ISBN: 978-3-95450-205-9 doi:10.18429/JACoW-Cyclotrons2019-MOP023

SYNCHRONIZATION AND HIGH SPEED HIGH VOLTAGE SWITCHER FOR PULSE BUNCHING SYSTEM OF THE CYCLOTRON U–120M

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Abstract

Pulse bunching system for neutron time of flight (TOF) measurements on the cyclotron U-120M exploits a unique pulsed vertical deflection of the selected final orbits of the internal accelerated beam of the H^- ions to an extractor-stripper. This system is described in details on an individual poster of this conference. A key device is the pulse high voltage (HV) power supply (HV switcher) which is supplying the deflector and elevates H^- ions in defined time structure to an extractor-stripper. The developed HV switcher is based on the SiC MOSFET transistors. It can provide HV pulses with the following pulse parameters: amplitude up to 13 kV, front edge less than 20 ns, flat top 20 ns, back edge less than 20 ns and repetition frequency up to several hundred of kHz. We have also developed the pulse synchronization with the cyclotron RF (25 MHz), which enables to set up front edge of bunching pulses within 2π with accuracy 80 ps. Human-machine interface is based on SCADA software Reliance and PLC Tecomat Foxtrot.

INTRODUCTION

U-120M Cyclotron

The U-120M cyclotron was originally designed as an accelerator of light positive ions (A/Z = 1–2.8) with the maximum energy up to tens of MeV. Since the early 1990s, the cyclotron has undergone major upgrade in terms of acceleration of negative ions H^-, D^- in order to increase external beam intensities [1].

The cyclotron is equipped with a beam line system for the transport of the accelerated and extracted ions to the experimental and target facilities. This system includes also a short beam line for the transport of ions extracted from negative regimes [2].

Protons can by used for neutron production (deuterons and ^{3}He particles were tested as well) for ToF, and are extracted from the beam using the stripping foil. The proton beam is directed to the target installed at the end of the beam pipe. In the negative ion mode of acceleration, the protons resp. deuterons with energies of 6–36 MeV resp. 10–20 MeV with good beam current stability are obtained and used for neutron production at the suitable targets. An average beam current for neutron production is usually 10–15 µA [2].

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Time Structure of the Cyclotron Beam

The cyclotron radiofrequency (RF) system is not operated at the continuous wave regime. In order to protect the RF accelerating system against discharges and to control the beam current, the RF frequency is modulated by a dedicated 150 Hz macropulsed signal. A duty cycle of the corresponding 6.67 ms signal period is adjustable and determines a time interval in-between the macropulses filled with proton bunches. For the lowest RF (≈10 MHz), the duty cycle can reach rather high values of about 65 %. On the other hand, for the highest RF (≈25 MHz) the maximum duty cycle is limited to 25 %. The cyclotron radiofrequency depends on required output beam energy [3].

Time Structure of the Buncher

For measured of neutron energy by the TOF method the required beam pulse width to beam pulse period should by lower than 1/400. The proportion of unwanted or parasitic pulses extracted between working pulses should not exceed 1 %.

We assume to use 25 MHz cyclotron RF. The period of the bunches is therefore t_{acc} = 39 ns and bunch duration is approximately t_b = 6.5 ns. Principle of the proposed bunching system of the cyclotron U-120M is shown in the Fig. 1. The deflection system consist of two parts with total length of 742 mm. The time of flight of the 36 MeV proton bunch through deflection system is t_{flight} = 11.1 ns.

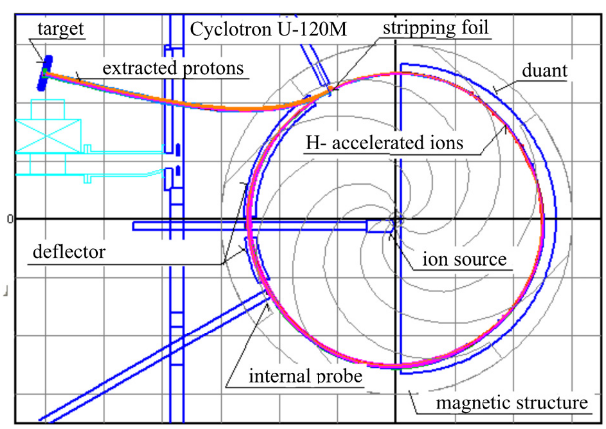

Figure 1: Schematic diagram of U-120M cyclotron with deflection and extraction system.

In the Fig. 2. is shown necessary time structure of pulsed deflection voltage U_{def} for trouble-free beam deflection. Amplitude of the voltage is 10 kV.

Flat top of deflection pulse have to be minimally $t_{ft} = t_b + t_{flight}$. So, t_{ft} = 17.6 ns. The time for switch on or switch off is $t_{switch} = t_{acc} - t_{ft}$. Thus, maximum possible time

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for deflection voltage change is 21.4 ns. We expect the commonly usable repetition rate of extracted bunches to be about 260 kHz, so $t_{rep} \approx 3.8$ µs.

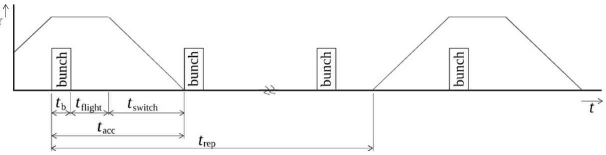

Figure 2: Deflection voltage timing. t_b – bunch duration, t_{flight} – ion time of flight through deflectors, t_{switch} –maximum possible time of switch on or switch off deflection voltage, t_{acc} – repetition time of bunches in accelerator, t_{rep} – repetition time of extracted bunches, U_{def} – deflection voltage.

HV SWITCHER

As described in the previos section, HV switcher should generate pulses supplying the deflector with flat top duration approximately 20 ns, rising and falling edge of pulses shorter then 20 ns and voltage amplitude about 10–12 kV. For this reason, a Silicon Carbide (SiC) power MOSFET transistor was selected as the switching element. Deflector capacitance was estimated to be 40 pF. The current flowing through the switch to the deflector was estimated by simulation to by up to tens of amps. A transistor meeting these conditions is manufactured by CREE with the type designation C3M0065090J [4].

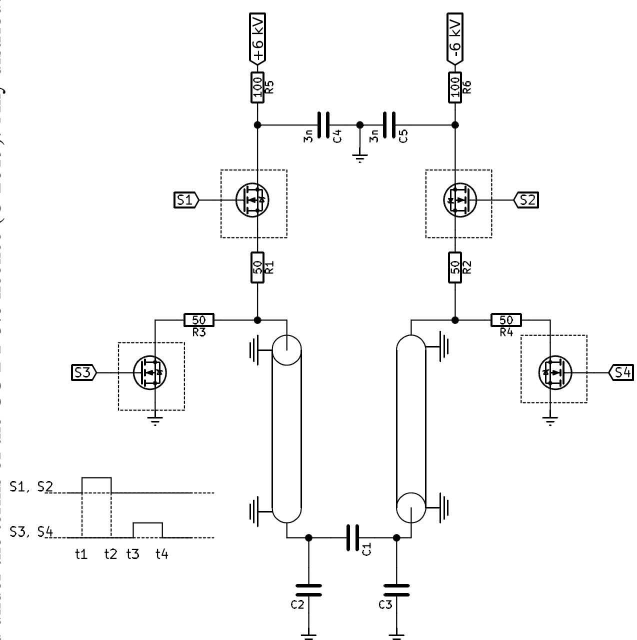

Figure 3: Wiring diagram of HV switcher with deflector. C1 – deflector capacitance, C2 and C3 – parasitic capacitance, S1–S4 – control pulses for SiC MOSFET switch, HV pulse is in time interval (t1; t3).

We can generate HV pulses with electrical circuit as shown in the Fig. 3. At the time t_1 the switch S1 and S2 turn on and deflector is charged to 12 kV. At the time t_2 the switch S1 and S2 turn off and the deflector remains charged. At the time t3 switch S3 and S4 turn on and deflector is discharged.

Each switch S1–S4 must be designed for min. 6 kV. We connected 8 transistors in series. Each transistor has separate driving of its gate with galvanically isolated coupling. The coupling is realized by transformer with one thread on the primary and one thread on the secondary side. Separate driving allows accurate timing of each transistor (block delay in the Fig. 4). We reached time mismatch between transistors better than 1 ns. Wiring diagram of one switch channel (one driver and one transistor) is shown in the Fig. 4.

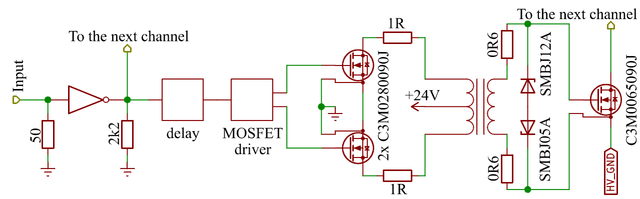

Figure 4: Wiring diagram of one channel of SiC MOSFET switch.

Control pulses at gates of C3M0280090J transistors [5] are shown in the Fig. 5. It is possible to set-up rising edge and also puls duration at gate of C3M0065090J by overlapping pulses.

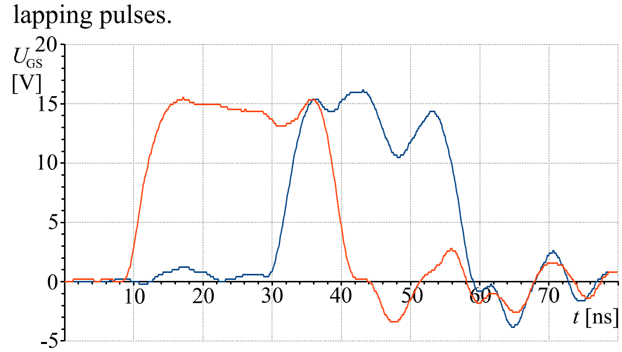

Figure 5: Gate-source voltage at C3M0280090J SiC MOSFET transistors.

The Fig. 6 shows voltage between gate and source (U_{GS}) each HV SiC transistor. Thanks to bipolar driving, the transistor reaches a very fast rising edge. Gate voltage limitation is provided by a pair of transils in anti-series connection.

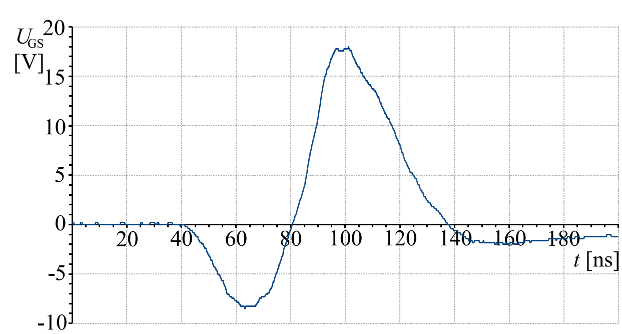

Figure 6: Gate-source voltage at C3M0065090J HV SiC MOSFET transistors.

We can see the rising edge of the HV switch in the Fig. 7. The measurement was provided with 2 m long

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coaxial cable between switch and load (deflector) and with 40 Ω serial resistor. The switch was turned off at the time value 67 ns and after this time the deflector is charged through high impedance resistor.

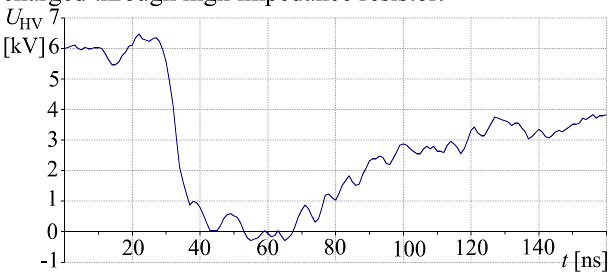

Figure 7: Rising edge of the HV switch.

SYNCHRONISATION SYSTEM

The synchronisation system for accurate timing of HV switcher at the optimal phase of accelerating RF is developed as a standalone device. The system enable turn on HV switcher in any phase within 2π of accelerating RF. The system generate all signals for each switch. Block diagram of the synchronisation system is shown in the Fig. 8.

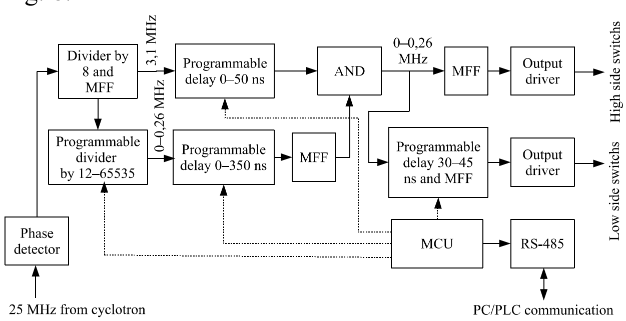

Figure 8: Synchronization system with phase tuning in 2π of accelerating RF. MFF – monostable flip-flop, MCU – microprocessor ATmega328, RS-485 – communication serial line.

The programmable delay 0–50 ns enable scanning accelerating voltage within 2π of RF with 80 ps steps. It enable setting up the turn on the HV switcher in any phase of the accelerating voltage. Programmable divider allows to set repetition rate of extracted bunches. With programmable delay 30–45 ns we can tune HV pulses duration. MCU ATmega328 [6] ensure communication with superior system eg. PLC or PC.

HUMAN–MACHINE INTERFACE

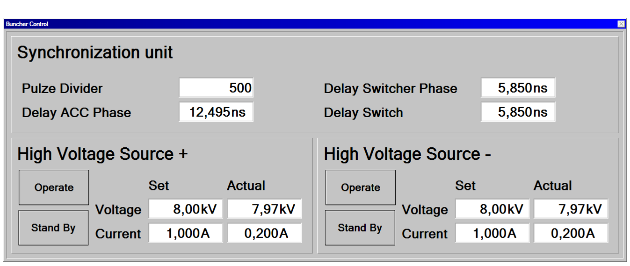

Figure 9: Human-machine interface for HV switcher.

For control the described HV switcher by the operator, a PLC with SCADA/HMI system is commonly used at our laboratory. The PLC was supplied by Teco company. The type designation is Tecomat Foxtrot with central unit CP-1003 [7]. The SCADA software is called Reliance [8]. In the software we prepare basic window for human–machine interface, which allow to control also the HV power supplies feeding the HV switcher (Fig. 9).

CONCLUSION

The HV switch allow the high voltage to be switched in very short time with very short pulse duration. The switch was tested with satisfactory result. We reached rising edge of the HV pulse to be shorter then 20 ns. Flat top duration of the pulse is adjustable and we achieve the value less than 20 ns. These results allow us to start working on assembling of the system as it is shown in the Fig. 3.

After realization of the whole bunching system we are expecting the width of 34 MeV proton beam bunch of approx. 5 ns (FWHM) and period up to 2 μs. 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 [9].

ACKNOWLEDGEMENTS

This work was supported by OP RDE, MEYS, Czech Republic under the project reg. No. CZ.02.1.01/0.0/0.0/16_003/0001812.

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