator (charge voltage, pulse repetition rate), its elements and auxiliary systems (heat of the thyratron, vacuum system), the remote control panel is connected to the installation by the fiber-optical channel, what lightens the work for service personnel. For generating a big width electron beam of (to 400 mm) was used the metal dielectric cathode from several emission elements to make not more than ~15 % non-uniformity distribution of beam current density on the outlet foil. The accelerator can be used for the radiation technologies in layers by thickness up to 0.3 g/cm^2.

1. Introduction

The electron accelerators applied in radiation technologies should meet some requirements, in particular, such as economy, stability of parameters and reliability, and operation and repair simplicity. The URT electron accelerators (Table) [1], based on a thyratron–pulse transformer–semiconductor opening switch scheme [2], largely correspond to these requirements[1]. These accelerators can be used for modifying film polymers [3], radiation sterilization [4], and obtaining nanopowders [5], i.e., in radiation technologies on the surface, in gases and layers of liquid, loose or hard materials with a layer thickness of up to 0.3 g/cm^2.

During the operation of the URT-1 electron accelerator, some drawbacks and imperfections were revealed, thus resulting in the necessity of its modernization. First of all, this relates to the accelerator design, which required a room equipped with a loadlifter with a ~4m height to a hanger for its assembling–disassembling.

These defects were in large part eliminated in URT-1M [6] accelerator in which were also used DHS condensers of Murata firm (Japan) and the new thyratron TPI1-10k/75, allowing to significantly increase the working charge voltage of the first stage from U_0=50 to 60kV, and is also put accelerator parameters monitoring automation.

However new design of the accelerator led to essential increase in volume of the tank V with transformer oil (for 17%) in which is the circuit of high-voltage impulses formation, in comparison with the volume of the URT-1 accelerator tank.

Table Parameters of URT accelerators

Accelerator type	U, kV	t_p, ns	S*, cm	f**, pps
URT-0.2	200	35	2*20	250
URT-0.4	400	~50	5*40	200
URT-0.5	500	~50	10***	200
URT-1	900	~70	17***	50
URT-1m	800	~90	5*40	50
URT-1m-300	900	~90	5*40	300

*S - electron beam cross section, **f - pulse repetition rate, ***In diameter.

For application in the mobile installation intended for disinfecting of clothes, footwear, documents and personal belongings from pathogenic microorganisms in field conditions which is mounted on the chassis of high passability, the weight and the geometrical sizes, and also possibility of transportation of the accelerator with working capacity preservation has essential value. Besides, for ensuring the demanded speed of picking up the absorbed dose at products radiation in the mode of the X-rays generator, it was required significantly (approximately by 6 times) to increase power in the electron beam.

The problems stated above were solved at producing of the URT-1M-300 accelerator.

2. Description of the accelerator design and test results

At creation of the accelerator, because of mobility requirements, it was necessary to solve inconsistent problems, including: reduction of dimensions and weight, at essential increase in power and increase of requirements to reliability.

The following measures were taken for reduction oil-filled tank dimensions in which are placed high-voltage pulses formation circuit elements (further tank).

First the core of the pulse transformer is executed from 3 rings of K550*400*25 from permalloy 50NP 10μm thick (instead of 20μm in [6]) that allowed to reduce width and height of a tank, to reduce losses of energy in cores and to improve their cooling, thereby to increase the operation frequency of cores on cooling from 200 to 500pps.

Secondly, the parasitic volumes which arose by means of not effective design of elements of the scheme [6] are namely reduced:

- use of the combined three electrode designs of the C0 condenser (instead of two identical modules);
- installation of the C1 condenser on a dielectric support over a vacuum insulator through passage,
- also transition to the additional solenoid in the form of a flat spiral.

The following measures were taken for increase of reliability of the accelerator operation: refusal of sockets, increase in insulating intervals, like clockwork, and on the surface of supporting dielectric frameworks, introduction of fixing extensions from the Capron cord, excluding swing and destruction of designs at movement.

For switching it is used experimental thyratron TGI2-5k/75 for operating voltage till 75kV, productions of JSC "Impulsnye tekhnologii"[7].

Thyratron has a tetrode construction (G1 grid of the preparatory category and G2 - the operating grid) with three high-voltage sections in ceramic-metal execution with the complex cathode which consists of the hollow and heated emitter.

Thyratron steadily worked at the charge voltage to U0=65kV, after selection of cathode heat parameters, hydrogen and getter generator.

To the lack of thyratron, as well as all tetrode constructions, it is possible to carry more difficult in comparison with triode scheme of inclusion and start.

Pulse transformer cores are fixed by captures from plexiglas which fasten to the bearing drafts from the same material. Captures and drafts are fixed with caprolon bolts and nuts. Such design provides high electric and mechanical durability. The coefficient of transformation is equal 10. For production of primary winding (2 rounds) was used the copper tape 100 wide and 0.7 mm thick, for a secondary winding the coupled acoustic MCS-10 cable, with a section of 10mm^2. Primary winding blocks about 1/3 secondary. Both windings are reeled up on frameworks from plexiglas. For increase in electric durability between rounds of a secondary winding on a frameworkare pasted T-figurative slips from plexiglas under each round.

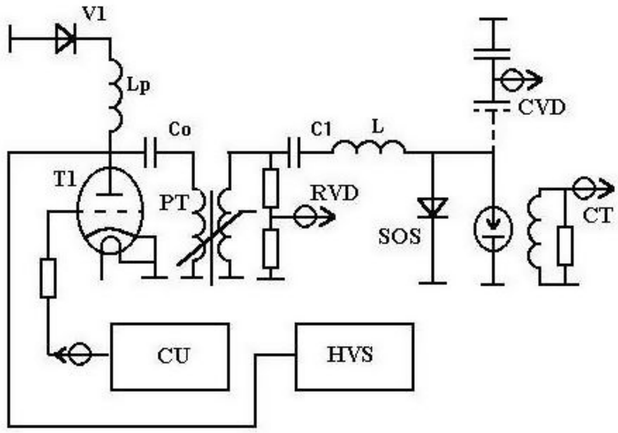

Fig.1. Accelerator URT-1M circuit: HVS - high voltage source; CU– start pulse former; SOS - semiconductor opening switch; CVD – capacitive voltage divider; T1- thyratron; PT-pulse transformer; V1 – recuperation diode; Lp, L–recuperation and additional inductivity, respectively; C0 and C1 – capacitors of the first and second stage.

Capacity of the first stage is C0=75 nF. It consists of 75 parallel sections each containing two UHV-9A condensers of TDK firm (Japan) (40 kV, 2000 nF) [10] switched on consistently that allows to use the charge voltage to U_0=70 kV. Sections are fixed by screws between three electrodes, thus on the central electrode moves the charge voltage from the HVS. Extreme electrodes fasten thirsts from plexiglas for the basis, in the formed gap are placed the recuperation circuit and the HVS protective resistor.

The recuperation circuit is used for more effective magnetic reversal of PT core, consists of four parallel branches, each of which contains the VD1 diode (SDL 0.4/160) and the inductance coil Lp (20 μH). The protective resistor is executed from

nichrome wire (500Ohm). The C0 condenser was charged from the HVS (production of JSC “Avangard”, Yekaterinburg). The source has remote control, output power 56kW at the voltage up to U_0=70kV. Capacity of the second stage C1 is equal 570pF and consists of four parallel sections from consistently switched on 14 UHV-9A condensers. Additional inductance is picked up experimentally (L=6μH), executed in the form of the flat spiral coil silt from sheet steel by thickness 2mm.
The semiconductor opening switch SOS contains two parallel branches from six consistently switched on SOS-180-4 diodes [2]. The block of the high-voltage pulse formation is placed in the tight metal case from carbonaceous steel which has an assembly window in 2/3 lateral faces, unlike the previous modification of the accelerator in which the cover was in all part. It allowed to facilitate a cover and to simplify its installation without use of load-lifting mechanisms. Besides the case has assembly hatches, for simplification of scheme elements installation inside. The internal volume of the case is reported with the atmosphere via the spherical crane closed at the movement, and the holder with silica gel.
The vacuum diode of the accelerator works with a pressure ~10^{-3} Pa, created by the vacuum diffusive pump NVD-250. The vacuum insulator of the diode is executed partitioned, with shielding dielectric surface by the acting skirts on gradient metal rings [8], and consists of 12 rings from plexiglas thickness near 30mm. For receiving the electron beam up to 400 mm wide is used the metal dielectric cathode from several emission elements (Fig.2) [9] with unevenness of electron beam current density distribution on the output foil ~ 15%. Which design was improved and allows to establish emission elements with a different frame space, depending on a necessary profile of electron beam current density distribution.
For the electron beam conclusion are used a final window of 450*10 mm, with a basic lattice from aluminum with transparency of 85%. On the lattice is keeping aluminum foil 50 microns thick within, on perimeter the lattice has the closed channel for water cooling.
For the mode of X-rays generator was created the convector which consists of an aluminum framework on which from the beam side is placed the tantalum plate 0,3mm thickness. For branch of a large number of heat forming when absorbing electron beam in a tantalum plate in an aluminum framework under it is arranged the cavity (depth 2mm and 120 mm wide) through which cooling liquid was pumped over. For reduction of X-rays radiation losses is made a reduction in the framework, and the total thickness of the aluminum design don't exceed 4mm in the beam zone.

Fig. 2. Metal dielectric cathode (200мм).

For voltage measurement on the vacuum diode was used the capacitive voltage divider CVD, thus the high-voltage shoulder of the divider was formed by the constructive capacity of vacuum insulator high-voltage part, and low-voltage was made of foiled fiber-glass plastic. Measurements of electron beam absorbed dose distribution in aluminum were taken by means of dosimetric films like SO PD(F)R-5/50 [10]. Detectors were placed at the distance of 5 cm from the vacuum diode output window behind aluminum foil layers of various thickness. Measurements were taken on 100 impulses given with a frequency of 1pps. The semiconductor detector (pin-diode) SKD1-02 which was installed at the distance of 100 mm and was used to power measurement of the X-rays absorbed dose (in the mode of the X-rays generator).
Experiments showed that linear dependence of voltage and the signal from the pin-diode remains in U_0=45-65kv range, thus voltage increases from 690 to 946kV, and the signal from the pin-diode with 2,8 to 4,6*10^4 Gy/s.
Results of accelerator tests showed that productivity of vacuum system was insufficient for long accelerators operation at big repetition rate (more than 50pps). It leads to critical falling of vacuum size at which there is a breakdown in gas vapors and electron beam generation is impossible. Carried out researches (including replacement of a vacuum insulator by an insulator of other design) showed that the main reasons for this phenomenon consists that pumping happened across the direction of the electron beam and unsuccessful geometry of high-voltage electrodes.

3. The Automated Monitoring System of Accelerator Parameters

The automated monitoring system of accelerator parameters is a subsystem of the mobile installation which contains 4 accelerators, 4 HVS (ИВН), operated by microcontrollers (МК), 4 vacuum systems (ВС). The block diagram of a control system by one of four accelerators is given in Fig. 3.

Management and control by all systems is exercised from the personal computer (ПК) connected to the control panel (ПУ) by means of the fiber-optical communication line 100 m long. The management and control program established on the personal computer, works under control of Windows 7 OS.

The ПУ distributes the teams arriving from the ПК to МК and the control units of vacuum systems (БУВС). МК carries out HVS inclusion/switching off, installation and voltage measurement and current. The high voltage moves to the accelerator on a high-voltage cable (ВН).

On command from the personal computer the microcontroller generates start pulses of TTL-level lasting 1μs with which arrival the shaper of start pulses (ФИ) forms the pulses with an amplitude of 2kV necessary for operation of thyratron. At the same time signals from sensors of the accelerator arrive on МК on the channel "Контр.".

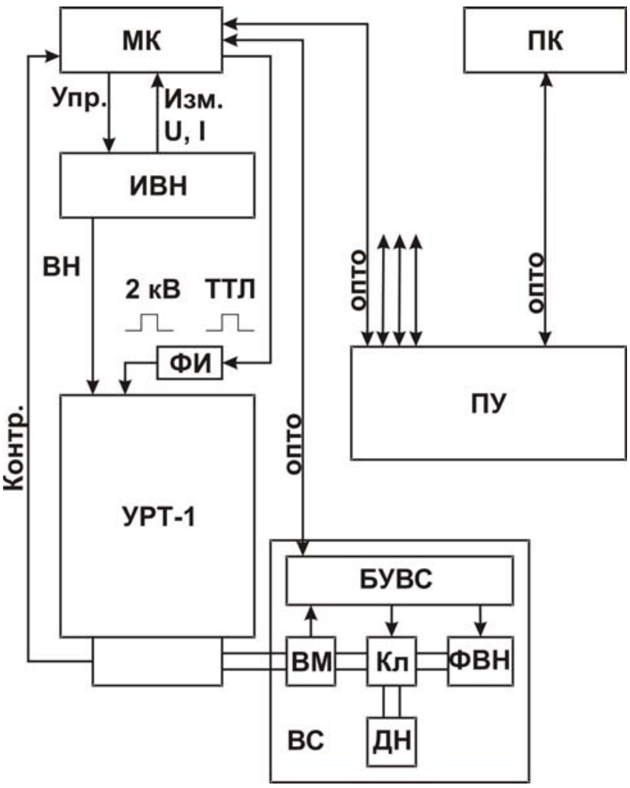

Fig.3. Complex control system

The card of the МК is also connected by the fiber-optical line with БУВС which exercises inclusion and control of operability of forvacuum (ФВН), diffusive (ДН) pumps, vacuum valves (Кл), and also a vacuum lock. Vacuum level is constantly measured by the vacuum gage (ВМ) information from which comes to БУВС.

Information on vacuum level, level of a high voltage, generation of pulses and on condition of all sensors comes to the program of management and control and registers in the text file.

Work is performed within a subject of the state order #0389-2014-0005 and with partial support of projects the Russian Foundation for basic research № 15-08-01381, № 12-03-31593 and № 13-03-00119 and Presidium Ural Branch Russian Academy of Sciences and Sverdlovskaya oblast Government (№13-08-96056, № 12-M-23-2007 and № 12-T-3-1009).

4. References

[1] S.Yu. Sokovnin, Nanosekundnye uskoriteli elektronov i radiatsionnye tekhnologii na ikh osnove Ross. Akad. Nauk (2007) ISBN 5-7691-1840-7

[2] S.N. Rukin *Instrum. Exper. Techn.* **42** (1999) 439.

[3] V.P. Pletnev, L.G. Filimonova, T.M. Nazarova, S.Yu. Sokovnin *Proc. 4th All_Russ. Conf. on Radiation Chemistry* (2005) 100.

[4] S.Yu. Sokovnin, M.E. Balezin, I.A. Buldakov, V.A. Skotnikov? S.V. Scherbinin *Izv. Vyssh. Uchebn. Zaved., Fiz.* **10/2** (2007) 188.

[5] M.E. Balezin, V.V. Bazarnyi, E.A. Karbovnichaya, S.Yu. Sokovnin *Nanotechnol. Russ..* **6** (2011) 757.

[6] S. Yu. Sokovnin, M. E. Balezina, and S. V. Shcherbinin *Prib. Tekh. Eksp.*, **56**, (2013) No. 4, 411.

[7] http://www.pulsetech.ru/thyratrons_rus.htm

[8] Yu.A. Kotov, A.L. Filatov, N.E. Rodionov, S. Yu. Sokovnin *Prib. Tekh. Eksp.* No. 2 (1986) 138.

[9] Yu.A. Kotov, S.Yu. Sokovnin, M.E. Balezin, *Instrum. Esper. Techn.* **43** (2000) 102.

[10] R.A. Abdulov, V.V. Generalova, M.N. Gurskii, A.A. Gromov, A.P. Zhanzhora, A.K. Pikaev, A.E. Sysyk *High Energy Chem.* **36** (2002) 22.