METHOD OF THE NANOSECOND MICROSTRUCTURE CREATION OF THE NEGATIVE ION BEAM

A.V. Novikov-Borodin
Institute for Nuclear Research of Russian AS,
60-th Oct. Anniv.pr.7a, 117312,Moscow, Russia
e-mail: novikov@al20.inr.troitsk.ru

The method of the nanosecond microstructure creation of the negative ion beam with nanosecond edge times is presented. The method of creation does not destroy the beam compensation by the residual gas, so it is available for low-energy beams. Such effects as a beam divergence and, therefore, a bad beam transport are overcome. The two-plate travelling wave chopper is used. The special shape of the plate deflecting voltage is needed. The estimations and a comparison with the existing methods of a beam deflection are presented.

PACS numbers: 29.27.-a, 41.85.Ja, 52.65.Rr

1 INTRODUCTION

The nanosecond microstructure beam production is needed for physics experiments and/or during the injection from a Linac to ring machines. To form the beam shape it seems much easier to use the low-energy beam. The usual methods [1-3] destroy the beam neutralization of the residual gas that, for low-energy beams (up to 200-300 keV), leads to a huge beam divergence and, therefore, to the bad beam transport and beam losses up to 50% for the 35 keV 100mA H^- beam [1]. The neutralization restore time constant is estimated from 2 - 5 μs [4] to 30-700 μs [5] and it may be considered as a limitation to a beam microstructure edge times. This process force people to use the higher energy beams for deflection.

The proposed method lets to deflect the negative ion beam without destroying the residual gas neutralization, which overcomes the above-mentioned problems. The two-plate travelling wave chopper is used. The special shape of the plate deflecting voltage is needed. The estimations and a comparison with the existing methods of a beam deflection are presented in this paper.

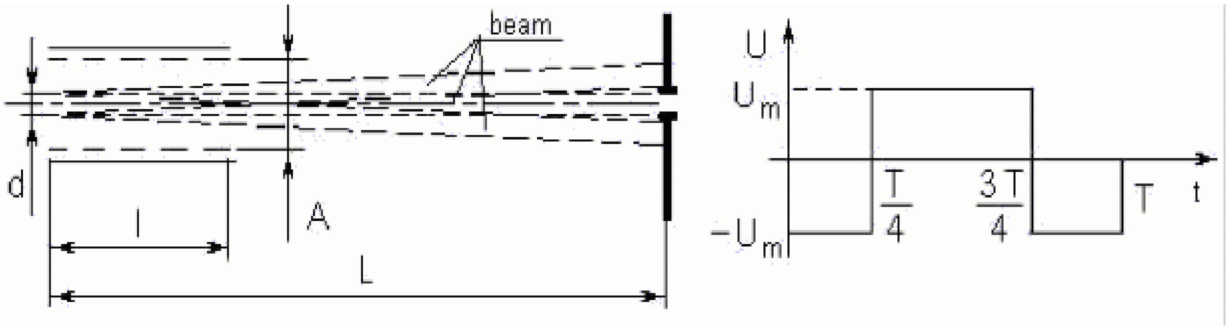


Fig. 1. Principal scheme of the beam deflection.

2 PRINCIPLE OF THE NON-DESTROYING DEFLECTION

The charged particle beam, moving in the beam tube, produces the opposite charged ions from the residual gas molecules, which compensate partially or even completely the beam charge. For positive charged beams the compensation is made by the free electrons and negative ions and for negative beams it is made by the positive ions. The residual gas ions oscillate inside the potential gap, created by the beam. It seems complicated to deflect the beam and to keep the opposite charged neutralized residual gas, but possible. In case of the negative charged beams the travelling wave chopper with a special way of operation is used for the non-destroying beam deflection. The principal scheme of the proposed installation is shown in Fig. 1.

Here A is the distance between the deflecting plates, l is their length, L is the distance to the beam damp and d is the vertical beam size at the input to the chopper. U is the voltage between deflecting plates during the time period (0 – T) when the beam needs to be deflected.

In the travelling wave chopper the deflecting field is moving with the beam. Deflecting different parts of the beam during deflection time period to the opposite directions, it is possible to keep the residual gas ions in the beam tube. For the structure and deflecting voltage, shown in Fig. 1, the non-relativistic beam deflection (up or down) will be described by the equation:

$$\Delta y_{beam} = \frac{1}{2} w_b \left(\frac{l}{\beta c} \right)^2 \left[1 - 2\left(1 - \frac{L}{l} \right) \right],$$

$$w_b = k \frac{q_b}{m_b} \frac{U}{A}, \qquad (1)$$

where βc is the longitudinal velocity of the beam, q_b, m_b are the charge and the mass of the beam particle, *k* is the efficiency coefficient of the deflecting structure.

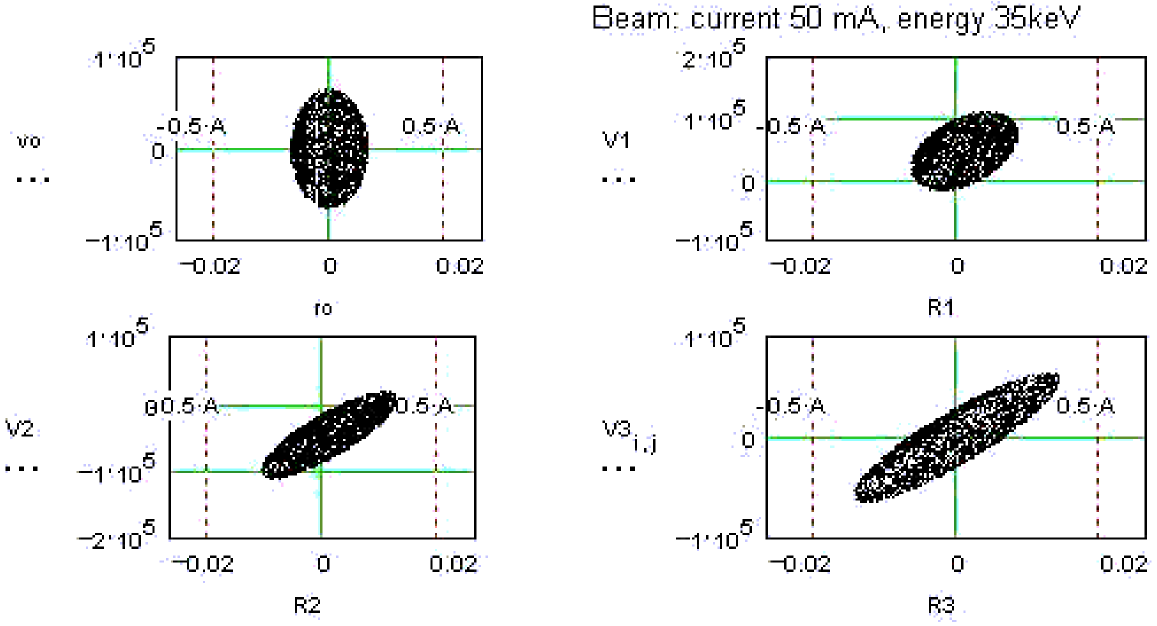


Fig. 2. Transverse motion distribution of the residual gas ions.

For the residual gas ions, their transverse motion will be described as a system of equations:

$$y_i = y_o + \int_t v dt, \quad v_i = v_o + \int_t w_i dt,$$

$$w_i = k\frac{q_i}{m_i}\frac{U}{A}, \tag{2}$$

where y_o, v_o are the initial transverse position and velocity of the ions, q_b, m_b are the charge and the mass of the ion.

The ionized residual gas initial position and velocity distribution are defined by the influence of the beam charge. Ions oscillate in the beam potential gap. For the estimation we will consider, that the beam potential on the beam diameter defines the maximum ion energy. So, for the initial transverse position and velocity of the ions we can get the estimation:

$$v_{o\max} = \sqrt{\frac{I_b}{4\pi\varepsilon_o\beta c}\frac{q_b}{m_i}\left|1-\left(\frac{2y_i}{d}\right)^2\right|},$$

$$y_{o\max} = \frac{d}{2}. \tag{3}$$

It is seen from (2) that for the deflection voltage from Fig. 1 the transverse velocity of the ions before and after deflection is the same. Only the transverse position is changed during the deflection. We will consider that the residual gas neutralization is not destroyed if the transverse position of the ions during the beam deflection is less than the aperture.

3 NUMERICAL CALCULATIONS AND ANALYSIS

We will estimate the non-destroying deflection for l=38 cm, L=50 cm, U_m=850 V, T=150 ns. We will analyze the H^- beam deflection with the diameter 1 cm, the energies around 35 keV and the current 20-100 mA. We need to analyze the transverse motion of the residual gas ions at the end of the periods of the voltage deflection. The transverse velocity and position distribution is shown on Fig. 2.

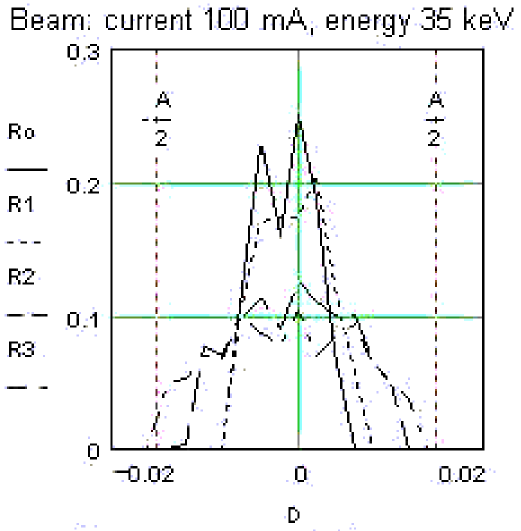


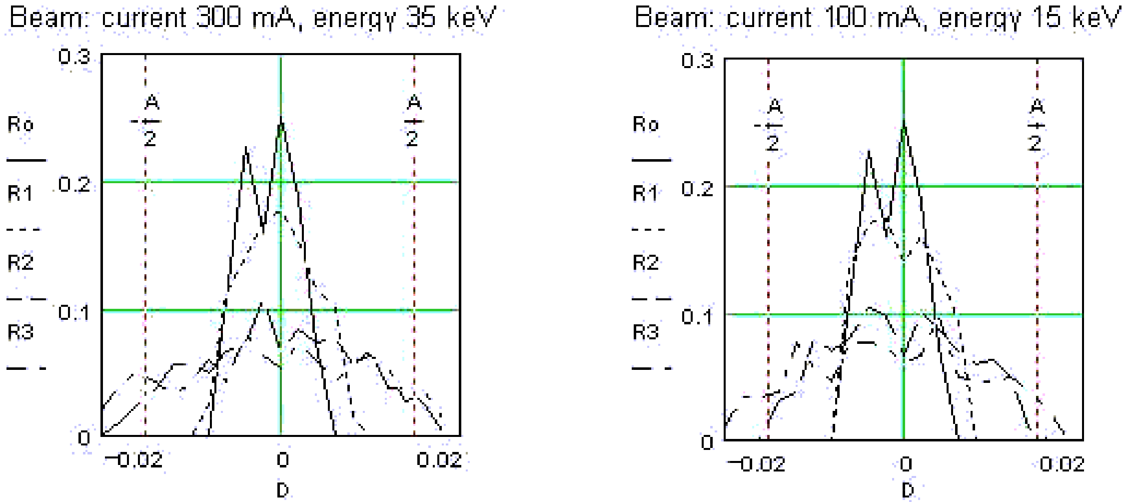
Fig. 3. Ion transverse distribution at the end of deflection.

Here (vo,yo) is the initial distribution (at t=0), (V1,R1), (V2,R2) and (V3,R3) are the distributions at t=T/4, 3T/4 and T, respectively. It is seen that the maximum position distortion is at the end of the deflection.

For the 100 mA beam, the residual ion distribution at the end of the deflection is shown in Fig. 3.

The transverse distortion of the residual gas is increasing with the beam current increasing and the beam energy decreasing that is illustrated in Fig. 4.

So, one can conclude, that for these beam parameters the neutralization will be partially lost. This is not the principal limitation, another parameters of the deflecting structure needs to be chosen.


Beam: current 300 mA, energy 35 keV

Beam: current 100 mA, energy 15 keV

Fig. 4. Ion transverse distribution at the end of deflection with different beam current and energy.

4 PRACTICAL REALIZATION

In practice, it is possible to create the deflecting voltage by using two identical modulators for upper and lower deflecting plates by applying the deflecting voltage consequently, as is shown in Fig. 5.

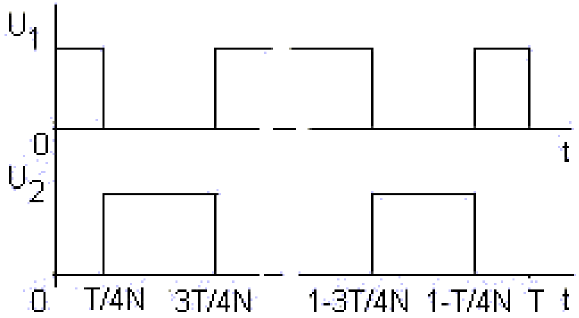


Fig. 5. Time diagramm of the fast modulators.

The number (N) of the meanders depends on the parameters of the deflecting structure and beam parameters, but it needs to be taken into account that there will be some non-deflected part of the beam at the meander edges.

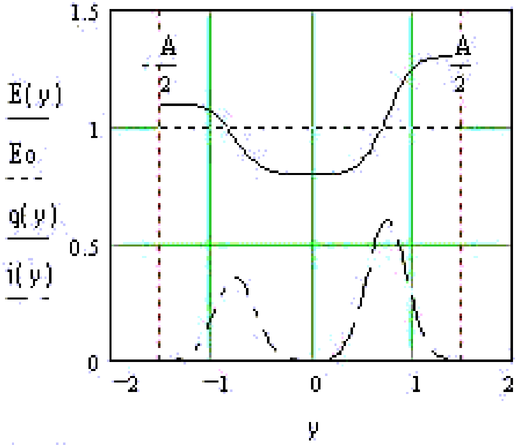


Fig. 6. Field distribution during deflection with 60% beam compensation.

Another question to be mentioned about is a variable transverse distribution of the deflecting field by the influence of the beam charge and the charge of the ionized residual gas during deflection. When the beam is compensated, we can consider the deflecting field as uniform, but during the deflection the beam and the residual gas are displaced. Uncompensated charge effects to the deflecting field distribution. The typical field distribution (E(y)) with 60% beam compensation during the deflection is shown in Fig.6. Here shown is also the average field (Eo) without the beam and the beam (q(y)) and ion (i(y)) charge distribution in relative units.

This picture is the first order approximation, the real pictures are more complicated [6], but in practice it is enough to project the system parameters with the deflecting field value much more than the field between the beam and the ionized residual gas. It is a limitation to the beam size, but usually for low-energy high-intensity beams it is not very important.

REFERENCES

1. J.G.Alessi, J.M.Brennan, A.Kponou. H^- source and low energy transport for an RFQ preinjector // *Rev. Sci. Instrum*. 61 (1), January 1990, p. 625-627.
2. A.V.Novikov, P.N.Ostroumov. Beam Chopper for 750 keV LEBT of MMF Linac // *Proc. of PAC'97*, Vancouver, Canada, May 1997.
3. S.S.Kurennoy, A.J.Jason, et al. Development of a Fast Traveling-Wave Beam Chopper for the National Spallation Neutron Source // *Proc. of PAC'97*, Vancouver, Canada, May 1997.
4. R.Ferdinand, J.Sherman, et al. Space-Charge Neutralization Measurement of a 75 keV, 130 mA Hydrogen-Ion Beam // *Proc. of PAC'97*, Vancouver, Canada, May 1997.
5. A.Jakob, et al. Diagnostic of the Compensation Process of Ion Beams with a Time-Resolving Ion Energy Spectrometer // *Proc. of PAC'97*, Vancouver, Canada, May 1997.
6. I.Hofmann. Emittance Growth of Beams Close to the Space Charge Limit // *IEEE Trans. on Nucl. Ph.*, v. NS-28, No.3, June 1981, p. 2399.