NEW TIME STRUCTURES AVAILABLE AT THE HZB CYCLOTRON

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Abstract

While most of the beam time of the cyclotron is used for proton therapy of ocular melanomas, an increasing amount of beam time is used for experiments. In response to a growing demand on time structures a new pulse suppressor was developed.

The set-up of the pulse suppressor, measurements on the time structures for various beams and examples of their experimental use will be presented.

INTRODUCTION

About 90% of the beam time of the cyclotron is used for proton therapy of ocular melanomas. However, there is an increasing amount of beam time for experiments. While most of these experiments can be performed with the quasi DC-time structure of the beam from the cyclotron, there is a demand for pulsed beams with a huge variety of time structures.

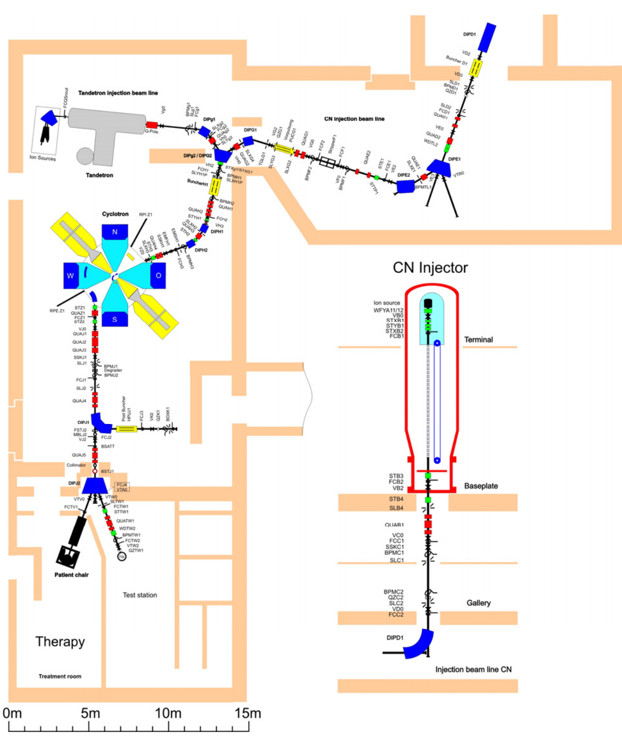

Figure 1: Layout of the accelerator. The yellow marked items influence the time structure of the beam.

Originally the accelerator complex was developed for heavy ions, as it is reflected in its first name VICKSI (*Van-de-Graaff Isochron-Zyklotron Kombination für schwere Ionen* – Van-de-Graaff Isochronous-Cyclotron combination for heavy ions) [1]. This reflects on the design of the pick-ups and the phase probes as well as the design of the bunchers and pulse suppressors. In order to analyse the time structure, we have developed a special pick-up, now permanently installed in the extraction line [2].

Figure 1 shows the actual layout of the facility with the devices influencing the time structure marked in yellow. While the Tandetron-cyclotron combination provides an extremely stable quasi DC beam, there exists no possibility to influence the time structure of the beam, as the last buncher in front of the cyclotron was designed for heavier ions with a charge to mass ratio between 1/2 and 1/8. Time structures can be achieved only using the 6 MV Van-de-Graaff as injector. A first buncher is situated in its terminal. Two bunchers and a pulse suppressor are located in the injection beam line. A second pulse suppressor on the extraction line after the 90° analysing magnet was used to get rid of parasitic pulses.

As mentioned above, for light ions we can use only the buncher in the high-voltage terminal and the first one in the beam line. Due to the lower time-focussing, the transmission through the cyclotron is only 50% compared to 100% achievable with heavy ions and the use of all bunchers. The pulse width of the beam is 1 ns for 68 MeV protons compared to 0.3 ns for heavy ions.

The limited transmission through the cyclotron is not a problem, as the requested beam intensities are far below 1 µA (DC equivalent). However, the limitations in the existing pulse suppressor yielded maximum repetition rates of 75 kHz for protons due to the necessary high voltages.

SINGLE TURN EXTRACTION

For proton therapy it is not relevant if single turn extraction is achieved. Figure 2 shows the pick-up signal of the extracted 68 MeV proton beam with a DC injection. The distances of the pulses are 50 ns, corresponding to the 20 MHz cyclotron RF and the pulse width is about 5 ns. Reflections on the cables are the reason for the multiple peaks about 5 ns after the first signal.

Figure 2: Pick-up signal of 68 MeV extracted proton beam (blue) with DC injection and cyclotron RF (yellow).

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However, for single pulses, single turn extraction is mandatory. Figure 3 shows the pick-up signal from the extracted 68 MeV proton beam in the beginning of a tuning process. A bunched beam with a repetition rate of 75 kHz was injected. The inflection time on the suppressor was chosen to be less than 50 ns. Nevertheless, five peaks with a distance of 100 ns, corresponding to the 2^{nd} harmonic, are observed. This is a clear indication that adjustments in the tuning of the accelerator are necessary.

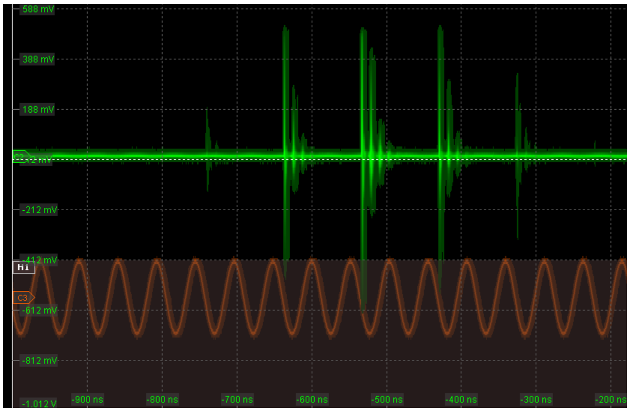

Figure 3: Pick-up signal of extracted 68 MeV proton beam (green) and cyclotron RF (red). In the beginning of the tuning process there is no single turn extraction.

For protons this pick-up provides the only mean to verify if single turn extraction is present. In contrast to our phase probes used for heavy ions, the pick-up provides just one single information in the extraction channel. Thus, tuning may be ambiguous, as both the phases of the two bunchers and the cyclotron RF as well as the magnetic field influence the signal and have to be adjusted. As can be seen in Figure 4, single turn extraction is achieved.

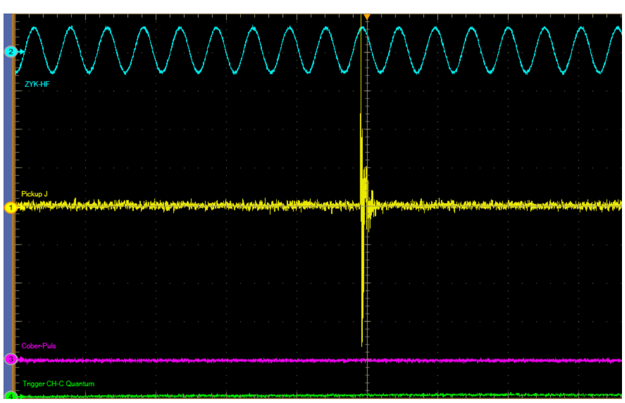

Figure 4: Pick-up signal (yellow) of extracted 68 MeV proton beam and cyclotron RF (light blue). Single turn extraction is achieved after phase adjustment and fine tuning of the magnetic field.

NEW PULSE SUPRRESSOR

The pulse suppressor consists of two adjustable parallel plates: the deflecting plate with a permanent high-voltage switched on and the injection plate with a high-frequency voltage which kicks the beam back on its flight path.

The request of the experimental side was a repetition rate of 1 MHz for single pulses. This is challenging, as for proton with 68 MeV the RF frequency of the cyclotron is close to its upper limit of 20 MHz giving a time window for injection of less than 50 ns. In addition, albeit the pulse suppressor is located at the low energy side of the cyclotron, the required voltages for the suppressor are about 1 kV for protons. For these reasons, a semiconductor HV MOS-FET switch from Behlke, Kronberg, Germany, was selected for the RF voltage of the suppressor. The parameters are given in table 1 in comparison to the old tube-based suppressor. The high frequency was chosen in order to guarantee stable operation at 1 MHz.

The electric part of the suppressor consists of:

- the electronic module for the pulsing, comprising the control unit, pulse processing, MOS-FET switch, and the HV power supply for the injection voltage
- the HV power supply for the deflection
- a heat exchanger.

The heat exchanger became necessary, as the dissipated loss is around 1500 W.

Table 1: Comparison of the parameters of the old tube-based suppressor to the semi-conductor based suppressor

Parameters	Old	New
max. repetition rate	150 kHz	2.4 MHz
max. amplitude	1.2 kV	2 kV
I_{max}	12.5 A	30 A
min. rise time	20 ns	11 ns
min. fall time	35 ns	11 ns

At the same time, the electronics for selecting the ratio and length of suppressed/unsuppressed pulses was replaced. It consisted of one 19” rack 5U and two 19” racks 2U for phase shifting and measuring. Built in the early eighties with wire-wrap cards, maintenance became difficult. In addition, the division of the pulses was only feasible in terms of 2^n of the cyclotron frequency. The new divider, from Quantum, Bozeman MT, USA, provides 8 different output-channels which may be set freely to different delays and pulse/pause ratios. The base for the division is, as with the old one, the cyclotron frequency. Figure 5 depicts the signal plan.

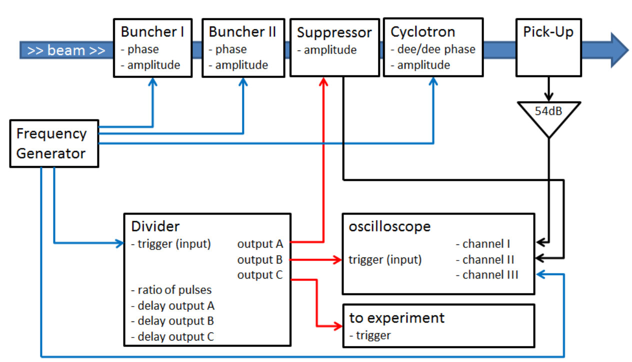

Figure 5: Signal plan of the RF elements comprising bunchers, cyclotron, pulse suppressor, pick-up, oscilloscope, and trigger signal for the experiment.

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The divider is controlled by a LabVIEW programme (Figure 6) for selecting the suppression rate in whole numbers of the cyclotron frequency and selecting the pulse length. Furthermore, the delay between cyclotron frequency and suppressor is adjusted as well as the delays needed for the display in the oscilloscope and for the trigger signal to the experiment.

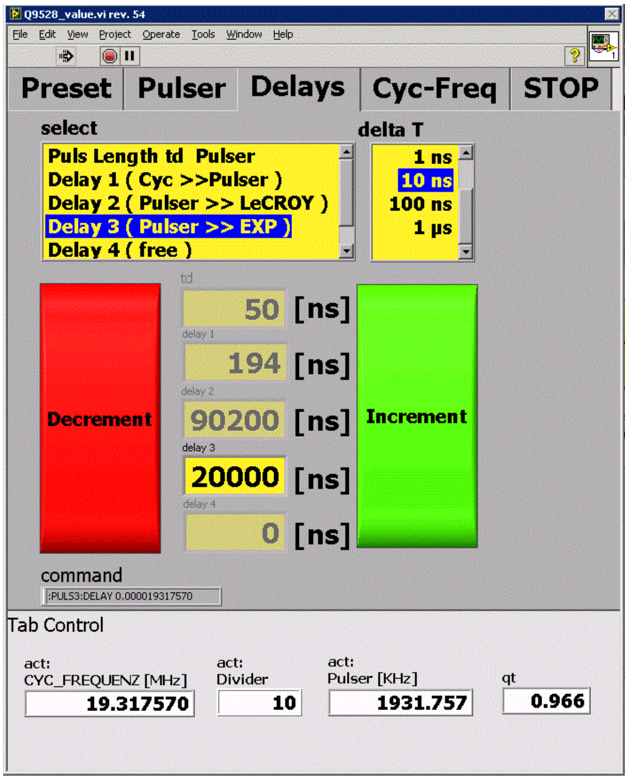

Figure 6: Screenshot of the LabVIEW programme for the control of the divider and the selection of pulse length and suppression rate.

RESULTS

For the first time, single turn extraction was achieved on our cyclotron for protons. Three different light ion beams with single pulses have been delivered to the experiment: protons with 68 MeV and helium with 50 MeV and 75 MeV respectively.

The reason for the increase of the repetition rate came from an experiment measuring the γ-ray emission from proton and α-particle irradiation of different thin targets [3]. The average beam intensity for good count rates was calculated to be in the order of 1 nA which leads to a pulse current of about 250 nA when using 75 kHz repetition rate. The request of a repetition rate of 1 MHz is based on avoiding dead-time effects in the detectors yet maintaining the average beam intensity, as well as taking the time structure of the induced background in the beam dump of a few 100 ns into account.

As shown in Figure 7, the new pulse suppressor allows us to provide pulsed beams with repetition rates greater than the requested 1 MHz. Even at the maximum repetition rate of the MOS-FET HV switch of 2.4 MHz, the suppressor was tested to be very stable without any HV dips for more than 10 hours. Thus it is far more stable at the high voltages required for protons than the old, tube-based suppressor.

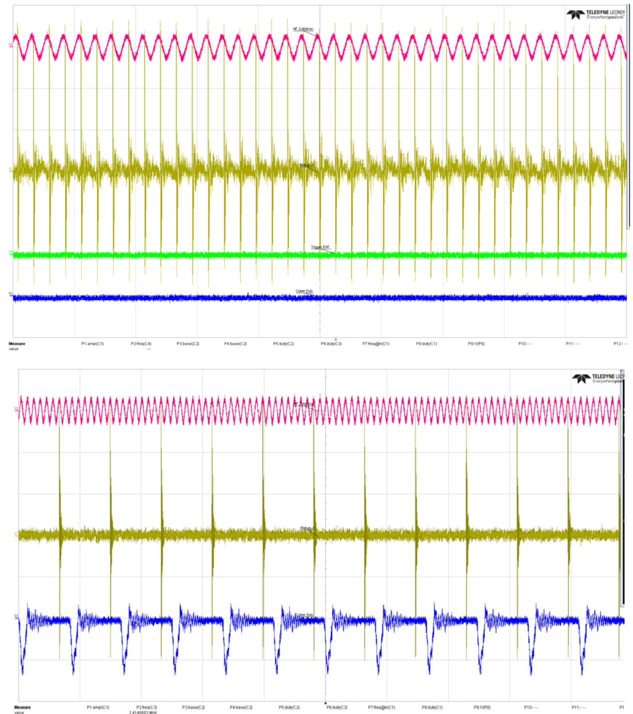

Figure 7: Time Structure of the 68 MeV proton beam. In red: cyclotron RF; blue: suppressor; yellow: pick-up signal. Upper image: suppressor switched off. Lower image: suppressor operating at a repetition rate of 2.4 MHz.

CONCLUSION

With this new pulse suppressor the repetition rate of the pulse may be varied from 2.4 MHz down to 1 Hz or less with a very stable operation. The pulse length can be freely chosen from a quasi-continuous beam to single pulses with a pulse width less than 1 ns for light ions. This was already used to simulate different time structures of synchrotrons and synchro-cyclotrons to investigate possible influences on the dosimetry.

The pulses are measured either with a specially developed Faraday cup or non-destructively with a pick-up in the extraction beam line. The measurement of single pulses with the pick-up surveys very precisely if single turn extraction is achieved.

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