Series of High Voltage Ion Accelerators for Use in Industrial Technological Lines

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Abstract

At INP there has been designed and is now under assembly and commissioning a series of high voltage ion accelerators including three variants, differing in energy and max current of single charged ions:

— at the range 100–300 keV, up to 5 mA, ION-300 installation;
— at the range 200–600 keV, up to 2 mA, ION-600 installation;
— at the range 500–1500 keV, up to 1 mA, ION-1500 installation.

The accelerators are equipped with oil-free vacuum, ion separation on the total energy, microcomputer (PC) control. A set of accessory sources provides for a wide ions spectrum. This series of the accelerators is distinguished for unification of main parts and units in all the variants. According to the type of the employed end station the ion accelerators can find application in microphotoelectronics, microelectronics, for modifying surfaces of materials and other purposes.

Budker Institute of Nuclear Physics (INP), Novosibirsk, Russia is involved with High Energy Physics, Plasma Physics and Particle Accelerators Physics including electron and ion accelerators for industry applications. In particularly, now INP is designing a new industrial particle accelerators set with common name "ION".

This paper is devoted to brief description of main features and essential distinctions of "ION" set.

1. SF_6 GAS INSULATION

A feature of IONs is the sulfur heksaftorid (SF_6) using for electric insulation goals. SF_6 not involves a chlorine and have no danger for the Earth ozone layer.

On installations having accelerating potential over 600 kV, we use SF_6 under a pressure of 0.5–1.2 MPa and on the 600 kV or lesser installations the pressure exceeded barometric in 5—70% used. The main advantage of SF_6 using is follows:

With barometric pressure of SF_6 the electric field breakdown threshold at least twice as much as the electric field breakdown threshold (EFBT) for dry air. Often the barometric pressure SF_6 using is economically efficient (if the insulation gap is comparable with the high voltage electrodes sizes, then the high voltage parts volume increases almost as the insulation gap in 3-rd power). The minor builded up pressure (0.11–0.18 MPa or 105—170% of barometric) using, allows to apply a cheap and lightweight pressure tanks, which not requires the State Safety Certification. With 1.7 atmospheres gas pressure, we have 4.25 times increased EFBT against air. In the ION-300 installation the insulating gap is only 6 cm on 300 kV voltage, having almost double techical excess of EFBT against calculated one. That design excess is useful, having in mind badly calculatable and predictable local electric field nonuniformity.

And on 1.5 MV potential with SF_6 pressure 1–1.2 MPa (10–12 atm) requires the 10 cm insulation gap (ION-1500 installation). The minimum insulation gap size exert main influence on sizes and cost of the high frequency power supply transmission system, which intended for the placed on high potential ion source power supplying.

The exposure of such harmful atmospheric factors as dust, humidity, oxygen etc. are hardly depressed.

The SF_6 convection cooling efficiency is 1.5–2 times as much as cooling efficiency of dry air, so the devices cooling problems (inside the gas tank) can be solved quite easier.

Disadvantages of SF_6 using:

The necessity exist to have air-tight case strong enough to withstand against the vacuum pumping.

The accessing time to the high voltage devices and ion source is substantially increased. The ion source service life requirements are critically increased (now we have a 10 mA ion source life time more than 120 hours). The reliability of an electronic equipment, especially a powerful, also should be raised. We had achieved the serious progress in the powerful electronic reliability and simplicity after change-over to the 20 kHz main high voltage terminal power supplying and wide using the nonlinear magnetic amplifiers and regulators.

2. HORIZONTAL LAYOUT

The "ION" installations set are characterized by the horizontal ion beam and main large-sized parts layout. The height of any installation not exceed 1.9 meters.

Horizontal layout gives a number of important advantages:

Processing advantage: quite lesser the contamination of the sample surface during the target ion bombardment.

The modular design and small height of installations allows free siting on practically any production area. Running technical service not requires the crane equipment and can be performed, as a rule, by one person walking on floor surface. All heavy-weighted installation parts can be easily moved along a rail track with one hand force.

3. THE MAIN HIGH VOLTAGE RECTIFIER USING 20 kHz POWER SUPPLY

In the ION accelerators we use the main high voltage rectifiers working on 20 kHz frequency power supply, excluding the ION-1500 which are supplying from electric motor-generator on 1 kHz frequency. The 20 kHz are supplying from the 3-phase powerful electronic generator, because the rectifier have 6-phase diode circuit. The rectified voltage ripple frequency with 3-phase supplying is 120 kHz (the full phase and voltage symmetry assumed), that allows to decrease significantly the rectifier column capacitors stored energy if loading current and voltage ripple is predefined. The small stored energy is important in connection with the accelerator tube service life, because the inevitable high voltage vacuum breakdowns leads to the insulators and metal electrodes degrading and the degrading rate is directly depend on a discharge energy dissipated.

The raised power supply frequency using also leads to the rectifier column weight reduction and simplifies the horizontal rectifier design. A rectifier assembled of the standard disk-shaped flat sections, which surrounded by polished metal rings. Each disc carry the set of high voltage capacitors, high voltage diodes, buffer and measuring resistors. To assemble some rectifier, the necessary number of discs must be threaded on carrying dielectric rods. High voltage rectifier and some other systems have some reserve on power and other parameters allowing to apply them in a new developments.

4. HIGH VOLTAGE TERMINAL HIGH FREQUENCY POWER SUPPLYING.

One of the essential features of the represented installations set is the high voltage terminal power supply system controlled independently of main rectifier supplying. The ion source regime is constant on any accelerating voltage varyations. Key point of that system is the 20 kHz frequency main power supply in combination with wide applying of non linear magnetic amplifiers and regulators. A powerful regulators, based on magnetic amplifiers, are characterized by high power efficiency (98% when output power is 1.5 kWt), high specific power (up to 3 kWt per kg) and an intrinsic abilities to stabilize, to limit output current (totally ignoring an output short circuits).

That system also organically include the subsystem of power supply (up to 2.5 kWt) across insulating gap. That subsystem include an electric resonant transformer (two part of it are separated by gas insulating gap and weighted only 4 kG) and works on the same main frequency. Both, the first and second coils of the transformer in combination with capacitors are the two high Q-factor resonant circuit. Coils have small magnetic coupling coefficient about 0.1–0.3. We use the round transformer coils measures 22 cm diameter and 3 cm high. When the gap between coils is 6 cm then the legal transferring power is up to 2.5 kWt, with energetic efficiency factor 0.9–0.97.

5. ORGANIC-FREE ACCELERATION TUBE

An acceleration tube assembled of alternating ceramic and metal rings joined together by diffusion soldering. That way the tube assembly have the minimum of the organic contaminants and significantly increase it Electric Field Breakdown Threshold (EFBT) and especially improve the ability to withstand against number of the partial and full electrical breakdowns without a pronounced decreasing of EFBT.

6. THE CHEVRON-SHAPED ACCELERATION TUBE ELECTRODES

The inner metal electrodes of acceleration tube which are forming the accelerating electric field, have a chevron-shaped form (close to the mediate diameter circle). The geometry is such, that the tube ceramic insulators surface are beyond the line-of-sight from the point of view of the ion beam area. If so, then UV light (produced by the residual gas and beam interaction) can reach to insulator surface not by direct way but scattered only. That result in decreasing the surface charges photo-generation and, consequently in increasing of EFBT. The surface contamination by residual gas fragments (broken by the high energy ions) is decreasing also. That contamination also will lead gradually to EFBT decreasing.

7. OIL-FREE PUMPING

The accelerators pumping system is made with turbomolecular pumps. Supporting mechanical forevacuum pumps are separated from a high vacuum areas by the gas traps (cooled by liquid nitrogen).

8. SEPARATION OF COMPLETELY ACCELERATED IONS

To purify the ion beam from impurities, we use the magnetic separator and the separation take place at the full ion energy. Disadvantages of that scheme are some full ion amperage increasing (travelling through accelerating tube), the main rectifier load increasing and the separating magnet power consumption is greater. Now we have the ion sources with the useful type ions yield up to 70—80%.

Alternative scheme with a small energy ions separation and further acceleration have a disadvantages against scheme using by us: the significantly greater power needed to transfer up to high potential (for magnet supply) and magnet cooling needed also. And due to a wide spectrum of the contaminating ions appearing inside accelerating tube (in beam to residual gas interactions), the full energy finish separation will be required in any case (if high purity beam needed).

9. DISTRIBUTED COMPUTER CONTROL SYSTEM AND OPTICAL FIBER LINK

Computer control system for the "ION" set of installations is designed specially for physical installations with high level of the powerful interference electric pulses (in particularly, appearing due to high voltage breakdowns) and for installations having complicated subsystems insulated on potential up to 2 MV.

Control system is distributed: it consist of central computer IBM PC XT/AT type and 3–6 intellectual universal control station (having all main functions needed). Each local station directly control one of the functionally or geographically separated subsystem (on high potential placed too). All control stations are connected with central computer by the duplex optical fiber link. The program in central computer consist of several program processes, running independently by time sharing program system. The central process, so called "manager", control the peripheral processes and each of it control one physical subsystem.

The control station processor placed on single board module and have a functionally full set of input/output units (32 double wired ADC's, 6 DAC's, 32 digital inputs, 24 digital outputs and 5 universal timers-counters).

The control station main features designed for withstand against powerful pulse interference:

— the processor module have automatic restart on accidental program malfunction and power fail, nonvolatile RAM, diode over-voltage protection on each of 115 input/output lines;

— the special blocking single-board module do a hard blocking of a accidental harmful processor signals (generated on processor malfunction). The harmful situations are simple and well defined and can be blocked by programming array logic circuits.

10. ION SOURCE

At present we have designed (for the installations set) two types of ion sources: duoplasmatron with single-charged ion amperage up to 10 mA (service life more than 120 hours without parts replacing) and high specific energy efficiency (power consumption on 10 mA ion current is about 800 Wt). Second ion source have radio-frequency discharge and gives up to 2 mA and characterized by simplicity and small consumption power about 300 Wt.

11. CURRENT WORK STATUS ON THE "ION" INSTALLATIONS SET

ION-1500 - the separated, single-charged ion beams of Hydrogen, Fluorine, Nitrogen and Argon are available with amperage about 1.0 mA and 1.2 MeV energy (the insulating gas pressure was decreased down to 6 atmospheres). Rectifier and accelerating tube was successfully tested under 1.5 MV voltage.

ION-600—rectifier and accelerating tube was successfully tested under 600 kV voltage.

ION-300—rectifier and accelerating tube was successfully tested under 350 kV voltage. A works with the ion beam began.

The main installation parts unification and successful ION-1500 testing gives us some confidence in the ION-600 and ION-300 successive development.