PHYSICAL DESIGN OF EXTERNAL TWO-STAGE BEAM CHOPPING SYSTEM ON THE TR 24 CYCLOTRON

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Abstract

We briefly introduce a new Cyclotron Laboratory of the Nuclear Physics Institute (NPI) of the Czech Academy of Sciences with the new cyclotron TR 24 which was commissioned in October 2015. One of the planned uses of TR 24 beams is a generation of high-intense fast neutrons fluxes with implementation of a chopping system for spectrometric measurements of neutron energy by the Time-of-Flight (TOF) method. For this purpose, physical design of a new ion-optical beam line was completed as well as comprehensive study of an external fast chopping system on this beam line. A set of home-made programs DtofDeflect has been developed for this system consisting of the first chopper powered by sinusoidal voltage and the second chopper powered by pulse voltage. The programs allow to find the optimum geometric and voltage parameters of the system by the means of mathematical simulations. The chopping system can provide the external 24 MeV proton beam with 2.3 ns pulse length at a repetition period of 236 ns in order to comply with the required pulse length to the repetition period ratio of 1 : 100.

INTRODUCTION

In 2011 it was decided to modernize an experimental basis of the NPI to supplement the original accelerator – isochronous cyclotron U-120M [1] (commissioned in 1977), with a new compact accelerator, which would take over some applications and extend experimental possibilities with its parameters. A good compromise solution between the required new cyclotron parameters (maximum beam energy at maximum beam current) and available funds was the purchase of the cyclotron TR 24 (24 MeV/300 μA) [2] of the Canadian company Advanced Cyclotron Systems, Inc. (ACSI). Research program of the TR 24 will be focused on production of established and novel medical radionuclides (e.g. ^{44}Ti, ^{67}Cu, ^{89}Zr and ^{68}Ga), and to feasibility study of implementing direct production of ^{99m}Tc via (p,2n) reaction as an viable alternative to reactor-produced generator ^{99}Mo/^{99m}Tc. Regarding the long-term experience with generation of fast neutron fields [3] on the cyclotron U-120M, the further important research program will be dedicated to experiments associated with the generation of high fast neutron fluxes. Physical design of the chopping system for spectrometric neutron TOF measurements fulfils one of the potential utilization of the TR 24 beam and defines conditions of its feasibility.

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NEW CYCLOTRON LABORATORY

The TR 24 cyclotron forms a core of the new laboratories built instead of a decommissioned (2012) Van de Graaf generator (VdG). The project started in 11/2012 and site acceptance test of the TR 24 was completed in 10/2015.

Figure 1: Old VdG and new cyclotron buildings.

Reconstruction of the VdG building covered design of the cyclotron layout and its shielding within the given ground plan. The cyclotron hall and hall for TOF system are located in the basement, the control room in the first floor above the cyclotron. Due to the space limitations, big care was devoted to minimizing thickness of the ceiling and the walls. Detailed simulations based on the MCNPX code resulted in reducing their thickness to 1.8 and 2.0 m, respectively, including the shapes of cable conduits and ventilation pipes. This solution required precise composition of heavy concrete with the density greater than 3 t/m^3. Effective cyclotron cooling and air-conditioning systems which include also air-conditioning for the radiochemical labs and the 6-floor building were designed so that more than 50% of thermal power produced by the cyclotron can be recuperated and utilized for heating of the building.

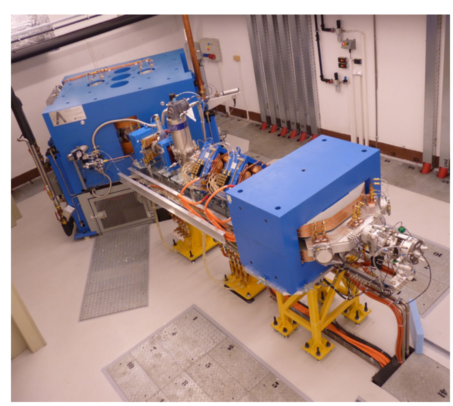

Figure 2: Cyclotron TR 24 with the beam line.

ISBN 978-3-95450-167-0

PHYSICAL DESIGN OF THE EXTERNAL BEAM-CHOPPING SYSTEM

Motivation

Neutron induced reactions play an important role in a wide range of applications including fusion technology – especially in such advanced and safe nuclear-energy concepts like the hybrid fusion-fission nuclear reactor. Due to dependence of technical projects reliability on the correct simulations of neutronic processes, additional measurements of cross-section data are requested (for fast neutrons in particular) for which the neutron source based on TR 24 proton cyclotron will provide neutrons in relevant energy range. Proposed chopping system for neutron facility on TR-24 proton beam is necessary tool for precise measurement of angle/energy-dependent cross-sections by TOF method. Planned facility would be a complementary to other TOF facilities in Europe (GELINA Geel [4], NFS Ganil [5]). Nevertheless, the synergy in research program of all existing facilities is strongly invited due to time and investment consuming character of nuclear data experiments.

Description of Program Utilities

The schematic view of the cyclotron TR-24 with the time structure of beam pulses is shown on Fig. 3.

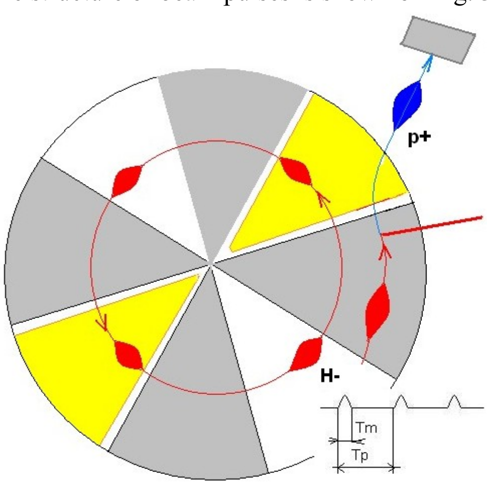

Figure 3: The time structure of the TR 24 beam:

- RF frequency: f_{dees} = 84.75 MHz (4. harmonic),
- width of beam bunches: T_m = 2.3ns,
- period of bunches T_p = 11.8ns,
- the ratio $T_m : T_p$ = 1 : 5.13.

For the TOF facility, it is required to reach the ratio $T_m : T_p \sim 1 : 100$. In order to meet these strict requirement and to reach the technical feasibility of the chopping system, two-stage vertical deflection system was chosen as in [6]. The first deflector is powered with sinusoidal voltage and the second one with a pulsed voltage (Fig. 4).

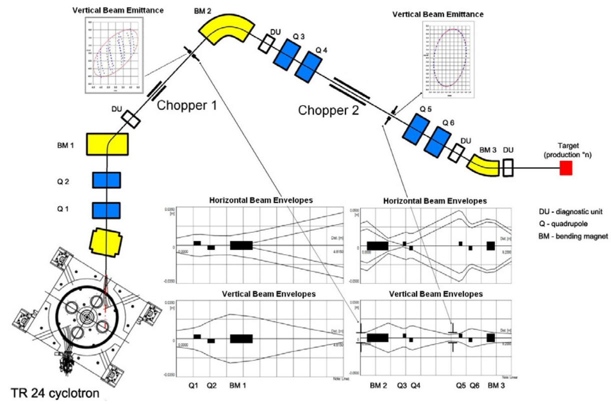

Figure 4: TR-24 external beam shopping system layout.

A mathematical simulation program DtofDeflect was developed for design of the beam chopping system on the TR-24 cyclotron.

This program allows for calculation of extracted beam trajectories when traveling through an electrostatic deflection system. For dynamic calculations, the home-made developed software was used [7]. In interactive mode of the running program, all parameters of the deflection system can be entered (see Fig. 5).

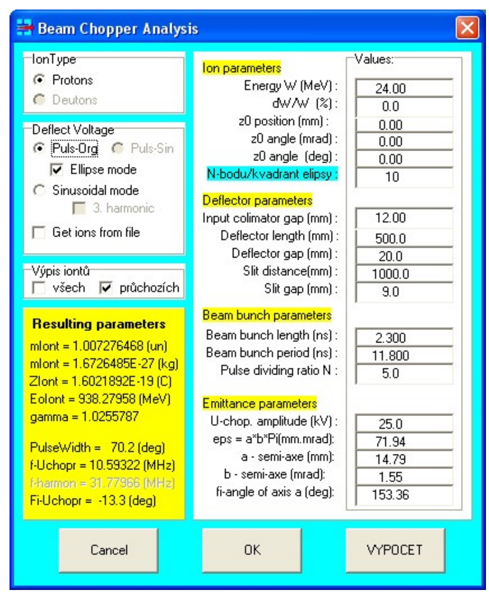

Figure 5: Main dialog window of the DtofDeflect program.

Optimal geometric parameters of the deflection system consisting of two stages are shown in Fig. 6 and Fig. 7.

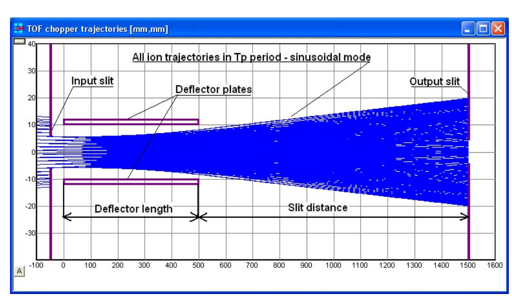

Figure 6: Sinusoidal deflection system arrangement.

ISBN 978-3-95450-167-0

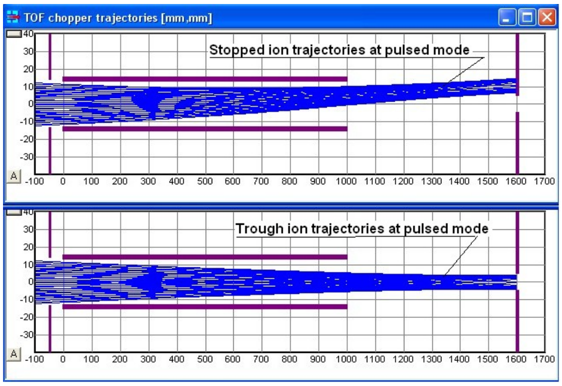

Figure 7: Pulsed deflection system arrangement.

Both deflectors are equipped with input collimators that restrict the undesirable impact of the beam to deflector electrodes and also reduce the output beam emittance. The aim of the thorough calculations was to find an optimal parameters of the ellipse emittance at the deflector entry and further parameters resulting in maximizing beam current through the deflector in selected pulses and minimizing residual beam current going, when beam is deflected to the deflector slit. Time structure of deflection voltage on both choppers is displayed on Fig. 8.

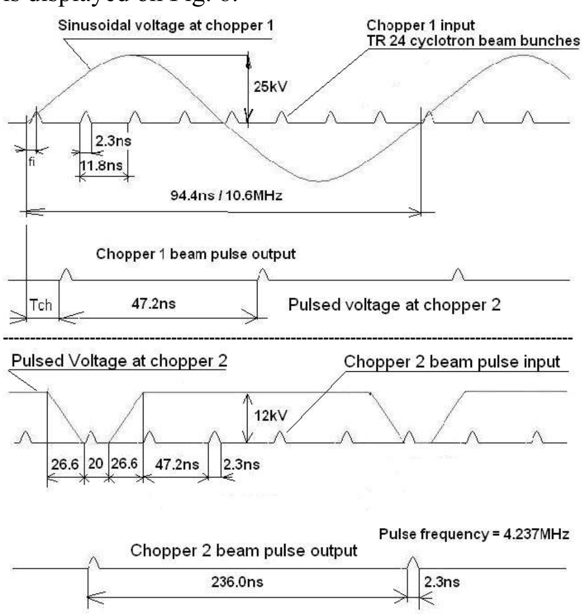

Figure 8: Timing of the deflector voltages on sinusoidal resp. pulsed chopper.

Forming the beam trajectories in the beam line outside the deflectors is carried out by quadrupoles and deflection magnets. Proton beam transport in these parts is solved by means of ion optics. Communication between the dynamic trajectory calculations in the deflection system (Delphi) and beam envelopes in the beam line (AGILE) is provided by conversion of calculated geometric parameters of the beam emittance ellipses to Twiss parameters and vice versa. The influence of a vertical ion velocity component to a horizontal one is negligible in this case. Therefore, the dynamic simulation calculates only the vertical emittance, while ion beam optical calculations provide both vertical and horizontal emittance. For the 24 MeV proton beam extracted from the cyclotron, the vertical emittance 72 mm.mrad resp. horizontal 45 mm.mrad at 95% of the beam intensity were considered [8,9].

Results and Discussion

The three variants (Table 1) that vary in combinations of deflector's voltages and other parameters were analysed. In spite of lower beam transmission, the version III was chosen. Mainly for acceptable parameters of required power supplies and for lower emittance of the selected beam bunches.

Table 1: Comparison of the Three Variants of the Vertical Chopper Arrangement

Sinusoidal chopper 1	**I.**	**II.**	**III.**
Input collimator aperture [mm]	26	26	12
Deflector voltage amplitude [kV]	70.0	40.0	25.0
Deflector plates aperture [mm]	30	26	20
Output slit aperture [mm]	24	12	10
Output slit passing ions [%]	25.0	21.3	15.6
Output slit passing power [W] (for 100µA from cyclotron)	600	510	375
Output beam emittance [mm.rad]	351.86	204.2	90.73
Pulsed chopper 2	**I.**	**II.**	**III.**
Input collimator aperture [mm]	44	40	26
Deflector voltage amplitude [kV]	44.0	22.0	12
Deflector plates aperture [mm]	46	40	26
Output slit aperture [mm]	22	12	10
Output slit passing ions [%]	20.0	20.0	20.0
Output slit passing power [W]	120	102	75
Total system transfer	**I.**	**II.**	**III.**
Through both choppers passes [%]	5.0	4.3	3.1
Total system passing beam power [W]	120.0	102.0	75.0
Output beam emittance [mm.rad]	351.86	207.35	90.48

CONCLUSION

The article briefly introduces the new laboratory of the NPI over the TR 24 cyclotron and planned research program. One of the possible use of the TR 24 beam is a facility for spectrometric neutron measurements with the Time Of Flight (TOF) method that requires defined time structure of the extracted accelerated bunches. The desired width of the bunch period ratio 1 : 100 (2.3 : 236 ns) is feasible by simultaneous employing of the sinusoidal and pulsed choppers. In spite of the reduced beam transmission, the easiest seems to be the alternative with the chopper 1 amplitude of the sinusoidal voltage of 25 kV and 12 kV of the pulsed chopper 2, respectively. The key and demanding task is the precise stable synchronization and phase setting of the deflector's voltage harmonized with the phase of the cyclotron dee voltage.

ISBN 978-3-95450-167-0

ACKNOWLEDGEMENT

We would like to thank ACSI for a kind providing the results of detailed simulations of the properties of the accelerated TR 24 beams. The work was supported by the Czech Academy of Sciences under the NPI research plan AV0Z10480505 and by the CANAM project funded by the Ministry of Education, Youth and Sports of the Czech Republic (project No. LM2011019).

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