PARTICLE ACCELERATORS AND NUCLEAR REACTORS

# ELECTRON STRING ION SOURCES (ESIS) ELECTRONICS DEVELOPMENT

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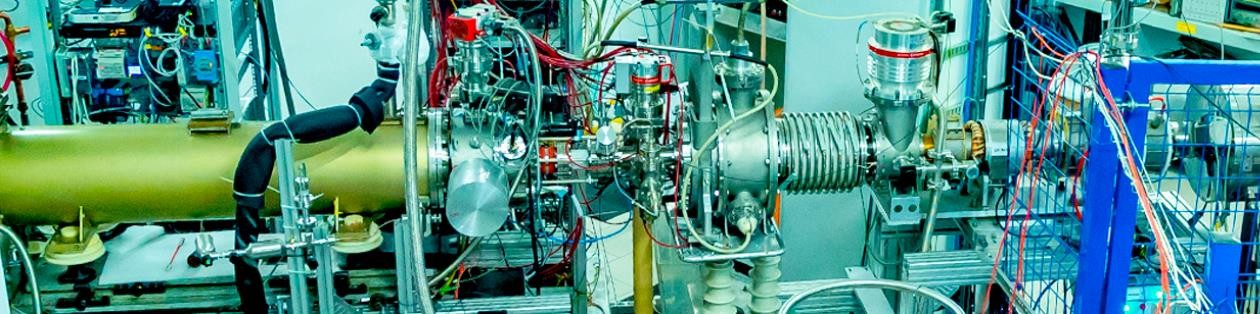
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**Abstract –** Electron String Ion Source (ESIS) is a type of ion source, which is under development since 1994 [1], when the electron string phenomenon was first observed at VBLHEP JINR. ESIS is a sophisticated modification of Electron Beam Ion Source (EBIS) working in a reflex mode of operation under specific conditions, when emitted electrons are multiply used for electron impact ionization, being transformed to a new steady state of a hot magnetically compressed plasma, called an «electron string». ESIS is a complex facility consisting of several systems: the superconducting solenoid, the cryogenic and vacuum systems, the electron gun, the electron reflector, the beam drift structure, the locking system, etc. To ensure the operation of these systems a special electronics and control systems developed by the engineers of the ESIS group are used. The article describes electron string ion sources measurement and control electronics and basic principles of their work.

## INTRODUCTION

The first ESIS KRION-2M was proposed, designed, produced and put into operation in the Laboratory of High Energy Physics of Joint Institute for Nuclear Research in Dubna by Prof. Evgeny Denisovich Donets (1935 - 2021) and his team; earlier Prof. E.D. Donets also invented EBIS and was one of the founders of highly charged ions sources physics [2]. In 2012, new KRION-6T ESIS was created and successfully commissioned. In the 55th Nuclotron run (February - April 2018) the C6+, Ar16+ and Kr26+ ion beams were produced, accelerated and used for physics experiments [3]. In April 2022, Krion-6T ESIS was installed on a HV platform of a new HILAC injector which is a part of a NICA/MPD [4] assembly which are under creation now at VBLHEP, JINR (Figure 1). Based on experience and experimental results with KRION-6T, ESIS a new ESIS KRION-N(ICA)1 for the NICA/MPD project at JINR is under development now.



ESIS KRION-6T \_

LEBT

RFQ LINAC

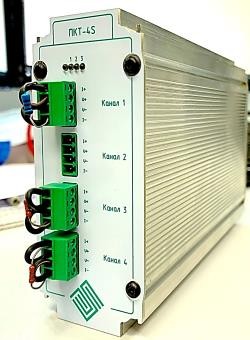
input

**FIGURE 1**. KRION-6T ESIS on a HV platform of a HILAC-NICA injector; October 2022.

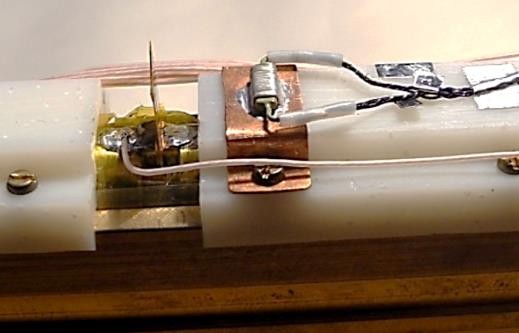
## ESIS ELECTRONICS

Globally, KRION electron string ion sources electronic systems and control systems can be classified into several parts – slow control system, electron gun supply electronics, ion motion and extraction control system, beam diagnostics. The slow control system combines the following monitoring and control elements: the magnetic optics; vacuum and temperature monitoring; emergency locking system, HV electrodes supply elements. Thermometry system is one of the most significant parts of the KRION-6T slow control system is a thermometry system. The source temperature monitoring necessity is caused by the fact that one of the main elements is a superconducting solenoid. A special measurement unit PKT-4 has been developed for these purposes (Figure 2). It includes the following functionality: PoE standard supply, Modbus RTU interface and onboard precision current source. The PKT-4 was used to monitor the cooling processes, maintain the superconductivity of the solenoid and its warming during the KRION-6T operation in the beam acceration runs.

* Measurement scale: 4 - 300 K;



**C**



**B**

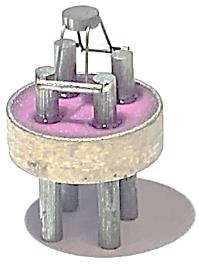
* Accuracy: ± 0,3 % up 30 K;
* Measurement channels: up to 4;
* ADC resolution: 24 bit;
* Meas.frequency: 1 Hz - 1 kHz;
* Onboard current source: 10, 100 uА;
* Current source accuracy: ± 0.1%;
* Supply: PoE or +24 V DC.

**A**

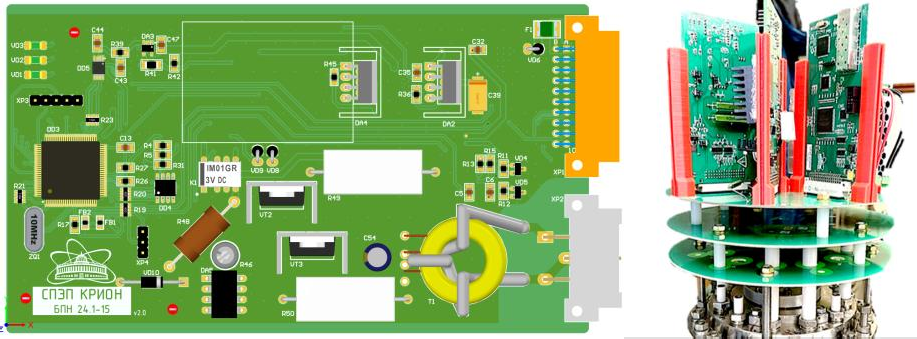
**FIGURE 2**. A) PKT-4S specification; B) cryogenic resistive temperature sensor TVO installation on the KRION-6T beam drift tube; C) PKT-4S temperature measurement module view.

Ionization of working species up to high charge states in Electron Beam/String Ion Sources (EBIS/ESIS) is provided by electron impact; a primary electron beam of a corresponding energy, compressed in a strong external solenoidal magnetic field, produced by an immersed electron gun containing a thermionic electron emitter assembly as its key element. Cathode assembly contains emitter itself (the cathode), false cathode, anode, power

supply unit and new special control and measurement electronic modules integrated into a complex control system (Figure 3).



**A**



**B**

**C**

**FIGURE 3**. ESIS electron gun supply elements:

1. IrCe electron emitter; B) emitter heating module PCB; C) cathode supply electronics assembly.

As the ESIS is a pulsed beam ion source, the electron emission is also a pulsed process, but according to the IrCe cathode operation feature it is not recommended to apply pulsed AC current. So, the current is applied to the emitter in a DC mode by a special electronic heating module (Figure 3B) and the electron emission is modulated by a special negative potential modulation electronic module, the element of the electron gun supply electronics [5].

Ions of working species are held inside a drift structure by positive potentials of an ion trap during ionization process. After ionization complete extraction of the high charge beam is provided by a high voltage (up to +3 kV) positive potential pulse applied to the certain beam drift tubes. All the ionization and extraction processes are provided by an ion motion and extraction control system (Figure 4) described in [6].



**B**

**FIGURE 4**. ESIS KRION-6T ion motion and extraction control system: A) assembly view;



**A**



Trigger pulse

+3 kV pulse

300 us

**C**

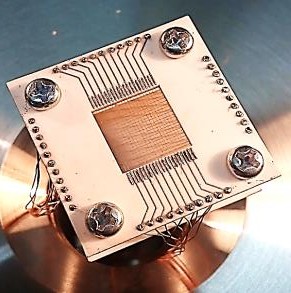
1. ion beam extraction PCB view; C) ion beam slow extraction positive pulse.

Designed electron and ion beam diagnostic system contains two measurement devices – unipolar precision ion beam size and position measurement and bipolar (electrons and ions

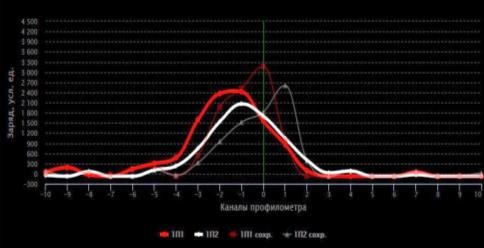
measurements). Beam profile measurements are based on a multi-wire beam monitor (Figure 5A, B) and the BPM v1.64 unipolar measurement modules. The BPM v1.64 module is multichannel, pulsed or DC low current positive charge signals measurement module based on precision analog integrator connected to the 14-bit ADC. The BPM v1.64 modules are used for the precision magnetic optics and the quadrupole deflector tuning in the KRION-6T external injection experiment, the Nuclotron injection channel tuning during the 55th run [7].



**A**



**B**



18Ar16+ 4 mm

**C**

**FIGURE 5**. The BPM v1.42/64 measurement module:

* 1. Beam profile monitor 3D model; B) beam profile monitor in assembly;

1. web-interface with measured ion beam profiles at the output of LU-20 LINAC.

Electron and ion beams actual size, position and total current are measured by the EBMM (Esis Beam Measurement Module, Figure 6B) module, which is 48-channel bipolar integrator. Beam charge collected by a sectional collector made of copper (Figure 6A) flows into input integrators feedback capacitors and causes output voltage signal proportional to the input charge. EBMM module used to accurately tune ESIS KRION-6T installed on the NICA injector during acceleration complex run in 2022/23 years, where 18Ar16+ and 54Xe28+ were accelerated.

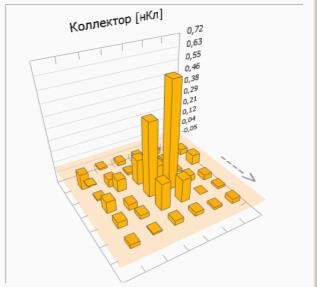


**A**

36 4x4 mm square



**B**



**C**

**FIGURE 6**. The EBMM measurement module:

1. Charge sectional collector; B) EBMM module front view; C) measured beam size and position 3D view.

## CONCLUSION

Described electronic systems provide ESIS reliable work at a test bench and also during NICA complex beam acceleration runs at LHEP JINR. All the systems as well as special software are still under development to ensure heavy ion NICA injector work. More detailed technical information can be found in articles presented at references.

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