TIME DEPENDENCE OF ION BEAM TRANSVERSE PHASE-SPACE PORTRAIT ORIENTATION DURING LINAC PROTON INJECTOR PULSE

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Abstract

It is shown that turn-on transients of the 400 kV column intermediate electrode potential is one of main processes responsible for change of beam phase-space portrait orientation during 200 µs, 50 Hz proton injector high voltage accelerating pulse. It has been found that significant variation of this potential takes place due to transition process during a pulse in the resistive-capacitive voltage water divider of the accelerating tube. The divider capacitors matching procedure has been performed. The beam emittance measurement results presented have shown significant decrease of a beam transverse phase-space portrait orientation change during injector pulse with the accelerating tube voltage divider being compensated.

The INR RAS linac proton injector provides a pulsed beam with the following parameters:
peak current – (65÷100) mA; duration – 200 µs; pulse repetition rate – 50(100) Hz; energy of ions – 400 keV. Schematic drawing of the accelerating tube is shown in Fig. 1. A beam of hydrogen ions is generated in the duoplasmatron type ion source.

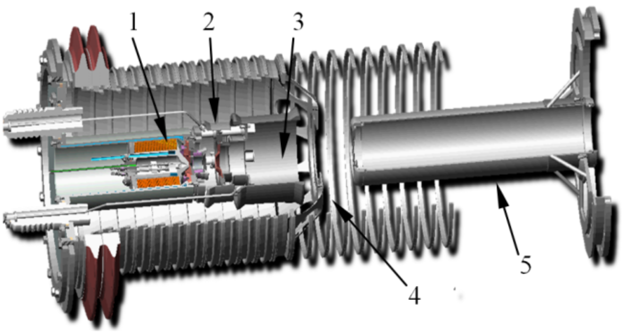

Figure 1: Schematic drawing of the accelerating tube: 1 - ion source, 2 – extracting electrode, 3 - focusing electrode, 4 - intermediate electrode, 5 - grounded electrode.

A beam is accelerated in the tube of about 1600 mm long with external surface being positioned in the open air. For decreasing of influence of coulomb repulsion of ions in beam a total length of inner accelerating gaps in vacuum have to be a minimal one, so the ion source and the grounded electrode are deeply in the tube (Fig. 1). The column has two inner accelerating gaps with a summary length of 220 mm: a) the first accelerating/focusing gap (100 mm) in which an ions have reached an energy about 95 keV; b) in the second gap (120 mm) an ions have been accelerated to an energy of 400 keV. The intermediate electrode (IE) is positioned at joint between two gaps. Focusing electrode and IE diaphragm represent electrostatic lens which determine the beam focusing/crossover location at LEBT channel entrance when focusing electrode potential being changed.

A high accelerating voltage is distributed along the tube by means of water divider with a total resistance about 1.5 MΩ. At nominal voltage of 400 keV a current through the divider is about 0.27 A; this value more than 3 times exceeds usual beam current of 80 mA. This is important for reliable distribution of voltage along the tube and full elimination of high voltage breakdowns. The IE is connected with the divider point where high accelerating voltage is divided in approximate ratio of 1:3.

Emittance measurements for ion beam at the injector exit show significant phase-space portrait orientation change during 200 µs injector high voltage pulse [1, 2].

Study of ion beam transport in the proton injector has been performed using Trak and SpaceCharge package developed at Field Precision LLC [3]. The numerical simulation takes into account plasma boundary formation at ion source expander, space charge effects for ion beam extracting, accelerating and transporting.

It has found that the causes of observed position/shape phase portrait changes during high voltage injector pulse can be as follows: instability of high voltage pulse; possible changes of the injector ion beam current; dynamic of ion beam space charge compensation process; the IE potential changes.

As a result of some efforts which have been made in recent times with the aim to decrease the injector accelerating voltage instability the latter is now not worse than ±0.085% (see Fig. 2). Pulse-to-pulse voltage instability does not exceed ±0.04% [4]. So the summary instability equals value of ±0.125% or less.

The beam transport simulation performed shows that such a change of high voltage amplitude during pulse has no influence on the ion beam transverse phase-space portrait orientation.

Influence of ion beam current changes on phase-space portrait orientation is especially important in the case of “noisy” mode of an ion source operation because of ion beam current fast variations which can reach tens percent of maximal value during a pulse. However, the present duoplasmatron source has “noiseless” operation mode [5]. As we can see from Fig. 2, beam current transients up to ±8% result in notable change of beam phase-space portrait orientation when beam current is about 65 mA.

Additionally to improve stability of beam current during a pulse and pulse-to-pulse stability the transistor stabilized arc modulator (instead of the thyristor unit based on pulse forming network) with no more than ±0.5% discharge current instability along a pulse has been developed and placed in operation. As a result, stability of beam current pulse plateau (see Fig. 3) has been improved [2].

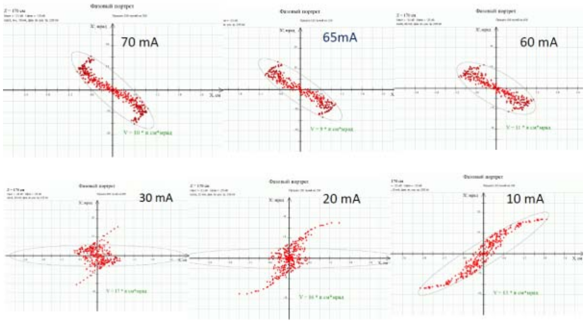

Figure 2: Influence of beam amplitude on position/shape of the injector exit beam phase portrait.

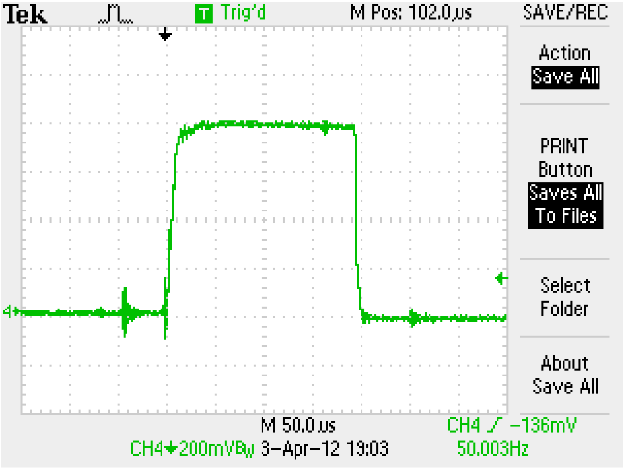

Figure 3: The ion beam current shape at the injector exit.

It is known that process of ion beam space charge compensation can lead to change of phase-space portrait orientation [6].

In our injector space charge compensation of the ion beam is prevented by electric fields of the accelerating tube beam forming system (extraction and focusing). These fields eliminate accumulation of electrons arising both due to ionization of residual gas molecules and hitting of ions with beam transport line apertures and walls.

It has been found that main process leading to a change of ion beam phase space portrait orientation at the injector exit is turn-on transient of the 400 kV accelerating tube IE potential.

Simulation have shown that change of the IE potential for a value less than 1% already leads to significant changes in the injector beam properties. The example of calculation results for different IE potential is shown in Fig. 4.

C_2 and C_1 capacities are the sum of each outer gap interelectrode capacity of the tube (~200 pF) and additional capacitors installed at each gap in front of and behind the IE. The additional capacitor values have been chosen to compensate influence of C_3 capacities between each electrode of the tube and “ground”.

Equivalent schematic diagram of the tube resistive-capacitor voltage divider is shown in Fig. 5.

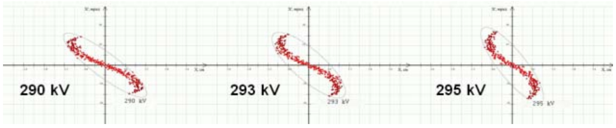

Figure 4: Influence of the IE potential value on position/shape of the injector exit beam phase portrait.

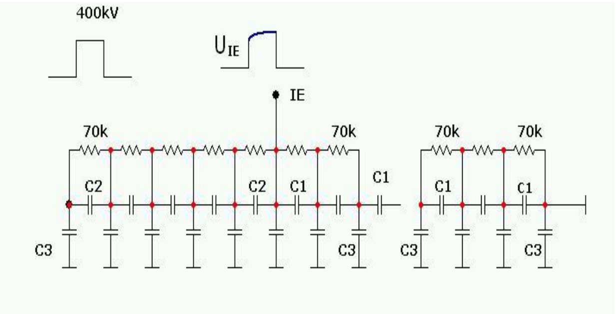

Figure 5: Equivalent schematic diagram of the tube resistive-capacitive voltage divider.

During matching procedure C_2 capacities have been changed more than once and every time the IE potential pulse shape has been measured. These measurements have been performed with the help of especially designed low capacity voltage divider at reduced injector pulse voltage (50 kV). Examples of the measurement results are shown in Fig. 6.

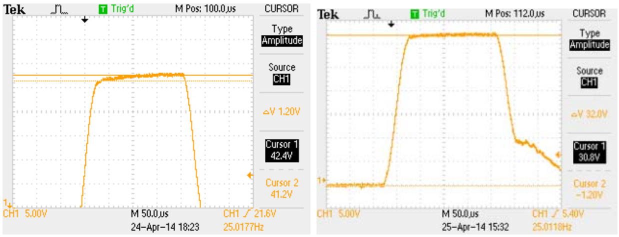

Figure 6: The IE voltage pulse shapes at reduced injector pulse voltage (50 kV). Left curve: C2 = 1200 pF; right curve: C2 = 1400 pF, C1 = 1000 pF.

Additional capacitors of 1200 pF, 20 kV have been chosen for the first five outer gaps of the tube before the IE as a result of matching procedure.

Studies of phase portrait parameters changes along 200 µs accelerating voltage pulse have been carried out. The duoplasmatron arc modulator has produced 25 µs duration beam which has been injected into the accelerating tube with multiple of 25 µs different delays relative to beginning of high voltage pulse plateau. It has been found that:

a) beam phase portrait changes its orientation during 200 µs pulse length in the case of noncompensated divider;

b) within the accuracy of measurements there is no change of orientation in the case of the compensated tube divider. Some of emittance measurement results are shown in Fig. 7.

Normalized emittance for 63% of 65 mA beam has been measured of value no more than 0.06π cm•mrad and 0.15π cm•mrad for 90% of beam in case of the compensated divider.

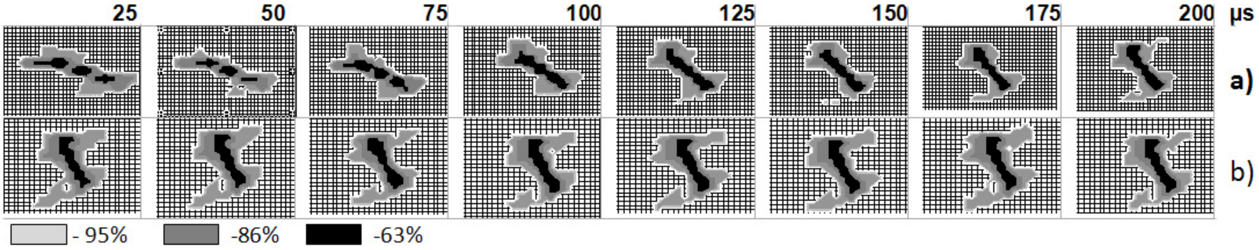

Figure 7: Beam phase portraits when scanning along 200 µs high voltage injector pulse plateau duration: a) noncompensated divider; b) compensated divider. Contours of black, dark-grey and light-grey regions contain 63%, 86% and 95% of beam current, correspondingly.

CONCLUSION

Analysis of the processes that can lead to a transverse phase-space portrait orientation change at the proton injector exit during beam pulse results in belief that the main processes are: possible changes of the ion beam current and turn-on transient of the 400 kV accelerating tube intermediate electrode potential.

Due to both installation of the compensated accelerating tube divider, using of duoplasmatron "noiseless" operation mode, stabilizing of ion source discharge current and improvements conducted to increase accelerating voltage stability a transverse phase-space portrait orientation change does not observed during beam pulse within the accuracy of measurements. A satisfactory agreement of beam parameter measurements and numerical simulation has been achieved.

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