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PROJECT OF A NOVEL MULTI-ORBITAL BEAM BUNCHING AND EXTRACTION FROM THE U-120M CYCLOTRON

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Abstract

We introduce the bunching system for a time structure control of the U-120M cyclotron beam. The system is based on a unique pulsed vertical deflection of the selected final orbits of the internal accelerated beam of the H^- ions to an extractor-stripper (a thin carbon foil positioned below the cyclotron median plane). A set of home-made programs have been developed for simulations and parameters determination of the system. Results of some simulations (i.e. dimensions of the deflection system, parameters of the pulsed high voltage power supply, position of the stripper, beam trajectories, beam parameters, beam losses, Be target position etc.) are presented. The system will be used for fast neutron generation and consequently for spectrometric measurement of neutron energy by the time of flight (TOF) method. The system will provide beam bunch interval up to 2000 ns range of a defined beam time structure (up to beam bunch period to beam bunch width ratio min 100).

INTRODUCTION

Motivation

For wide range of applications and advanced technological systems (i.e. nuclear power reactors, accelerator driven systems (ADS), fusion technology) neutron induced reactions play irreplaceable role. The data for neutronic calculations is based on transport codes with evaluated data libraries, supported by measurements and experimental tests of reaction models. Proposed chopping system supplies pulsed proton beam of the cyclotron U-120M which in connection with the Be target provide necessary tool for precise measurement of angle/energy-dependent cross-sections by neutron TOF method. Planned facility will be complementary with the parameters of the European TOF facilities (nTOF CERN, GELINA Geel, NFS Ganil [1]). The NPI has a long-term experience with the design, manufacture and operation of targets for production of fast neutrons and their use in various projects and experiments [2]. Study and project of the TOF system [3] on the new cyclotron TR-24 (repetition frequency 85 MHz/pulse width 2.3 ns) which was based on the double deflection (sinusoidal and pulsed) was not implemented also due to very strict requirements for the parameters of deflection voltage. For that reason, we focused on the design and implementation of the TOF system on the cyclotron U-120M (26 MHz/5 ns).

Beam Pulse Parameters

For the fast neutron generation, the maximum H^-/proton beam energy (i.e. 36 MeV) of the cyclotron U-120M was chosen. In this case the width of the beam pulse should be approx. 5 ns (FVHM) and period of approx. 40 ns. The required beam pulse width to beam pulse period should be approx. 1/100. The proportion of unwanted or parasitic pulses extracted between working pulses should not exceed 1 %.

PROPOSED SOLUTION AND DESIGN

We were inspired by the system implemented in 60 s on the cyclotron in Karlsruhe [4]. Internal vertical H^- beam deflection we combined with the stripping extraction method. The beam of accelerated, H^- ions is directed after vertical deflection to the stripping foil and extracted to an external Be target located outside the acceleration chamber. In order to solve this task, the program of simulation of acceleration and extraction of beams on the cyclotron U- 120M – Durycnm18 [5] was extended by additional modules. Due to the narrow aperture (20 mm) inside the 180° Dee the accelerated beam is shifted above the regular median plane using the built-in correction coil of the cyclotron.

This vertical beam shift provides more space for vertical deflection of the beam in working pulses. The beam accumulated between the working pulses in the range of radii 47–50 cm is vertically deflected by the two-section deflector to the stripping foil and extracted to the short beam line with Be target at the end. Bunching system layout is demonstrated in the Fig. 1.

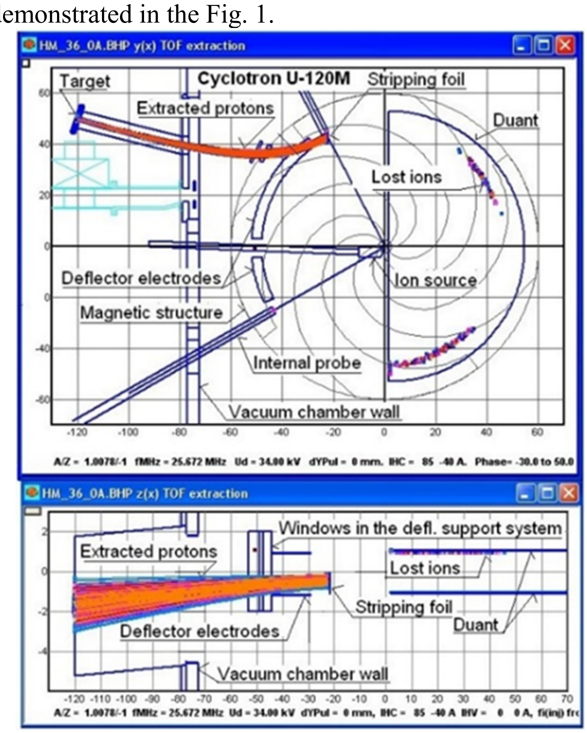

Figure 1: TOF extraction system arrangement.

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BUNCHING SYSTEM

Description, Parameters

The deflection system consists of two parts. The gap in between the electrodes is 20 mm. According to the detailed simulations optimal amplitude of pulsed high voltage energized simultaneously each electrode should be min. + 4.5 kV and − 4.5 kV, respectively. The photo of the manufactured deflection system is in the Fig. 2.

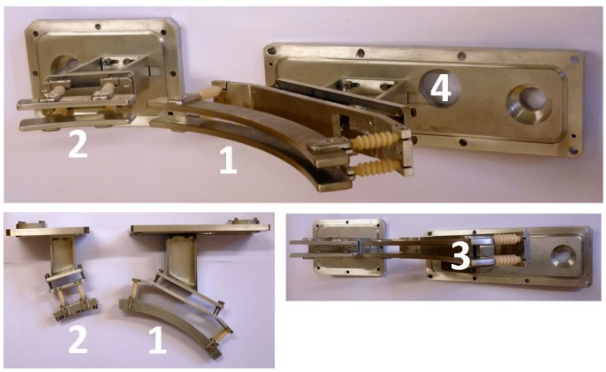

Figure 2: Two section of the deflection bunching system. 1) 1st deflector section, 2) 2nd deflector section, 3) beam entry, 4) beam exit window.

Time Structure

The time structure of the beam and HV pulses with respect to the Dee voltage is shown in the Fig. 3. The widths tn and td are maximum values which prevent from extraction of unwanted ions outside the working periods.

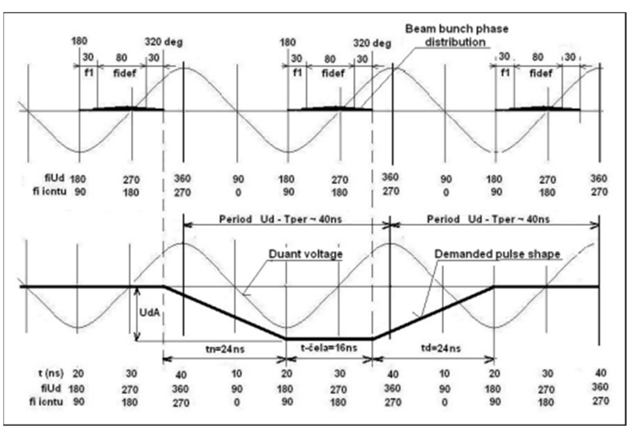

Figure 3: Time structure of the HV pulses.

RESULTS OF COMPUTER SIMULATIONS

Deflection During Acceleration

Vertical motion of the deflected ion during first period after HV pulse is show in the Fig. 4.

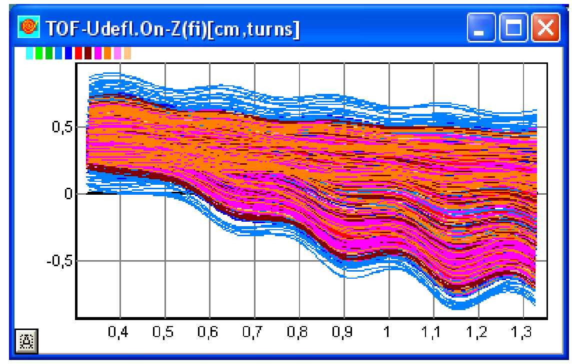

Figure 4: Vertical motion of the deflected ion during first period after HV pulse.

Characteristics of Extracted Beam

The beam cross-section and the extracted beam densities distribution are shown in the Fig. 5. By suitable choice of the position of the stripping foil it was achieved that the extracted beam covers the target area well.

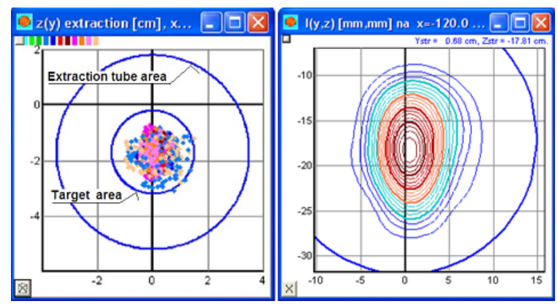

Figure 5: Extracted beam cross-section at the Be target.

The average energy of the extracted beam is 34 MeV with SQR dispersion about 0.9 MeV (see the Fig. 6).

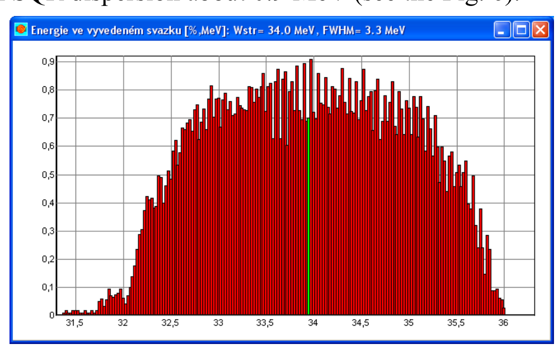

Figure 6: Extracted beam energy dispersion.

The calculated horizontal RMS emittance is 740 π·mm·mrad, vertical 59 π·mm·mrad. The extraction efficiency depends on the number of the beam turns between working pulses. At a low number, the space above the foil is not fully filled, at a high one the ions continue in acceleration to the target placed on the inner probe at higher radius. Maximum efficiency is achieved when ions accelerated between working pulses just fulfil the space above the foil. Suppression of unwanted ions extracted between the working pulses is achieved by correctly adjusting the vertical deflection of the magnetic median plane, the vertical position of the upper edge of the foil, and the

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amplitude of the HV pulses delivered to the deflectors. Unfortunately, the stray electric field of the deflectors on the inner radii in the periods following the HV pulse causes vertical oscillations of non-extracted ions in front of the foil. These ions can hit the upper side of the Dee or the foil with the subsequent extraction between the working pulses. This undesirable effect can be minimized by appropriately selected the radial position of the foil relative to the adjusted magnetic medial plane distortion. However, these effects may be negligible on cyclotrons with greater aperture of the accelerator system elements.

The stripping foil was positioned so that ions on radii 47 and 50 cm were directed to a target centre in the distance of approximately 40 cm from the wall of the acceleration chamber. At the beam rotation period of 40 ns, the HV pulse repetition interval of 2 µs was selected, corresponding to 50 periods during which the radius area above the foil is filled by accelerated ions. The FWHM time of the extracted beam bunch is approximately 5 ns. From the 90 accelerated ions, 2118 ions entered the extraction process. From these ions, 1712 (80.8 %) good ions were extracted at the time of the first pulse period, 395 (18.7 %) were lost on the duant, 9 (0.4 %) were stopped on the foil frame, and 2 (0.1 %) undesired ions were extracted outside working period. Ions distribution is demonstrated in the Fig. 7. If the repetition interval is longer, the extraction efficiency and the power lost on the duant will be reduced. At shorter intervals, efficiency decreases because accelerated ions do not completely fill the space above the foil.

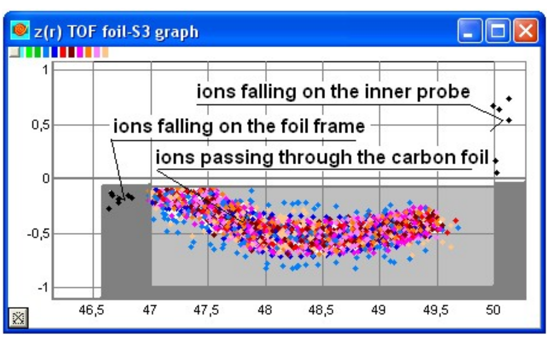

Figure 7: Ion beam distribution in the stripping foil area.

PULSED POWER SUPPLY

Design and development of the pulsed power supply based on the SiC MOSFET transistors (amplitude up to + 6 kV resp. − 6 kV, HV voltage pulse front edge 24 ns/amplitude 16 ns/back edge 24 ns, repetition frequency up to 1 MHz) as well as the pulse synchronization with the cyclotron RF are described on an individual poster of the conference [6].

CONCLUSION

The article briefly introduces unique "deflection-bunching" TOF system which is based on the vertical deflection of the internal negative H^- beam deflected with the two-section deflector to the striper and converted into the proton beam by means of the stripping method. Compared to the standard selection of working bunches for TOF measurement on an extracted cyclotron beam, the described system has a number of advantages. In the working pulse, it emits about 20 times more ions at an incomparably lower level of residual radioactivity caused by collimator slits activation with the ion beam deflected between working pulses. Positioning of the Be target outside the acceleration chamber allows greater flexibility in spatial arrangement and easier manipulation of the target without risk of vacuum chamber contamination. On the other hand, the disadvantage is the much wider energy spectrum and greater horizontal emittance extracted proton beam. However, for the purpose of TOF measurements, deterioration of these properties does not matter. In accordance with the results of the performed simulations, a system of electrostatic deflectors with an external beam line system and a pulsed HV power supply have been manufactured. Extraction of the beam into the beam line was tested on the U-120M cyclotron in the static mode. Testing of the complete system on the cyclotron is under preparation. We expect the 34 MeV proton beam pulse of width of approx. 5 ns (FWHM) and period up to 2 µs directed to the external Be target. The pulse width to the period ratio should be up to 1:400 which meets well the required parameters. After implementation the system should provide white spectrum of neutrons up to 34 MeV, TOF neutron flux $7 \cdot 10^6$ n/s/cm^2 at 3 m distance and energy resolution ≤ 4 % FWHM at 15 m distance.

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