STUDY OF PROTON INJECTOR BEAM TRANSVERSE PHASE SPACE VARIATIONS DURING ACCELERATING VOLTAGE PULSE

A.S.Belov, O.T.Frolov, E.S.Nikulin, V.P.Yakushev, and V.N.Zubets,
Institute for Nuclear Research of RAS, Moscow, 117312, Russia

Abstract

The proton injector of INR RAS linac provides a pulsed beam with the following parameters: current – 100÷120mA; duration – 200 µs; pulse repetition rate – 50 Hz; energy of ions – 400 keV. The results of numerical calculations and experimental studies of beam phase space variations during injector high voltage pulse are presented. It is shown that these variations are caused by instabilities of both beam current and accelerating tube intermediate electrode potential. Instability of beam current has been minimized by using of noiseless mode of operation for the pulsed duoplasmatron and by stabilization of ion source discharge current. The high voltage pulse stability has been improved and is now better than ±0.1%. For the most part of beam pulse duration a transverse normalized emittance for 90% of beam current has been measured to be of 0.09π cm·mrad and variations of the emittance are in limits of ±4% value.

INTRODUCTION

INR RAS linear accelerator proton injector is operated regularly from the end of 80-ies. And the work on its improvement is in progress all the recent years. The basic conditions of beam loss minimization in linac are as more as possible smaller transverse emittance and stability of beam phase portrait position. After installing a new expander cup isolated from duoplasmatron the beam transverse normalized emittance of 0.076π cm•mrad for 63% of central part of the 115 mA beam has been measured at the injector output in noiseless mode and 0.2π cm•mrad for 90% of the beam, respectively [1].

A number of measurements and numerical simulation of injector ion beam formation and transport to the linac LEBT input have been performed. Significant changes in the beam phase portrait position/shape have been found as a result of calculations and beam emittance measurements. In the past two years the injector structure has undergone further modifications which have improved qualitative characteristics of the beam.

NUMERICAL SIMULATION

Numerical simulation using Trak and TriComp SpaceCharge package developed Field Precision LLC has been conducted. Schematic drawing of the proton injector is shown in Fig.1. A beam of hydrogen ions is generated in duoplasmatron type ion source. The beam is accelerated and focused in two-gap accelerating tube by the electric fields between the ion source focusing electrode, intermediate and output (grounded) accelerating tube electrodes.

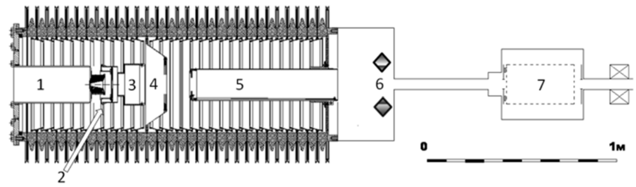

Figure 1. Schematic drawing of the proton injector: 1 - ion source, 2 – extracting electrode, 3 - focusing electrode,4 - intermediate electrode, 5 - grounded electrode, 6 – steering magnet, 7 – diagnostics box.

Simulation have shown that changing of the intermediate electrode potential by a value less than 1% already leads to significant changes in beam properties at the injector output. The example of calculations result is shown in Fig. 2.

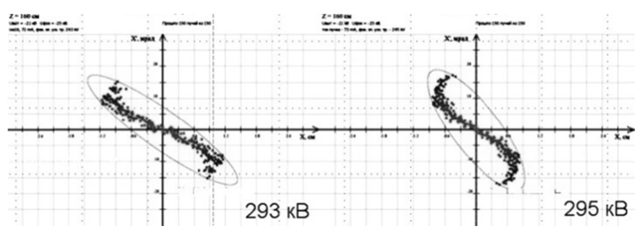

Figure 2. The influence of intermediate electrode potential value on position/shape of the injector output beam phase portrait. Intermediate electrode potential equals 293 kV and 295 kV.

Agreement between simulation and measurement is particularly evident when considering the various aberrations of beam. One of the aberration types studied is shown Fig.3.

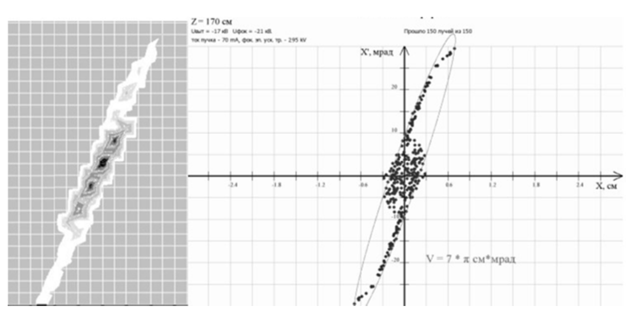

Figure 3. One of the phase portrait aberration types studied when transporting hydrogen ions beam
(left - measurement, right - simulation)

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STRUCTURAL CHANGES AND RESULTS

It has found that the causes of observed position/shape phase portrait changes during high voltage injector pulse are mainly the intermediate electrode potential changes and instability of proton beam current.

To reduce the intermediate electrode potential changes during high voltage pulse the compensated high voltage divider has been installed at the injector accelerating tube. Initially a chain of the 28 680pF×20kV capacitors has been mounted in parallel to the existing water resistive divider. Later another chain of seven 200pF×20kV capacitors has been added at initial part of the accelerating tube from high voltage electrode to intermediate one.

To increase the stability of the beam current during the pulse and pulse-to-pulse stability the transistor stabilized arc modulator (instead of the thyristor unit based on artificial line) with ±0.5% discharge current stability along the pulse has been developed and placed in operation.

As a result, the stability of the beam current pulse plateau has been increased (Fig.4). Beam emittance for 63% of the 115mA beam has been measured of 0.07π cm•mrad and 0.17π cm•mrad for 90% of the beam.

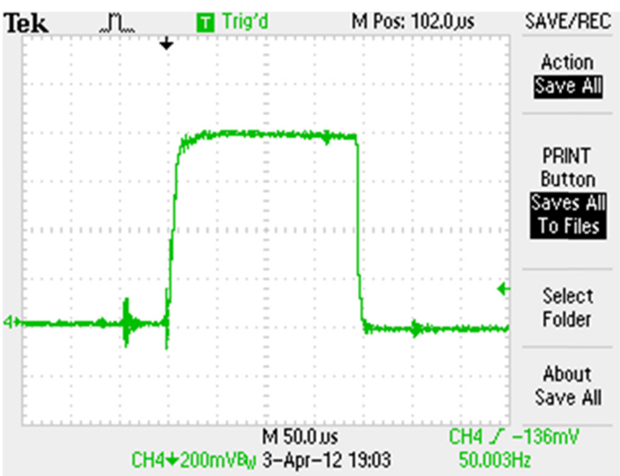

Figure 4. Ion beam current shape at injector output.

Studies of changes of the phase portrait parameters during 200 µs accelerating voltage pulse have been carried out. Duoplasmatron arc modulator has produced a 25 µs duration beam supplying into the injector with multiple of 25 µs different delays relative to beginning of the high voltage pulses .

It has found that the beam phase portrait turns through an angle of Δξ ≈14° during 200 µs pulse length. This angle is twice smaller than before installation of the compensated divider and the stabilized discharge current modulator [2].

In recent times some efforts have been made to improve the injector accelerating voltage stabilization:

- characteristic impedance of the high voltage pulse generator artificial line has been reduced thus increasing current in the capacity-diode stabilizer;
- high frequency component of the capacity-diode stabilizer current has been filtered;
- a part of saw-shaped voltage amplitude with greater degree of linearity than earlier has been used when compensating the pulse plateau slope.

Some of emittance measurement results are shown in Fig.5, 6.

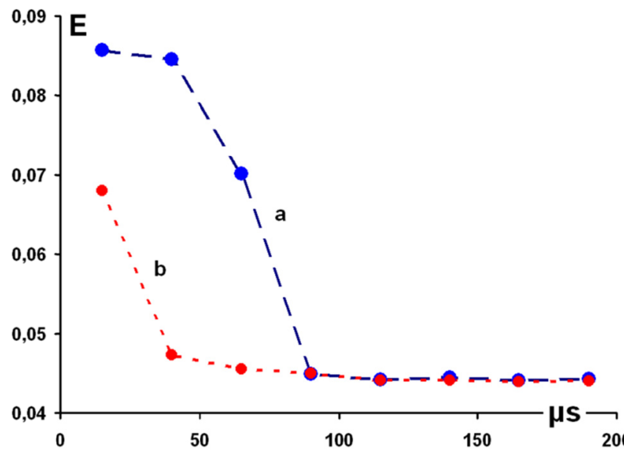

Figure 5. A 25 µs duration beam emittance dependence on multiple of 25 µs different delays along high voltage pulse when installing transistor arc modulator:
a) non-compensated divider;
b) compensated divider and improved accelerating voltage pulse plateau stabilization.

Results of the accelerating voltage pulse plateau stability improvements are shown in Fig. 7.

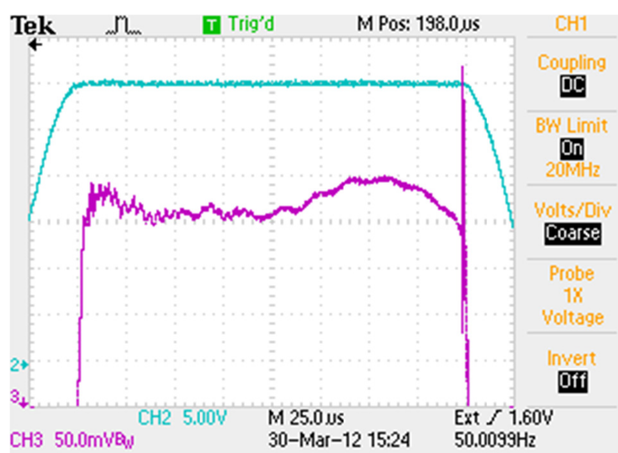

Figure 7. The accelerating voltage pulse shape: upper curve - total amplitude (30 V), lower curve - top of the pulse.

From our measurements it follows that stability of the accelerating voltage pulse plateau is now better than ±0.1% instead of the previous ±0.2% value. Emittance of 100÷105 mA beam for 63% of the beam has remained at the same values and, in fact, is now close to a value of beam emittance in the first few tens of microseconds. For the greater part of the injector pulse beam length, namely

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for τ = 25 ÷ 200µs, its value does not exceed 0.05π cm•mrad and for 90% of the beam emittance has reduced to 0.09π cm•mrad. It should be noted particularly that rotation of axis of ellipse described by the phase portrait has decreased to $\Delta\xi = 10°$.

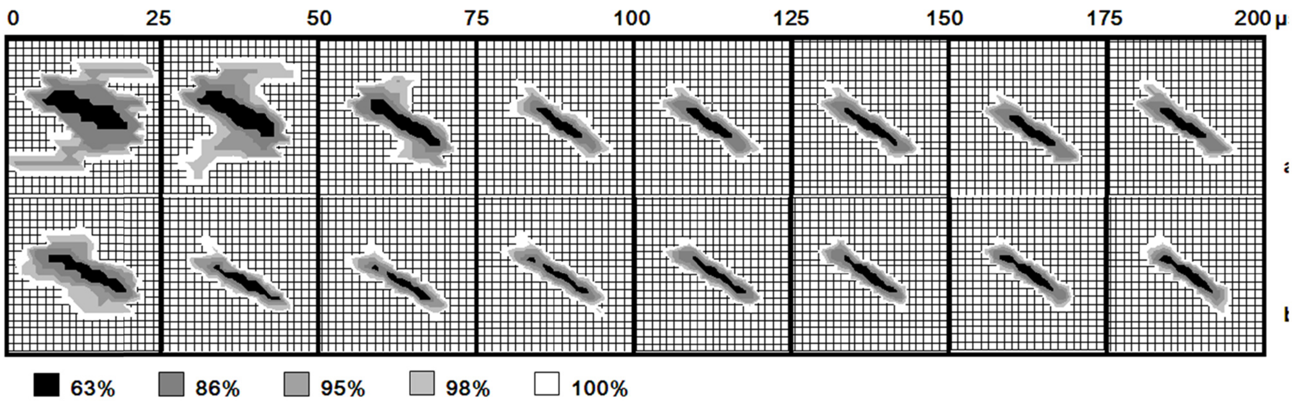

Figure 6. The beam phase portraits when scanning along high voltage injector pulse duration:
a) non-compensated divider;
b) compensated divider and improved accelerating voltage pulse plateau stabilization.

CONCLUSIONS

Due to installation of the accelerating tube compensated divider, stabilizing of duoplasmatron discharge current and improvements conducted to increase accelerating voltage stability the beam emittance and rotation of the phase portrait during beam pulse have been decreased.

Both compensated accelerating tube divider high voltage shape and beam current shape have become close to trapezoidal one with flat plateau throughout injector pulse. Stability of ion beam current throughout the injector pulse and pulse-to-pulse stability have been improved.

A satisfactory agreement of beam parameters measurements and numerical simulation has been achieved.

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REFERENCES

[1] A.S.Belov et al. Study of the INR RAS Linac Pulsed Duoplasmatron. Proc. of RUPAC-2010, Protvino, Russia,pp.289-291, http://www.accelconf.web.cern.ch/accelconf/r10/papers/thchb01.

[2] A.S.Belov et al. The INR of RAS Proton Linac Injector Beam Study // Problems of atomic science and technology. Series "Nuclear Physics Investigations" http://vant.kipt.kharkov.ua›ARTICLE/VANT_2012_3/article_2012_3_44.pdf

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