DEVELOPMENT OF ACCELERATOR FACILITIES AT SSC RF – IPPE

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Abstract

Short overview of status and operation of accelerator facilities of the SSC RF – IPPE for various applications in nuclear science and technologies is given. Some results obtained as well as prospect of development of the accelerator facilities are described.

INTRODUCTION

An infrastructure for experimental research in nuclear physics based on high-voltage accelerators has been developed at the SSC RF-IPPE for more than half a century. The results obtained have made significant contribution to the solution to problems of fission physics, solid-state physics and studies of materials under radiation, as well as to the build-up of nuclear data for development of fast neutron reactors and to some other fields of basic and applied research.

At the present time scientific research on the accelerators at the SSC RF-IPPE is carried out in the following main fields:

- Low and intermediate energy nuclear physics. Nuclear data for nuclear power engineering. Closed fuel cycle. Safe handling of radioactive waste and spent fuel [1-4].
- Solid state physics. Physics of radiation damage and studies of materials under radiation [5-7].
- Nuclear microanalysis. Analysis of composition and structure of materials [8-10].
- Basic research on dusty plasma physics [11-13].
- Development of technology of membranes [14].
- Nuclear medicine [15-16].

Experimental facilities based on six electrostatic accelerators were constructed at the institute. The EGP-15 tandem accelerator (Fig. 1), the largest electrostatic accelerator in Russia, is among those six machines. This tandem accelerator was designed and manufactured at the Institute for Physics and Power Engineering in close cooperation with many Russian scientific organizations.

The accelerator facilities provide a wide spectrum of species of accelerated ions (H, He, Li, C, O, F, Al, Si, Cl, Fe, Ni, Zr) formed in the continuous or pulsed ion beams with current in the range 10^{-8} A to 10^{-3} A and energy varying from several hundred keV to tens of MeV. The main operational characteristics of the accelerators are given in Table 1.

The following factors determining interest in electrostatic accelerators can be mentioned among the others:

- high uniformity of energy of accelerated beam;
- broad range of accelerated ions;
- possibility of quick alteration of species of accelerated particles;
- intensity of ion beams produced at the accelerators of this type are in the range 10^{-8} A to 10^{-3} A;

Figure 1: The EGP-15 tandem electrostatic accelerator.

Table 1. The main operating characteristics of accelerator facilities of the SSC RF-IPPE

Model	**Ion Energy, MeV**	**Ion species**	**Beam Mode**	**Beam Current μA**
EG-2.5	0.2÷3.1	P, D	continuous	0.1÷30
		He, N, Ar, O		0.01÷10
EG-1	0.9÷4.5	P, D	continuous	1.0÷20
			pulsed	2000
KG-2.5	0.3÷2.2	P, D	continuous	100÷2000
EGP-15	4÷12 (P)	P, D	continuous	5
			pulsed	400
		heavy ions	continuous	0.01÷1.0
EGP-10 (temporarily closed)	3.5÷9.0	P, D	continuous	0.01÷10
			pulsed	400
KG-0.3 (temporarily closed)	0.3	P, D	continuous	10÷2000
			pulsed	5000

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- smooth adjustment of energy of accelerated ions from several hundred keV to several tens of MeV;
- simplicity of service, reliability, small energy consumption (power consumption - some tens of kW).

Wide use of these accelerators in the world as tools for basic and applied research, as well as for beam technologies is caused by the features mentioned above.

Ion sources of various types, accelerating tubes, charging systems, ion-optical devices, high voltage power supplies, special electronic systems for the accelerators, as well as beam control instruments were developed and implemented at the accelerator facilities of the Institute for Physics and Power Engineering. Vacuum systems, beam lines and cooling systems of the accelerators were upgraded. Many of the developments are protected by copyright certificates and patents.

ACCELERATING TUBES FOR ELECTROSTATIC ACCELERATORS

Research-and-development activities aimed at designing, production and comprehensive studies of the accelerating tubes for the electrostatic accelerators have been carried out at the Institute for Physics and Power

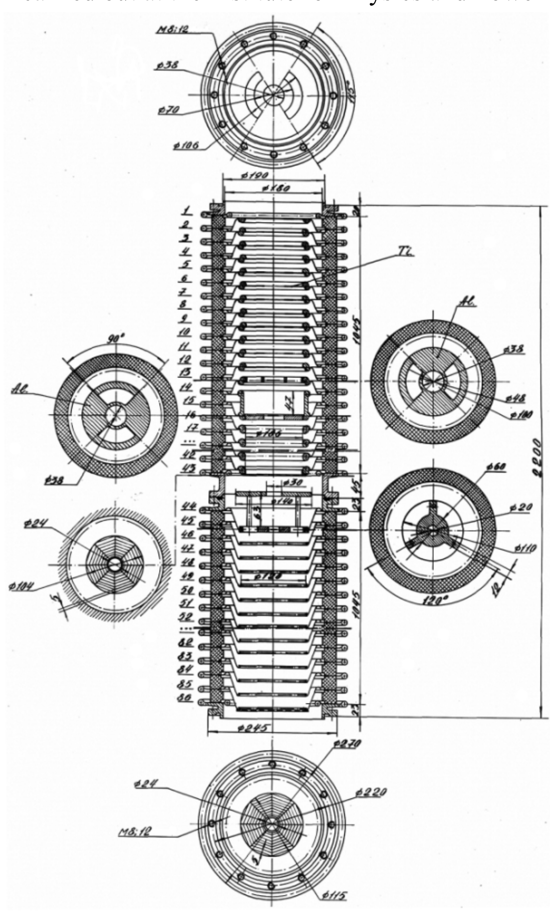

Figure 2: Design of accelerating tube of the EG-2.5 electrostatic accelerator.

Engineering for more than 50 years. For many years of research, development and operation of the accelerating tubes a wide range of activities was fulfilled, including:

- identification of features of discharge processes determining the level of electric strength of the individual accelerating gaps and accelerating tubes in general;
- development of techniques of high-voltage tests of accelerating gaps;
- development of method of manufacture of accelerating tubes;
- elaboration of the criteria of electric strength that must be taken into account in the manufacturing of accelerating tubes designed for operating gradient over 1.2 MV/m;
- studies of the gaps of accelerating tubes depending on surface area and the shape of electrodes, as well as material of insulating rings and the shape of their vacuum-side surface;
- development of ion-optical calculation techniques as applied to the accelerating tubes with straight and inclined fields;
- calculation analysis of dynamics of multiply charged heavy ions in the inclined field accelerating tubes of the tandem accelerators;
- development of various designs of the accelerating tubes with straight and inclined fields, as well as their full-scale testing.

A design of the accelerating tube of the EG-2.5 electrostatic accelerator is shown in Fig. 2 as an example of the developments carried out at the Institute for Physics and Power Engineering.

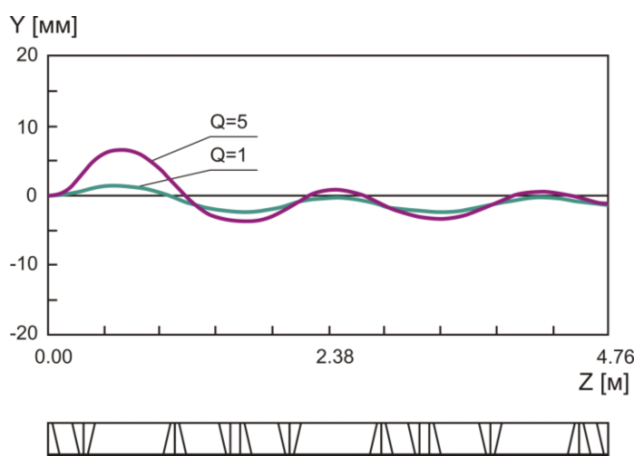

Figure 3: Trajectories of ions with charge states of 1 and 5 in high-energy inclined field tube of the EGP-15 tandem accelerator.

Fig. 3 shows the motion of multiply charged heavy ions in the inclined field tube of the EGP-15 tandem accelerator. This accelerating tube was designed and produced at the SSC RF-IPPE as well. A feature of the inclined field accelerating tubes in the mode of acceleration of multiply charged heavy ions is dispersion of the ion trajectories depending on their charges. The dispersion is caused by change of the ion charges from -e

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to +Qe occurring in the stripper. An electrode structure for the inclined field tube of the EGP-15 tandem accelerator making it possible to minimize the dispersion of ion beams with different charge states was selected on the basis of calculation results [17].

CHARGING SYSTEMS FOR ELECTROSTATIC ACCELERATORS

Until recently, one of the most unreliable units of the electrostatic accelerators was the charging system based on the belt conveyor of charges. The main disadvantages of the previous charging belts were their short lifetime and high degree of wear of the working surface. Limited lifetime of the belt prevented from efficient use of the expensive equipment and resulted in additional costs of purchase of the insulating gas mixture. Increased wear of the belt led to the dust pollution of insulating gas and elements of the high-voltage structure that caused significant decrease of electric strength of the accelerator.

Activities aimed at development of the reliable belt conveyor of charges for the electrostatic accelerators have been carried out at the SSC RF – IPPE for many years. Previously used belts produced on the basis of cotton fabric had short lifetime (300-1000 hours) and high degree of wear of the rubber coating. Many types of synthetic and cotton fabrics, as well as their various combinations have been tested.

The new KBN-1591-RD conveyor of charges produced on the basis of combined polyester cotton fabric with the use of butadiene-nitrile rubber was developed in cooperation with the experts of JSC "Jaroslavrezinotehnika" [18]. This belt conveyor of charges is characterized by high electrical and mechanical properties and high wear-resistance. Production of two-layer and four-layer belts with thickness from 1.2 mm to 3 mm and width up to 800 mm has been organized. The lifetime of belt conveyors of this type is more than 10000 hours.

HIGH-VOLTAGE STRUCTURES

A computer code for optimization of high-voltage accelerator structures was developed at the Accelerator department of the SSC RF – IPPE [19-24]. The "Modulus of electric strength" calculation model now in use allows finding the breakdown voltage of elements of rather complicated systems such as accelerators solely by analytical techniques. The model has no analogs in the world practice in terms of simplicity and calculation accuracy (2-3%).

Upgrade of the high-voltage structures of the EG-2.5 electrostatic accelerator and the EGP-15 tandem accelerator was carried out on the basis of calculations. The modernized column of the EG-2.5 accelerator is shown in Fig. 4. Some results of high-voltage tests of the column are given in [24].

Operational voltage exceeding the nominal value by 24 % was achieved as a result of implementation of the "Twice orientated oval" engineering solution at the EG-2.5 accelerator.

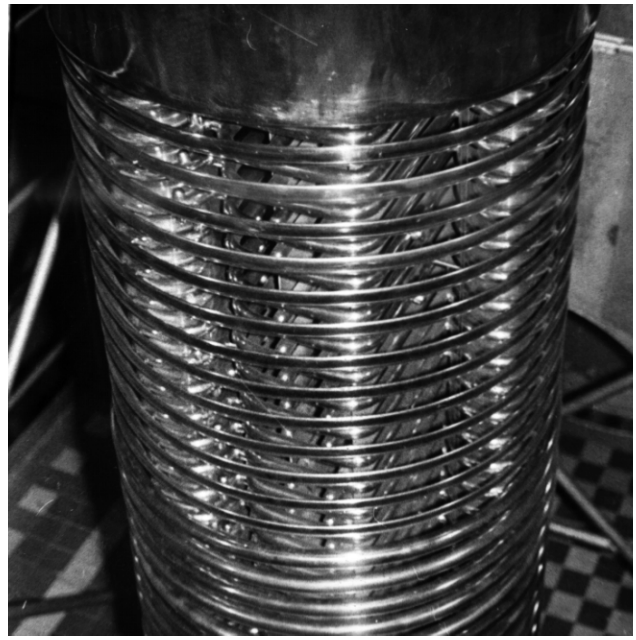

Figure 4: High-voltage column of the EG-2.5 electrostatic accelerator after upgrading.

ION SOURCES

Several designs of RF-ion sources developed at the Institute for Physics and Power Engineering are widely used at the electrostatic accelerators in Russia and abroad. The main features of these sources are low gas flow rate and high content of atomic ions (more than 80%) in the extracted beam. Characteristics of some RF-ion sources designed at the institute are given in Table 2.

Table 2. Characteristics of the RF-ion sources

Model #	Beam Current, μA	Gas Flow Rate, cm^3/h	Cathode Lifetime, h
1	200	1.5	1000
2	2000	2.5	500

The MISS-790 Cs-sputter negative-ion source designed at Helmholtz-Zentrum Dresden-Rossendor, Germany is used at the EGP-15 tandem electrostatic accelerator to produce negatively charged heavy ion beams.

To ensure required energy of injection of the negative ion beams into the EGP-15 tandem accelerator, a pre-acceleration tube with improved electric strength of the vacuum insulation was designed and manufactured at the SSC RF – IPPE. In spite of the possibility of penetration of cesium vapour to vacuum volume of pre-acceleration tube from working chamber of the ion source, the tube is able to withstand required high-voltage for the long period of time.

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ION OPTICS AND BEAM TRANSPORT

Work performed at the SSC RF – IPPE in the field of ion optics and charged beam transport reflects the specifics of high-voltage accelerators, namely: a) predominance of devices in which static fields are used for acceleration, focussing and transport of charged beams; b) close interrelation between the process of ion acceleration and phenomena in the accelerating channel leading to breakdown of vacuum electric strength of the accelerator; c) wide range of accelerated particles: from single-charged ions of the hydrogen isotopes to multiply charged heavy ions; d) need for efficient change of the acceleration mode (for example, change of ion species or beam energy).

In the framework of the research, analytical and numerical methods of computation of the straight and inclined field tubes were developed [17, 25]. The results obtained were used in designing, modernization and running of accelerating tubes of the accelerator facilities.

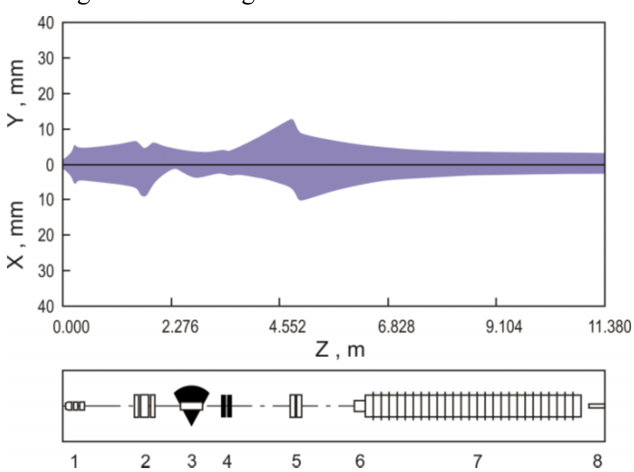

Figure 5: Beam envelopes in low-energy stage of the EGP-15 tandem accelerator calculated for Ni^- ions: 1 – ion source lens; 2 – electrostatic quadrupole triplet; 3 – magnetic analyzer; 4 – electromagnetic quadrupole doublet; 5 - electrostatic quadrupole doublet; 6 – gridded lens; 7 – accelerating tube; 8 – stripper.

Considerable attention was paid to the development of the system of injection of negatively charged heavy ions into the EGP-15 tandem accelerator. This accelerator was designed to accelerate the beams of light ions, first of all, ions of hydrogen isotopes. This circumstance, in particular, determines application of electromagnetic quadrupole lenses in the injection channel. During transition to the modes of acceleration of heavy ions, such as Ni ions, it was found that the optical power of the electromagnetic quadrupole lenses was insufficient to transport beams of singly charged negative heavy ions from the ion source to the entrance to the accelerating tube, as well as to ensure the appropriate conditions for matching of the injected beam to the accelerating channel.

The first stage of modernization of the injection channel including the replacement of two electromagnetic quadrupole lenses by the electrostatic quadrupoles was performed on the basis of the ion-optical calculations [26]. This, in particular, allowed increasing current of the beam injected into the accelerating tube from 2.5 μA to 7.0 μA and more for Ni^- ions and from 0.2 μA to 1.5 μA for ZrH^- ions. The calculated envelopes of the beam of negatively charged Ni ions in the injection channel and the low energy accelerating tube of the EGP-15 tandem accelerator are shown in Fig. 5.

In more detail this ion-optical studies (the calculation methods and their applications) are described in the papers [27-31].

PROSPECTS OF DEVELOPMENT OF THE ACCELERATOR FACILITIES

With a view to enhancement of the unique accelerator facilities it was decided to purchase a new commercially available tandem accelerator with potential of the high-voltage terminal up to 3.3 MV.

It is assumed that experimental research on nuclear physics, solid state physics, studies of materials under radiation, nuclear microanalysis and high-energy ion implantation will be carried out at this new accelerator.

To ensure optimal conditions of the experimental research the ion beams will be extracted to the existing experimental chamber of the KG-2.5 high-current cascade accelerator. This allows performing experiments on two ion beams obtained simultaneously from two accelerators.

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