OPERATION OF THE ENERGY SPREAD OF BEAM WITH USING OF EXCHARGE TARGET

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1 INTRODUCTION

For matching of the longitudinal emittances or damping of the transversal and longitudinal instabilities, at the injection into the cyclic or linear accelerator, the creation of the operating energy spread is needed. In this paper the authors propose the method of the creation of this spread with using the excharge target. It is possible by using the tandem accelerator as injector or by excharge injection into cyclic accelerator. The idea of the method is following. The longitudinal electric field is applied in the excharge target along the beam direction. Depending on the particle charge sign this field accelerates or decelerates the particles. The longitudinal coordinate of the excharge point is a random value. Therefore, after passing through target the particle energy can reduce or increase depending on the coordinate of the excharge point. The derivable beam energy spread is generated in every point of the beam longitudinal coordinate, in contrast then RF resonator is used. In last case there is only the modulation of energy which depends on the longitudinal coordinate of the beam.

A gas jet, vapour, an electron and photon beams and a think foil can be used as the excharge target. Usually the gas target is used at the pulse mode, the foil is used at the streaming operation. Our method can be simply realised in the case of the gas target. In the foil case the realisation is more difficult. But the comfortable construction, which consists of the set of foils located at the different potentials, can be found.

2 ANALYTICAL ESTIMATIONS

In this chapter the calculation, which demonstrates the possibility of using this method at the proton tandem accelerator, is shown. Let us consider the excharge process $H^- \to H^+$ at the homogenous gas target. In the excharge area the longitudinal electric field $\vec{E}$ is applied. In Fig.1. the schematic plot of this process are shown.

Let us select for the distinctness the direction of the field so as the protons will decelerate. The probability of the process $H^- \to H^+$ at the depth of target x (nucleus/cm^2) is [1]

$$F_1(x) = \sigma_{-11} \cdot exp(-\sigma \cdot x)dx, \qquad (1)$$

where $\sigma_{-10}, \sigma_{01}, \sigma_{-11}$ are the cross-sections of the processes $H^- \to H^0, H^0 \to H^+, H^- \to H^+$ accordingly, and $\sigma = \sigma_{-10} + \sigma_{-11}$. The probability of the processes, in which ion H^- lost the electrons in the depths of λ and s $(\lambda < s)$ is

$$F_2 = \sigma_{-10}\sigma_{01}\, exp(-\sigma \cdot \lambda) \cdot exp(-\sigma_{01}(\lambda - s))d\lambda ds \qquad (2)$$

The total probability of proton excharge in the depth s is

$$F = \left(\sigma_{-11} + \frac{\sigma_{-10}\sigma_{01}\left(exp((\sigma - \sigma_{01})s) - 1\right)}{(\sigma - \sigma_{01})}\right) \cdot exp(-\sigma s)ds \qquad (3)$$

After integration (3) the conversion coefficient is

$$\Phi(\delta) = 1 - \left(\sigma_{-11} + \frac{\sigma_{-10}\sigma \cdot exp(-(\sigma_{01} - \sigma) \cdot \delta) - \sigma_{-10}\sigma_{01}}{\sigma - \sigma_{01}}\right) \times \\ \times \frac{exp(-\sigma\delta)}{\sigma}. \qquad (4)$$

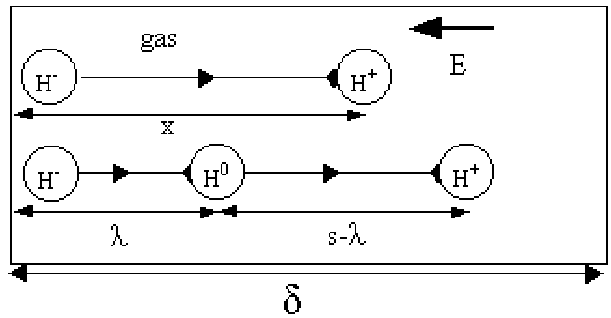

Figure 1: The schematic plot of the excharge ion $H^- \to H^+$ process on the gas target.

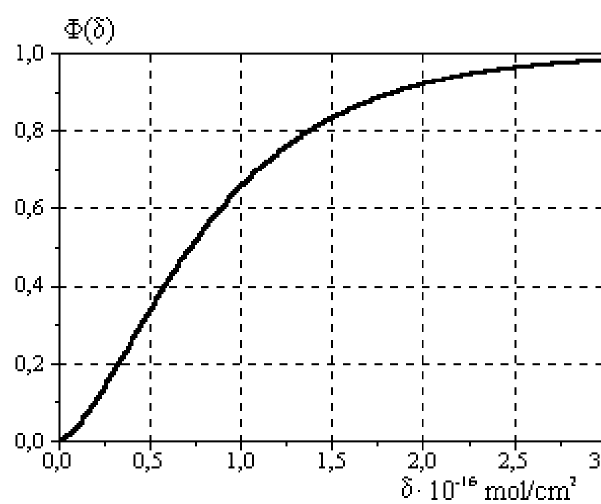

Figure 2: Dependence of the conversion coefficient on the target thickness.

Let us consider the proton energy spread after conversion in case of the homogenous electric field distribution and homogenous gas distribution in target body.

Let $W = \frac{\Delta E}{eU}$ is the relative increment of energy, where U is the potential difference, ΔE is the particle energy change. Then the energy spread can be described in the following

$$S(W,\delta) = \frac{\delta}{\Phi(\delta)} \cdot \begin{cases} S_1(W,\delta) + S_2(W,\delta) & -1 < W < 0 \\ S_1(W,\delta) + S_3(W,\delta) & 0 < W < 1 \end{cases}, \quad (5)$$

where $S_1(W,\delta) = \sigma_{-11}\, exp(-\sigma \cdot (W+1) \cdot \delta / 2) / 2$, (6)

$$S_{2,3}(W,\delta) = \frac{\sigma_{-10}\sigma_{01}}{\sigma - 2\sigma_{01}} \frac{exp((\sigma - 2\sigma_{01}) \cdot (1 \pm W) \cdot \delta / 2) - 1}{exp(\sigma(W+1) \cdot \delta / 2)} \quad (7)$$

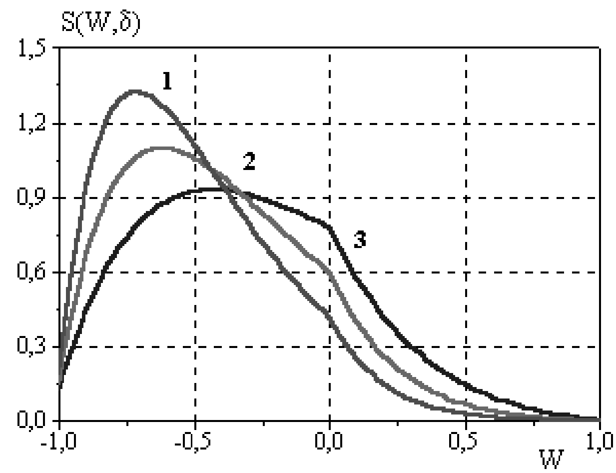

Figure 3: Distribution of the proton energy spread for the different target thicknesses. Curves 1, 2, 3 show results for δ = $2 \cdot 10^{16}$mol/cm^2, $1.5 \cdot 10^{16}$mol/cm^2, $1 \cdot 10^{16}$mol/cm^2, respectively.

Note that $\int_{-1}^{1} S(W,\delta) dW = 1$. The mean change of proton energy $\langle W \rangle$ and the mean-square energy spread $\langle W^2 \rangle$ can be found from equations

$$\langle W \rangle = \int_{-1}^{1} W S(W,\delta) dW \,, \langle W^2 \rangle = \int_{-1}^{1} (W - \langle W \rangle)^2 S(W,\delta) dW \quad (8)$$

For example we consider the H^- excharge process at the nitrogen target, with energy $E = 0.9$ MeV. The cross-section values are $\sigma_{-10} = 3.5 \cdot 10^{-16}$ cm^2/mol, $\sigma_{01} = 1.5 \cdot 10^{-16}$ cm^2/mol, $\sigma_{-11} = 0.17 \cdot 10^{-16}$ cm^2/mol [2]. To provide the proton output near 100% the thickness of the target must be $\delta \approx (3 \div 4) \cdot \sigma_{01}^{-1}$.

In Fig.2. the conversion coefficient depending on the target thickness is presented. The distributions of the proton energy spread for different target thicknesses are shown in Fig.3. The dependence of the mean change of proton energy and the mean-square energy spread on the target thickness are shown in Fig.4.

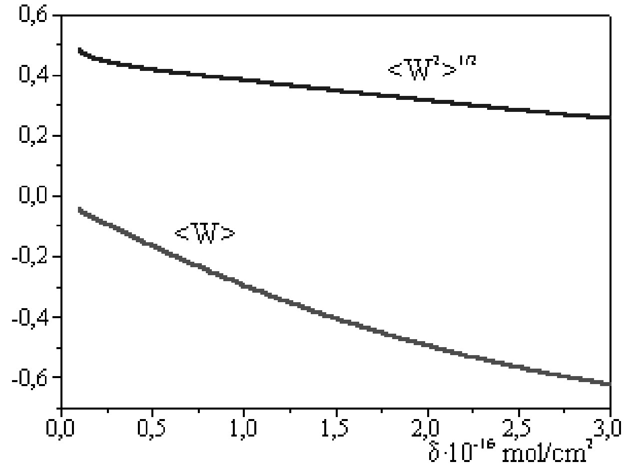

Figure 4: Dependence of the mean change of proton energy $\langle W \rangle$ and the mean-square energy spread $\langle W^2 \rangle$ on the target thickness.

3 COMPUTER SIMULATION

The above analytical calculations have a place for simple case of the homogenous gas target. However, in reality the gas distribution has the more complicated form. The computer simulation with using of the Monte-Carlo methods was made for detail considering of the effect in the case of the arbitrary gas distribution. The good agreement between analytical calculations and results of simulation was obtained in case of the homogenous target.

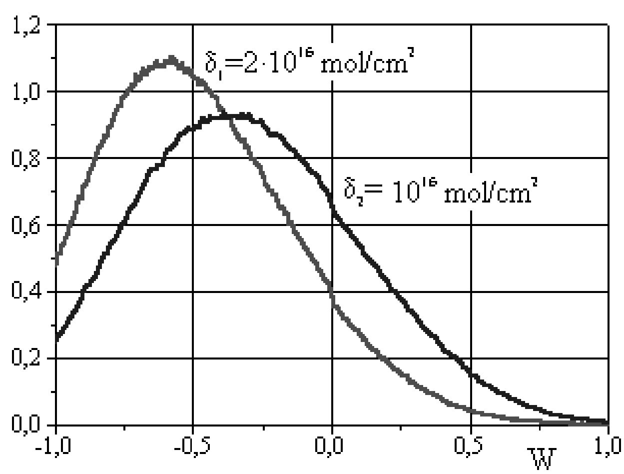

Figure 5: Distribution of the proton energy spread for the different target thicknesses, in the case of the Gaussian distribution of the gas density.

In Fig. 5. the results of energy spread modelling for Gaussian distribution of the gas density depended on the target thickness are presented; $\rho(x) = \frac{exp(-(x/\Delta)^2)}{\sqrt{\pi} \cdot \Delta}$. Here

x is a longitudinal coordinate of the target. The homogenous field presents in the region $[-\Delta,\Delta]$. The field is absent outside this region .

Then the mean changes of proton energy are $\langle W_1\rangle = -0.31, \langle W_2\rangle = -0.49$, the mean-square energy spreads are $\langle W_1^2\rangle^{\frac{1}{2}} = 0.4, \langle W_2^2\rangle^{\frac{1}{2}} = 0.35$ for target thicknesses $\delta_1 = 10^{16}$ mol/cm^2, $\delta_2 = 2\cdot 10^{16}$ mol/cm^2, accordingly.

In this case the small fraction of the protons, which have maximal and null change of energy, are appeared, since the part of gas in the tails of distribution locates outside the electric field area. The values of fractions with changes of energy $W = 0$ and $W = -1$ are 1.2% and 3.9%, 0.7% and 7.6% for δ_1 and δ_2, accordingly.

4 CONCLUSIONS

The above calculations was made for the new injector in the proton synchrotron TRAPP, designed for the cancer therapy [3]. However, such method of operating of energy spread can be used at the realization of the roughing targets for the ion accelerators or by excharge injection into cyclic accelerators.

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6 REFERENCES

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