DESIGN AND CONSTRUCTION OF TUBULAR ELECTRON STRING ION SOURCE *

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Abstract

The Electron String Ion Source (ESIS) developed at JINR is effectively used here during the last decade. The Tubular Electron String Ion Source (TESIS) has been put forward recently to obtain a 1-2 orders of magnitude increase in the ion output as compared with ESIS. The project is aimed at creating TESIS and studying the electron string in the tubular geometry. The new tubular source with a superconducting solenoid up to 5 T is under construction now. The method of the off axis TESIS ion extraction will be realized to get TESIS beam emittance comparable with ESIS emittance. It is expected that this new TESIS will meet all rigid conceptual and technological requirements and should provide an ion output approaching 10 mA of Ar^{16+} ions in the pulsed mode and about 10 μA of Ar^{16+} ions in the average current mode. Design, construction and test of separate TESIS systems are discussed in this report.

TUBULAR ELECTRON STRING ION SOURCE

The ESIS is based on a specially designed electron gun and an electron reflector that allows multiple uses of beam electrons [1-3]. At some conditions the electron string is formed with about few hundreds reflections for each electron. The electron string can be used for production of highly charged ions similarly to beam electrons. The interest in the ESIS mode was motivated by the attractive possibility of decreasing the electron beam power by a factor of 100 preserving simultaneously the same ion yield. The Krion-2 ESIS has been used successfully at the injection complex of JINR synchrotron Nuclotron for production of highly charged ion beams: Ar^{16+} - 200 μA, Fe^{24+} -150 μA in 8μs pulses (Table 1) [3]. It was found experimentally [1-3] that the maximum number of electrons N_e accumulated in a linear string was proportional to a confined magnetic field B to the third power:

$$N_e=\kappa B^3. \quad (1)$$

An increase in the magnetic field from 3T in Krion-2 to 5T in constructed Krion-5T (Fig.1) permits 4.5 times increases of the ion yield.

The idea of using TESIS was proposed in [4] to obtain a considerable increase of ion outputs (Table 1) in comparison with the ESIS and simultaneously a small ion beam emittance, usually provided by ESIS.

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Figure 1: Construction of the new JINR Krion 5T ion source at magnetic field of 5T.

Table 1. Parameters of electron string ion sources

Ion source	Krion-2	TESIS
Electron energy, keV	3÷5	3÷5
Number of stored electrons	$5\cdot10^{10}$	$3\cdot10^{12}$
Magnetic field, T	3	5
Ion current, mA	0.15	10
Pulse duration, μs	8÷∞	8÷∞
Maximal number of Ar^{16+} extracted ions	$5\cdot10^8$	$3\cdot10^{10}$
Ion extraction frequency, Hz	1	5
Average ion current, mA	0.15	10

The method of the off–axis TESIS ion extraction was proposed in [4-5] to get beam emittance comparable with ESIS one.

In fact, the number of produced ions is proportional to the number of the stored electrons and for a given source length it is proportional to the beam cross-section area. The ratio of the stored electrons/ions in the tubular source N_{TESIS} and in the solid cylindrical beam N_{ESIS} of the same length is $N_{TESIS}/N_{ESIS}\approx 4r/a \approx 25\div50$, where a is the radial electron beam thickness and r is the main radius for the tubular electron beam. Second crucial point is that the use of tubular geometry of drift tube structure allows avoiding the virtual cathode formation for the corresponding amount of accumulated electrons in comparison to the cylindrical drift tube structure.

EXPERIMENTS WITH QUASI-TUBULAR ELECTRON BEAMS

Experiments with quasi-tubular electron beams were performed on the modified ion source Krion-2. Eight electron guns were installed on equal radial distance but at different azimuthal angles along the circle in fringe magnetic field region (1/20 B). Each such IrCr emitter of 1 mm diameter injected a separate pencil beam towards uniform magnetic field region where tubular drift tube structure has been installed as well.

Annular repeller ring was installed at opposite side of the source mirror symmetrically to the gun geometry in respect to the centre of the solenoid. However only 4 holes in repeller were produced and 4 corresponding electron collectors behind them were installed.

The quasi-tubular electron beam has been formed by those 8 pencil azimuthally distinct electron emitters. Special electrodes were installed in the modified Krion-2 source to produce radial electric field leading to the azimuthal electron drift motion in the longitudinal uniform magnetic field.

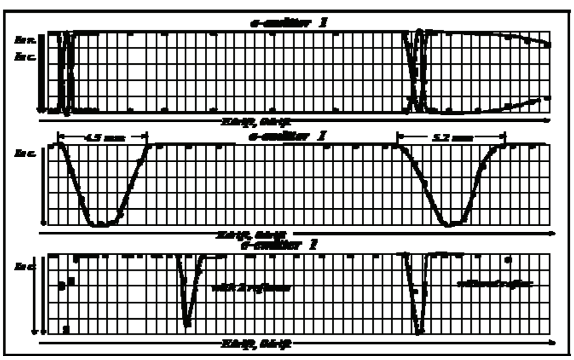

Figure 2: Dependences of collector and repeller currents on the radial electric field.

The electron beam widths are given in Fig. 2b for first and second collectors. They are equal to 4.5 mm in the first collector and 5.2 mm in the second one. The increase in the beam width in the second collector is due to the action of the large radial electric field of the drift electrodes together with the electron angle and energy spreads. The collector current of the pencil electron beam depends on the number of the reflections from repeller electrode and cathode. The collector current without reflection is 20% larger than its value after two reflections from the repeller electrode and the cathode.

The experiments in such set-up allowed to investigate dynamics of separate beams as well as to check effects related to the azimuthal asymmetry of the solenoid magnetic field and the azimuthal imperfection of the ion source mechanical constriction. The experimental results related to transportation of the pencil electron beams are given in Fig 2.

When the pencil electron beam is accepted by the collector the repeller current is became equal to zero. At variation of the radial electric field one can provide condition when the pencil electron beam is turned on azimuthal angle 90^0 by the drift electrodes and therefore it is collected by second collector (second peak in the Fig 2a).

The reflex mode of operation with a separate pencil electron beam in a tubular structure lead to transition linear electron string and accumulation of electrons up to 20 nC (Fig.3).

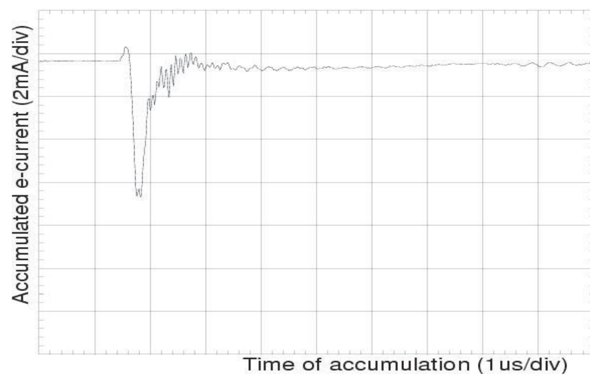

Figure 3: Accumulation of separate linear electron string in the tubular structure.

DESIGN OF TESIS KRION T1

The tubular electron string ion source [6-8] (Fig.4) consists cryomagnetic, electron-optical, ion-optical vacuum systems, power supplies, diagnostic and control electronics. The superconducting solenoid is fixed by two supports on the vacuum chamber.

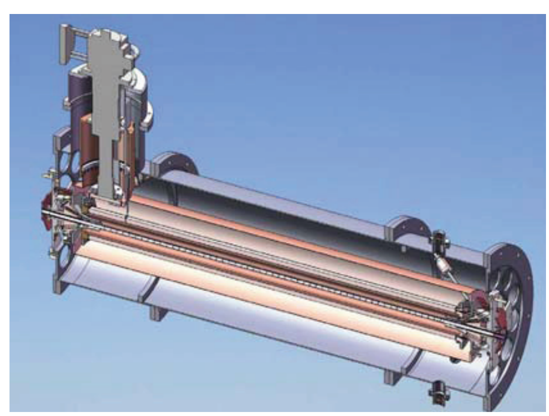

Figure 4: Common view of TESIS Krion T1.

Machine for TESIS solenoids coiling was manufactured in JINR (Fig.5). The process of coiling control can be manual, automatic and computer.

Figure 5: Machine for TESIS solenoids coiling.

The cryocooler head is placed at the edge of the cryostat part. The current loads, thermal shielding, superconducting keys, cooled diodes and resistors are placed between the cryocooler and the solenoid. The thermal shielding is connected with the first cryocooler section at the temperature of 4.2 K. The power of the first cryocooler section is 1.5 W. The temperature of the second cryocooler section is of 40 K. The electron gun, reflection electrodes and other elements have temperature from room to cathode temperature.

Ultrahigh vacuum of 10^{-9}–10^{-10} Pa is the a feature of the tubular electron string ion source. The choice of the vacuum system design is dictated by a small diameter of drift tubes (internal diameter is 0.9 cm, external one is 1.5 cm) which are 120 cm long. The cryo-pumping conception was adopted for TESIS. The external pumping provides preliminary pressure of 10^{-4} Pa and then an ultrahigh vacuum is achieved at cryosorption of surfaces cooled to temperatures of 4.2 K and 40 K.

The electron-optical and ion-optical systems is designed on the basis of the computer simulations. The electron gun has three electrodes. The diameter of the cathode emitter is 73.8 mm, its width is 1 mm. The suppressing electrodes are installed to suppress emission by the appropriate voltage. The gap between the annular emitter and the suppressing electrodes is 0.4 mm, the slit between the suppressing electrodes has radial width 1 mm. The cathode–anode gap corresponds to 10 mm. The chosen gun is an annular version of the Pierce-type on gun since the slopes of the focusing electrodes are 22.5^0 with the central magnetic flux line. The entrance anode diaphragm has a radial size of 4.5 mm that corresponds to an available aperture of the tubular string electrons in the ion confinement region of 1 mm. The anode diaphragm provides collection of the string electrons that leave the system in the radial direction due to electron scattering and diffusion.

The electron reflector was chosen to be mirror symmetrically with respect to the solenoid center. The orifice for ion extraction is foreseen to be arranged instead of the emitter at some azimuthal position of the reflector. The reflection voltage is chosen to be a few kV lower than the cathode voltage in order to ensure total reflection of the whole electron beam.

The drift tube structure consists of several electrodes which are used for production of ion traps, formation of a tubular ion beam, off-axis ion extraction, and observation by means of pick-up electrodes of processes related to the electron string and ion beam formation. The ion extraction channel runs along the magnetic flux line at a definite azimuthal angle. The azimuthal width of the extraction channel was optimally chosen to be 10^0. The extraction channel begins in the uniform magnetic field region and consists of several electrodes which follow the shape and size of the corresponding magnetic flux lines up to B_{min}. Azimuthal ion migration in a uniform field region naturally occurs due to drift motion of ions in the longitudinal magnetic and radial electrical fields. When ions approach the beginning of the extraction channel, they are reflected back to the uniform field region by the applied positive voltage, except those ions which are captured in the extraction channel. Ions in the extraction channel are azimuthally confined due to the potential well created everywhere along the extraction channel in the azimuthal direction. Moreover, ions are accelerated towards the extraction orifice in the weak magnetic field due to the gradual decrease in the applied potentials along the extraction channel. The electron reflector mounted at B_{min} reflects electrons and extracts ions. The extracted ion beam penetrates the orifice in the reflector placed at the same azimuthal position as the ion extraction channel. The extracted ion beam has an ellipsoidal shape with diameter 2 mm in the radial direction and diameter 8 mm in the azimuthal one. The radial and azimuthal emittances of the extracted ion beam accelerated to energy of eU_{ac} $=25\cdot Z$ keV are $\varepsilon_r \cong 5$ π·mm·mrad and $\varepsilon_\varphi \cong 20$ π·mm·mrad.

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