

Current status of DC high power ELV electron accelerators

Nikolay K. Kuksanov, Rustam A. Salimov, Sergey N. Fadeev, Petr I. Nemytov, Yury I. Golubenko, Alexey I. Korgachin, Alexandr V. Lavruchin, Alexey V. Semenov, Victor G. Cherepkov, Dmitry A. Kogut, Evgeny V. Domarov, Denis S. Vorobiev, Mikhail Golkovsky

ELV accelerators are widely used for electron beam processing. The ELV electron accelerators are DC machines purposed for wide application in various technological processes. BINP develops and manufactures high power electron accelerators for industrial application. The efficiency of substitution of electricity for electron beam power is also high. It was started in 1970-s. From that time over 170 accelerators were delivered both inside Russia and abroad. There are systems of ring and double side irradiation, 4-side irradiation system, extraction device for extraction of focused electron beam into atmosphere. We had developed and delivered accelerators for the tire industries. These accelerators have the energy of 0.3 – 0.5 MeV, up to 2 meters extraction device and beam current of over 130 mA. The new design of extraction device for the focused beam e was realized. The first device is already manufactured and is tested in different kind of experiments with extracted focused beam.

Keywords – ELV electron accelerators, tire industries, extraction devise, 4-side irradiation, extracted focused beam.

Introduction

ELV series electron accelerators are well known all over the world. ELV accelerators are about 15% of all accelerators which are used in industrial production. They were designed for industrial applications. That is why the attention was paid not only to the parameters but also to the operational characteristics: ease of operation, availability of the elements base, reliability in operation. Since 1973, more than 170 accelerators have been supplied to the Customers [1]. 120 of them are still in operation. The average service life of the accelerator exceeds 20 years. ELV accelerators are widely used in radiation-chemical technologies. Just in this field they received wide recognition. ELV accelerators are used in almost all industrial technologies where an electron beam is used. The main application is electron-beam modifications of polymers: cable insulation, heat shrinkable tapes and tubes, foamed polyethylene, component processing for automobile tires production. Specific machines were used for sterilization, grain disinsectization and for environmental technologies. A significant number of accelerators were used in scientific organizations for testing the electron-beam technologies. Fig. 1 and Fig. 2 shows the accelerator appearance and the

technological unit for cable insulation treatment.



Fig. 1. ELV-8 accelerator has max. energy 2.5 MeV and max. beam power 100 kW.

To date, the design of ELV is quite stable and the changes concern mainly to the elements base updating, improving the quality of electron beam processing (replacing high-voltage diodes and capacitors, changing the operating frequency, 4-sided

and circular irradiation systems, under-beam transport systems).



Fig. 2. The cable treatment with ELV accelerator.

Accelerators with the foil window

Almost all accelerators meant for radiation technologies use an extraction device with a window made of titanium foil. The maximum current density in such a window is $200 \mu\text{A}/\text{cm}^2$, the operating value is $100 \mu\text{A}/\text{cm}^2$. Especially impressive the treatment of cable. The accelerator and technology are adapted each other so that allows to treat the 4 cables simultaneously (so called 4 in – 4 out). The integral speed of treatment for some cables can achieve 2000 m/min or 2500 km/day per 1 accelerator.

Due to the increasing demand for the processing of automobile tires components, it has become necessary to complete the accelerators with local radiation protection.



Fig. 3. Treatment of cord base for automobile tire with ELV accelerator. Width of tape is 1400 mm.

This is quite simple, because for this technology the accelerators with an energy range of 0.3 - 0.5 MeV are required. The installation is quite compact and

easily fits into the production line complex. The Fig. 3 and Fig. 4 show the installation of electron beam treatment of the cord tape used in the tires production in China.



Fig. 4. Accelerator with steel local shielding in technological line. The dimensions are $6 \times 6 \times 6.5 \text{ m}$ and weight is 45 Ton.



Fig. 5. Accelerator with conveyor and a concrete stationary shielding in South Korea company EB-TECH.

Accelerators with the foil window

Together with the development of the extraction device with a window made of titanium foil for ELV accelerators, a device meant for the focused beam extraction into the atmosphere was developed [2]. The electron beam in this case is a highly concentrated source of energy. For this purpose, a multi-stage differential pumping system was used. The vacuum in the chambers is carried out by continuously operating vacuum pumps. By means of a number of such chambers, the pressure decreases step by step from the atmospheric (or other high pressure of the gas medium) to the working pressure of the accelerating device (10^{-6} torr). The electron beam in the extraction device is focused by the separated magnetic lenses. In

1975, the first similar extraction device was installed at ELV-4 accelerator with electron energy of up to 1.5 MeV and a beam power of up to 40. The beam size at the exit from the accelerator was about 0.8 mm with an effective emittance of $\sim 10^{-2}$ cm*rad. The electron energy pulsations were no more than $\pm 2.5\%$. The diaphragms service life was determined by the increase of diaphragm holes size, associated directly with the beam arrival onto diaphragm, and indirectly with the action of a high-temperature of gas stream flowing from the atmosphere aggressive beam impact products (ozone, sprays of molten processed material, etc.), the number of accelerator start up (process stabilization). The duration of work was on an average:

- no more than 20 hours with a beam power up to 20 kW and number of start up of more than 20;
- 10 hours at a power of 20 – 40 kW and the number of start up of up to 20;

In the Institute of Nuclear Physics, the experiments on the influence of the focused electron beam onto various materials (metals and alloys, rocks, ceramics, plastics, etc.) extracted into gas at the atmospheric pressure were performed [3]. Also, technological experiments (nonvacuum electron beam welding, quenching [4-6], surfacing [7, 8], rocks, etc.) were made. Electron beam was extracted into the air, argon, helium. After the performance of the experiment in BINP, the accelerators with this extraction device were delivered to the Institute of Mining, to the Institute of Nitrogen Industry, the “Giprocement” Institute, to the metallurgical enterprises in Dnepropetrovsk and Lipetsk. All these facilities were of laboratory level and meant for experimental works.

The existing interest to the focused beam extracted into the atmosphere demanded to outline the ways of improving the extraction device and the pumping means for the focused electron beam extraction, as well as to increase the requirements to the beam formation at the accelerator output. Namely, to reduce the effect of transverse magnetic fields in the acceleration track, to reduce energy pulsations, to reduce the emittance of the beam. The modification works on the extraction device meant for the focused beam extraction into the atmosphere were continued. In 1985 the ELV-6 electron accelerator with electron energy of up to 1.4 MeV and the maximum power in the beam of 100 kW equipped with a modernized system of focused beam extraction into the atmosphere was put into operation (Fig. 5).

General view of the device for focused electron beam extraction into the atmosphere from ELV-6 accelerator is shown in Fig. 6.

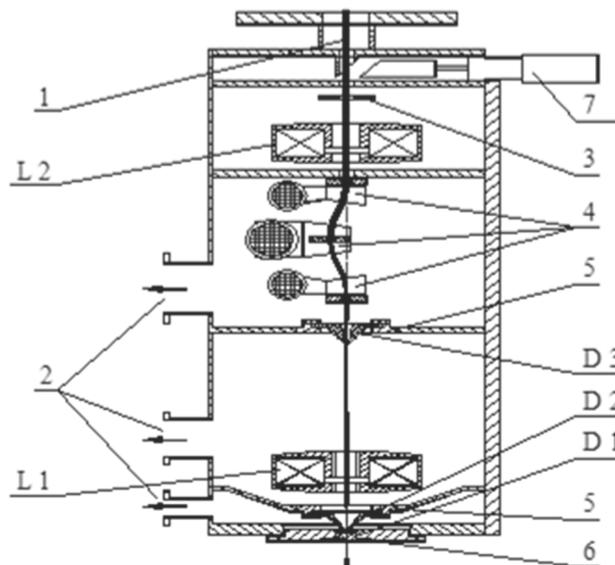


Fig. 6. The drawing of extraction device for focused beam L2 – magnet lenses; D1, D2 and D3 – diaphragms; 1 – beam profile; 2 – flange for vacuum quid; 3 – measuring diaphragm; 4 – shift of beam; 5 – insulators of diaphragms; 6 – slot nozzle, 7 – gate valve.

During extraction device operation in modes of the melting and evaporation of various metals, their alloys, as well as high-temperature oxides and carbides, the penetration of fine particles of the treated substance into the differential pumping system is possible. To prevent the processed material particles penetration into accelerating tube double parallel transfer of the beam returning it to the axis and slot nozzle located below the extraction device are provided. Such an airflow was enough to eliminate the penetration of foreign particles (processing products) into the beam extraction system and to ensure its trouble-free operation. At the same time, the stream of the nozzle increases the life of the diaphragms of the extraction device, protecting them from the influence of a high-temperature gas stream of the hot target.

During many years of the operation of the extraction device with a focused electron beam extracted into the atmosphere the possibility of long-term (several thousand hours) failure-free operation of the device was established at the beam powers up to the limit with unlimited number of start-up and shut-off of the electron beam. The principal possibility of using the devices of this type meant for extraction of electron beams of up to 100 kW power into the atmosphere under the conditions close to the industrial ones was shown. Run-to-Failure can reach several thousand hours, which is comparable to the operation times of similar foil equipment. The main parameters of the focused beam extraction system are:

- the maximum beam power in the stationary mode of the system operation is 100 kW;
- the range of accelerated electrons energies is 0.8–1.4 MeV;
- number of stages of the differential pumping system is 3;
- the maximum hole size in the first diaphragm of the extraction device after operation with a beam of more than 2000 hours is no more than 2.5 mm.

The accelerators are continuously operating from 1989 to the present. It had the status of a unique scientific installation. At this installation: accelerator with a modernized system of focused beam extraction into the atmosphere, together with the representatives of various Soviet, Russian and foreign organizations, numerous experiments on the use of such a beam in technological processes were performed. In particular, the technological modes were perfected. Valuable scientific results in steel products hardening (including the hardening of the railway rails lateral surfaces, which later had passed the verification nature tests at the East Siberian Railway [4, 5] and showed their high capacity); surfacing of the wear-resistant coatings onto metal substrates (including surfacing of wear-resistant coatings onto copper plates of the crystallizers of steel continuous casting plant and two-layers materials on titanium basis with anti-corrosive coating [13, 14]) were obtained. High power focused electron beam was used as heat source for testing the carbon target for prototype of the high-power production target for the Fast Rear Ion Beam (FRIB) [9, 10]. Various experiments were carried out for radiation-thermal processes in the field of chemistry of solids (including the technology of obtaining a cheap highly active ammonia synthesis catalyst from catalyst production wastes). High-performance practice of obtaining nanopowders of metals and their oxides, as well as silicon oxide by means of its direct evaporation from the melt were developed and put into practice. Successful experiments on thermal testing and heating of graphite target prototypes meant for the facilities of rare isotopes beams receiving at FRIB (University of Michigan, USA) and under the European project EURISOL, as well as other high-temperature technological processes were performed. In spite of the intensive loading of the experimental stand, there was practically no real need of such machines for 30 years.

New design of extraction device for focused beam

Recently, in connection with the interest in the method of obtaining nanopowders by means of evaporation, there emerged a need for accelerators with focused beam extraction into the atmosphere. Therefore, we decided once again to revise the design of the extraction device, having in mind that over the past time, both accelerators and pumping facilities have changed constructively, for example, turbomolecular pumps have appeared. In the accelerator, instead of an accelerating tube with permanent magnets, an accelerating tube with a large aperture is used. The new tube is easier to manufacture and has better operational parameters, and the technology of old tubes manufacturing has not been used for 25 years and now it is lost. The beam parameters at the tubes output are completely different.

The design of the extraction device and the selection of pumping equipment were determined for the ease of service convenience and operational reliability when operating not in laboratory conditions but in the Customer's industrial and semi-industrial production. In accordance with this, the main criteria in the development were not only the obtaining of limit parameters and minimization of pumping equipment, but the simplicity of the design and optimization of the vacuum pumps.

The aperture of the new tubes is 100 mm and the beam is moving almost the whole time in a uniform electric field, and its parameters at the tube output are: beam size D and divergence α are determined only by the distribution of the electric field near the cathode. The problem is complicated by the fact that the potential distribution near the cathode electrode forms the minimum of the potential, the so-called electrical gate, which prevents particles, being produced as a result of secondary ion-electron emission, entering into the tube aperture. This distribution has a strong focusing and should be taken into account.

The electron emitter is a LaB6 tablet, the heater is a cylindrical spiral (like solenoid) made of tungsten wire. On the tablet surface there is a magnetic field of about 10 Gs, which gives to the electrons moving at the edge of the beam an azimuthal impulse of 5 Gs*cm. It is equal the impulse of an electron accelerated to 2.5 V. As a result, at the tube output, the beam has an angle of about 10^{-3} rad and an emittance of 1.5×10^{-3} rad*cm. The cathode operates in the mode of selection of the total emission current, i.e. the beam current value is determined by the cathode temperature. In order to reduce the influence of the

space charge, the perveance of the injector is chosen to be high, i.e. the current defined by the law $3/2$ is much greater than the working current of the emitter. To measure the beam parameters (D and α , emittance), the installation which made it possible to do it was assembled at ELV-4 accelerator. The electron beam was not extracted into the atmosphere, but was taken onto the vacuum target with a circular scanning. The cooling mode made it possible to receive an electron beam with a power of no more than 50 kW onto this target. Within a few days, the system was set up and through the estimated diaphragms the beam passed almost without deposition at a power of 50 kW at 1.5 MeV. This was in August 2017. Measured results, at least in qualitative terms, fitted with the calculations.

According to these measurements, the extraction device, which can be installed at ELV accelerator having a tube with a large aperture, was designed and manufactured (Fig. 7). At that time we have no possibility to install new extraction device exactly on ELV-4 accelerator with accelerating tube with large aperture. So we installed the new extraction device onto ELV-6 accelerator with an old tube.

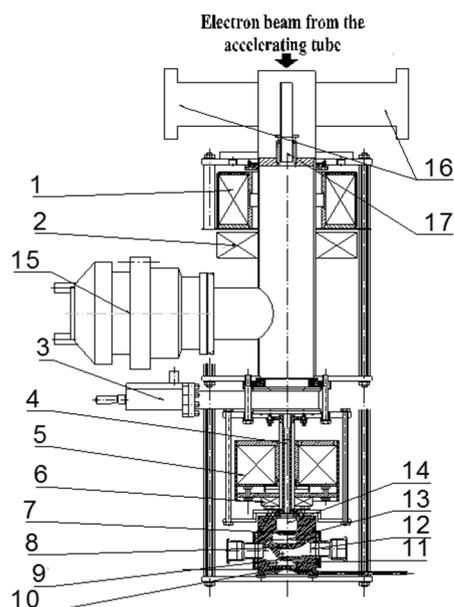


Fig. 7. The drawing with new design of extraction device for focused beam 1 – magnet lens; 2 – correction coil; 3 – gate valve; 4 diaphragm; 5 – magnet lens; 6 – correction coil; 7, 8, 9, 10 – diaphragms; 11, 12, 13, 14 – vacuum flanges; 15 – turbomolecular pump, 16 – flange for pumping.

The output of tube was modified. The old extraction device was conserved. In a short time, the beam was extracted into the atmosphere onto the target located 1 m from the extraction device. The

quite steady operation at a beam power of 70 kW and a short-term operation at a power of 100 kW were achieved. In the new design, the size of the extraction device has been reduced by the factor of 3 by means of the improvement of some operational parameters, such as current deposition at the diaphragms and vacuum in the pumping stages. At present, the installation for silica nanopowder (sand) production is operating at this beam.

Conclusions

ELV accelerators are adapted for industrial and research application. The set of the extraction and supplementary devices makes possible all existing electron beam technologies.

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Prof. PhD Nikolay K. Kuksanov - Main researcher of DC accelerator laboratory of BINP.

Tel: +7 383 3294365, +7 9139489705;

e-mail: kuksanov47@mail.ru

adress: BINP, 11, ac. Lavrentiev av., Novosibirsk 630090, Russia

Prof. PhD Rustam A. Salimov - Main researcher of DC accelerator laboratory of BINP.

PhD Sergey N. Fadeev - Head of DC accelerator laboratory of BINP.

Tel: +7 383 3294434, +7 9138942393;

e-mail: Fadeev1960@mail.ru

adress: BINP, 11, ac. Lavrentiev av., Novosibirsk 630090, Russia

Prof. PhD Petr I. Nemytov - Leading researcher of DC accelerator laboratory of BINP.

Yury I. Golubenko Leading - researcher of DC accelerator laboratory of BINP.

PhD Alexey I. Корчагин - Senior researcher of DC accelerator laboratory of BINP.

Alexandr V. Lavruchin - researcher of DC accelerator laboratory of BINP.

Alexey V. Semenov - researcher of DC accelerator laboratory of BINP.

Dmitry A. Kogut - researcher of DC accelerator laboratory of BINP.

Evgeny V. Domarov - researcher of DC accelerator laboratory of BINP.

Denis S. Vorobiev - researcher of DC accelerator laboratory of BINP.

PhD Victor G. Cherepkov - Senior researcher of DC accelerator laboratory of BINP.